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Volume 5

# Department of Energy
## FY 2024 Congressional Request

# Science

## Science

### Proposed Appropriation Language

For Department of Energy expenses including the purchase, construction, and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or any facility or for plant or facility acquisition, construction, or expansion, and purchase of not more than [35] *35* passenger motor vehicles [including one ambulance for replacement only], [$8,100,000,000] *$8,800,400,000*, to remain available until expended: *Provided*, That of such amount, [$211,211,000] *$226,200,000* shall be available until September 30, [2024] *2025*, for program direction.

### Explanation of Change

Proposed appropriation language updates reflect the funding and replacement of passenger motor vehicle levels.

**Public Law Authorization**

Science:
- Public Law 95-91, "Department of Energy Organization Act", 1977
- Public Law 102-486, "Energy Policy Act of 1992"
- Public Law 108-153, "21st Century Nanotechnology Research and Development Act 2003"
- Public Law 108-423, "Department of Energy High-End Computing Revitalization Act of 2004"
- Public Law 109-58, "Energy Policy Act of 2005"
- Public Law 110-69, "America COMPETES Act of 2007"
- Public Law 111-358, "America COMPETES Reauthorization Act of 2010"
- Public Law 115-246, "American Super Computing Leadership Act of 2017"
- Public Law 115-246, "Department of Energy Research and Innovation Act", 2018
- Public Law 115-368, "National Quantum Initiative Act", 2018
- Public Law 117-167, "CHIPS and Science Act", 2022
- Public Law 117-169, "Inflation Reduction Act of 2022"

Isotope R&D and Production:
- Public Law 101-101, "1990 Energy and Water Development Appropriations Act", establishing the Isotope Production and Distribution Program Fund
- Public Law 103-316, "1995 Energy and Water Development Appropriations Act", amending the Isotope Production and Distribution Program Fund to provide flexibility in pricing without regard to full-cost recovery

Workforce Development for Teachers and Scientists:
- Public Law 101-510, "DOE Science Education Enhancement Act of 1991"
- Public Law 103-382, "The Albert Einstein Distinguished Educator Fellowship Act of 1994"

**Science**
**(dollars in thousands)**

| FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request |
|---|---|---|
| $7,475,000 | $8,100,000 | $8,800,400 |

*Note:*
- *FY 2023 Funding does not reflect the mandated transfer of $20 million from the Office of Nuclear Energy to the Office of Science for Nuclear Facilities O&M Oak Ridge National Laboratory ORNL Operations and Maintenance.*

**Overview**

The Office of Science's (SC) mission is to 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 (U.S.). SC is the Nation's largest Federal sponsor of basic research in the physical sciences and the lead Federal agency supporting fundamental scientific research for our Nation's energy future.

SC accomplishes its mission and advances national goals by supporting:

- *The frontiers of science*—exploring nature's mysteries from the study of fundamental subatomic particles, atoms, and molecules that are the building blocks of the materials of our universe and everything in it to the DNA, proteins, and cells that are the building blocks of life. Each of the programs in SC supports research probing the most fundamental disciplinary questions.
- *The 21st Century tools of science*—providing the nation's researchers with 28 state-of-the-art national scientific user facilities, the most advanced tools of modern science, propelling the U.S. to the forefront of science, technology development, and deployment through innovation.
- *Science for energy and the environment*—paving the knowledge foundation to spur discoveries and innovations for advancing the Department's mission in energy and environment. SC supports a wide range of funding modalities from single principal investigators to large team-based activities to engage in fundamental research on energy production, conversion, storage, transmission, and use, and on our understanding of the earth systems.

SC is an established leader of the U.S. scientific discovery and innovation enterprise. Over the decades, SC investments and accomplishments in basic research and enabling research capabilities have provided the foundations for new technologies, businesses, and industries, making significant contributions to our nation's economy, national security, and quality of life. Select scientific accomplishments enabled by the SC programs are described in the program budget narratives. Additional descriptions of recent science discoveries can be found at https://science.osti.gov/Science-Features/Science-Highlights.

**Highlights and Major Changes in the FY 2024 Request**

The FY 2024 Request for SC is $8,800.4 million, an increase of 8.6 percent above the FY 2023 Enacted level, to implement the Administration's objectives to advance bold, transformational leaps in U.S. Science and Technology (S&T), build a diverse workforce of the future, and ensure America remains the global S&T leader for generations to come. The FY 2024 Request supports a balanced research portfolio of basic scientific research probing some of the most fundamental questions in areas such as: high energy, nuclear, and plasma physics; materials and chemistry; biological and environmental systems; applied mathematics; next generation high-performance computing and simulation capabilities; isotope production; and basic research to advance new accelerator and energy technologies.

The Request increases investments in Administration priorities including basic research on climate change and clean energy, including additional funding for the SC Energy Earthshots and accelerating fusion development in support of the Bold Decadal Vision for Commercial Fusion Energy initiative. The SC Request establishes new Microelectronics Science Research Centers as authorized under the CHIPS and Science Act. The SC Request also promotes the domestic establishment of critical isotope supply chains to reduce U.S. dependency on foreign supply and increase U.S. resilience. SC increases efforts to support underserved communities through the Reaching a New Energy Sciences Workforce (RENEW) and Funding for Accelerated, Inclusive Research (FAIR) initiatives. The request continues support for the National Quantum Information Science (QIS) Research Centers for basic research and early-stage development to accelerate the advancement of QIS through vertical integration between systems, theory, hardware, and software. Additional quantum-related R&D support will focus on early-stage research associated with the first steps to establish a dedicated Quantum Network as well as research in quantum algorithms, applications, testbeds, and technology development of QIS isotopes of interest. The Request also supports ongoing investments in priority areas including microelectronics, biopreparedness, artificial intelligence (AI) and machine learning (ML), critical materials, exascale computing, fundamental science to transform manufacturing, accelerate innovations in emerging technologies (Accelerate), and accelerator science and technology. These initiatives position SC to address new research opportunities through more collaborative, cross-program efforts.

In FY 2024, SC requests funding for the following:

- Fusion energy sciences investments grow to over $1 billion and aligned with the recommendations of the recent Long-Range Plan developed by the Fusion Energy Sciences Advisory Committee and the Administration's Bold Decadal Vision for commercial fusion development, including through partnerships with private fusion efforts, four new Fusion Energy R&D Centers, and studies and research for a future fusion neutron source facility that is critical to the development of materials for fusion energy.
- New Microelectronics Science Research Centers will focus on a multi-disciplinary co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.
- The SC Energy Earthshots initiative will expand to include new topics and further research that crosscuts the Energy Earthshots. Energy Earthshot Research Centers (EERCs) bring together multi-investigator, multi-disciplinary teams to address key research challenges at the interface between basic research and applied Research and Development (R&D) activities. EERCs will entail collaboration within each team awards involving academic, national laboratory, and industrial researchers and close coordination between SC and DOE energy technology offices, establishing a new era of cross-office research cooperation.
- The SC RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups in SC research activities. As part of this increase, a RENEW graduate fellowship will increase participation of students in fields aligned with SC programs. The fellowship will focus on students who received their bachelor's degree from non-R1 minority serving institutions or emerging research institutions. The goal is to advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research.
- Facility operations investments increase to ensure operations of these state-of-the-art user facilities. The 28 SC scientific user facilities are unique resources stewarded by DOE for the Nation and made available to the scientific community free of charge, based on merit review to support the best scientific ideas. Researchers access these cutting-edge tools to push the frontiers of science and technology, with nearly half doing research supported by other funding agencies, from the National Science Foundation, the National Institutes of Health, and the Department of Defense and others, as well as from industry. These facilities have delivered extraordinary breakthroughs, such as accelerating our nation's response to COVID by supporting rapid development of vaccines and helping usher new battery technologies to the marketplace. Further, these facilities are often the portal through which the next generation of researchers begin their engagement with the DOE and its national laboratories, providing invaluable opportunities for developing the diverse, equitable, and inclusive workforce our country needs to meet the major economic and national security challenges ahead.
- The DOE Isotope Program supports research and development in accelerator science, reactor physics, nuclear and radiochemistry, and isotope enrichment science aimed at enabling new capabilities for producing critical isotopes. Emphasis will be given to developing domestic supply chains for isotopes in which the U.S. is dependent on other countries, particularly Russia. Isotopes are foundational and enable emerging technology. It is essential for the nation's scientific and technical strength, as well as economic prosperity, that high priority isotopes needed for national security, medicine, energy, quantum computing, microelectronics, essential industrial applications, and discovery research be produced or available domestically.
- Artificial Intelligence Technology Office (AITO) will transfer to SC. AITO will continue to be the principal organizer of cross-cutting AI/ML activities including research, development, demonstration, strategy, and AI activities for the U.S. Department of Energy (DOE). AITO will continue to identify and work in collaboration with the program offices and national laboratories to address gaps in research, development, implementation, and deployment of AI investments.
- SC is committed to ensuring that students, trainees, and postdoctoral fellows are paid a fair and equitable wage sufficient to allow a reasonable standard of living. For graduate students, SC considers a reasonable living wage to be an annual income of $45,000, excluding benefits. Thus, SC plans a modest increase in research awards to support graduate student stipends at this level.

- Managed by BES, the funding requested in FY 2024 for the DOE Established Program to Stimulate Competitive Research (EPSCoR) program is distributed among the six major research programs within SC.

The Request supports SC's basic research portfolio, which includes extramural grants and contracts supporting nearly 32,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. In FY 2024, SC's suite of 28 scientific user facilities will continue to provide unmatched tools and capabilities for nearly 37,000 users per year from universities, national laboratories, industry, and international partners. In additional to facility operations, the Request will support the construction of new and upgraded user facilities and the R&D necessary for future facilities to continue to provide world class research capabilities to U.S. researchers. SC also continues to update its business processes for awards management and research related activities to advance diversity, equity, and inclusion in its extramural research programs. SC allocates Working Capital Fund charges for common administrative services to the research programs and the Program Direction account.

SC supports the following FY 2024 Research Initiatives:

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| | (dollars in thousands) | | | |
| **Office of Science** | | | | |
| Accelerate Innovations in Emerging Technologies | – | 38,051 | 40,051 | 2,000 |
| Accelerator Science and Technology Initiative | 34,725 | 28,872 | 28,872 | – |
| Advanced Computing | – | 35,658 | 66,658 | 31,000 |
| Artificial Intelligence and Machine Learning | 129,837 | 165,873 | 167,000 | 1,127 |
| Biopreparedness Research Virtual Environment (BRaVE) | 21,756 | 59,756 | 63,756 | 4,000 |
| Climate Resilience Centers | 5,000 | 5,000 | 10,000 | 5,000 |
| Critical Materials/Minerals | 25,000 | 25,000 | 25,000 | – |
| DOE Isotope Initiative | – | – | 14,500 | 14,500 |
| Exascale Computing | 445,000 | 268,000 | 14,000 | -254,000 |
| Funding for Accelerated, Inclusive Research (FAIR) | – | 35,508 | 49,000 | 13,492 |
| Integrated Computational & Data Infrastructure | 32,657 | – | – | – |
| Fundamental Science to Transform Advanced Manufacturing | 25,353 | 27,000 | 27,000 | – |
| Microelectronics | 47,701 | 47,701 | 109,701 | 62,000 |
| National Virtual Climate Laboratory (NVCL) | 3,000 | 3,000 | 3,000 | – |
| Quantum Information Science | 293,075 | 288,749 | 280,429 | -8,320 |
| Reaching a New Energy Sciences Workforce (RENEW) | 30,000 | 60,000 | 107,000 | 47,000 |
| SC Energy Earthshots | – | 100,000 | 175,000 | 75,000 |
| U.S. Fusion Program Acceleration | – | – | 275,674 | 275,674 |
| Urban Integrated Field Laboratories | 18,079 | 22,000 | 23,000 | 1,000 |
| **Total, Research Initiatives** | **1,111,183** | **1,210,168** | **1,479,641** | **+269,473** |

*Note:*

- *The Integrated Computational and Data Initiative is rolled into Advanced Computing Initiative in FY 2023.*

Highlights of the FY 2024 Request by Program Office include:

- *Advanced Scientific Computing Research (ASCR)* supports research to discover, develop, and deploy computational and networking capabilities to analyze, model, simulate, and predict complex phenomena important to the DOE and the U.S. The ASCR Request of $1,126.0 million, is an increase of $58.0 million, or 5.4 percent, above the FY 2023 Enacted level. The Request will strengthen U.S. leadership in strategic computing with operations of the Nation's exascale computing systems, Frontier at Oak Ridge National Laboratory, and Aurora at Argonne National Laboratory. The Request includes $14.0 million for SC's contribution to DOE's Exascale Computing Initiative (ECI) to close out the Exascale Computing Project (ECP) following the deployment of the exascale computing software ecosystem and mission critical applications to address national needs in FY 2023. To ensure progress during and after ECP, the Request increases support for basic research in applied math and computer science, while transitioning research and development efforts from ECP. The Request supports new microelectronics research centers, the FAIR initiative to expand clean energy research and capabilities at MSIs, the Accelerate initiative to support fundamental research that accelerates the transition of science to technologies, and efforts to retain midcareer staff at the national laboratories. Funding increases for the SC Energy Earthshots initiative, including the establishment of additional Energy Earthshot Research Centers (EERCs) and increase support for core research that addresses the basic cross cutting research challenges of the EERCs. The Request also supports Scientific Discovery through Advanced Computing (SciDAC) partnerships with the Department's applied technology offices, NIH, and other agencies, to improve emergency response and broaden adoption of AI on leadership systems. Investments in QIS testbeds, centers, and networking are maintained. Activities implementing the Integrated Research Infrastructure, including continued planning for state-of-the-art scientific high-performance computing data resource, continue to address the unique challenges of near real-time computing needed to support the explosion of scientific data from upgrades at SC's Scientific User Facilities. The Request provides robust support for ASCR user facilities operations to ensure the availability of high-performance computing and networking to the scientific community as well as upgrades to maintain U.S. leadership in these areas. This includes upgrade planning for the National Energy Research Scientific Computing Center and the Leadership Computing Facilities. To increase participation of underrepresented groups, institutions, and regions in ASCR research, funding will support the Computational Science Graduate Fellowship, RENEW, and EPSCoR.

- *Basic Energy Sciences (BES)* supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels to provide foundations for new energy technologies. The BES Request of $2,692.9 million is an increase of $158.9 million, or 6.3 percent, above the FY 2023 Enacted. The Request focuses resources on the highest priorities in early-stage fundamental research, operation and maintenance of a complementary suite of scientific user facilities, and facility upgrades. New microelectronics research centers are established. In the SC Energy Earthshots Initiative, the Request increases support for research on innovations for the scientific challenges that crosscut the technological issues for individual Earthshots and for EERCs, which work toward realizing the stretch goals of the DOE Energy Earthshots. High priority areas in core research include clean energy, critical materials, manufacturing, biopreparedness, QIS, data science including AI/ML, accelerator science and technology, the Accelerate initiative, and efforts to retain midcareer staff at the national laboratories. The Request continues funding for the: Energy Frontier Research Centers, with a focus on clean energy research; multi-disciplinary National QIS Research Centers that perform basic research and early-stage development to advance QIS technologies; computational materials and chemical sciences to deliver forefront software infrastructure to the research communities; and the Batteries and Energy Storage and the Fuels from Sunlight Energy Innovation Hub programs. The Request continues support for the EPSCoR program, led by BES but funded across SC's core programs, to strengthen participation of underrepresented institutions and regions; for RENEW, targeted training opportunities to increase participation and retention of underrepresented groups in BES research areas; and for the FAIR initiative to expand BES topical research including clean energy research at underrepresented institutions. BES maintains a balanced suite of complementary tools, including supporting operations of five x-ray light sources, two neutron sources, and five nanoscale science research centers (NSRCs). At 90 percent of the optimal funding levels, the support in the FY 2024 Request will balance high priority activities required for safe and reliable user facility operations while maintaining a strong user community. The Request provides support for ongoing construction activities: Linac Coherent Light Source-II High Energy, Second Target Station, and Cryomodule Repair and Maintenance Facility; provides final funding for Advanced Light Source (ALS) Upgrade, Proton Power Upgrade and for two Major Item of Equipment projects (MIEs): the NSLS-II Experimental Tools-II project for the phased build-out of beamlines at NSLS-II and the NSRC Recapitalization project; initiates the NSLS-II Experimental Tools-III and High Flux Isotope Reactor Pressure Vessel Replacement projects; and initiates planning for two MIEs for additional beamlines at Advanced Photon Source and ALS.

- *Biological and Environmental Research (BER)* supports transformative science and scientific user facilities to achieve a predictive understanding of complex biological, Earth, and environmental systems for clean energy and climate innovations. This fundamental research, conducted at universities, DOE national laboratories, and other research institutions across the country, focuses on pushing the envelope on research and innovation, taking advantage of the best tools and capabilities DOE has to offer. The BER Request of $931.7 million is an increase of $23.0 million, or 2.5 percent, above the FY 2023 Enacted level. The enhanced Bioenergy Research Centers (BRCs) will provide new research through individual efforts and inter-BRC shared-theme research underpinning production of clean energy and chemicals from sustainable biomass. Funding continues for the Energy Earthshot Research Centers that will remove barriers to implementing innovations from basic research into potential solutions in response to technological challenges and increased university research involving Earthshots that focus on science at the nexus of clean energy production and climate. Furthermore, enhanced biotechnology innovations will be pursued to assist development of advanced manufacturing techniques. The scope of Biopreparedness Research Virtual Environment (BRaVE) will extend to include Low Dose Radiation research. RENEW and FAIR expand with targeted efforts to broaden participation and belonging, accessibility, justice, equity, diversity, and inclusion across BER activities. EPSCoR broadens support for universities in underrepresented regions. Efforts focus on retention of midcareer staff at the national laboratories. BER will enhance its research on climate science by: expansion of both the Urban Integrated Field Laboratories (Urban IFLs) and the network of climate resilience centers, affiliated with Historically Black Colleges and Universities (HBCUs) and other Minority Serving Institutions (MSIs); and continue investments in AI approaches for improving Earth and environmental system predictability. The Request supports operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory (EMSL), and the Atmospheric Radiation Measurement Research Facility (ARM). JGI will explore new plant transformation capabilities to accelerate the ability to understand and design new beneficial functions into plants. ARM will operate at the Alabama observatory. EMSL will initiate construction of the molecular microbial phenotyping capability. The Microbial Molecular Phenotyping Capabilities project at PNNL to generate molecular phenotypic data for rapid development in high throughput genome sequencing and synthesis.

- *Fusion Energy Sciences (FES)* supports research to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. The FES Request of $1,010.5 million is an increase of $247.3 million, or 32.4 percent, above the FY 2023 Enacted level. The Request is aligned with the recommendations of the recent Long-Range Plan (LRP) developed by the Fusion Energy Sciences Advisory Committee, and the Administration's Bold Decadal Vision for commercial fusion energy development. The Request supports partnerships with the private fusion sector through the Fusion Development Milestone Program and INFUSE. The Request supports research and facility operations at the DIII-D national fusion facility at 90 percent of the optimal run time; continues to support the recovery of the National Spherical Torus Experiment-Upgrade (NSTX-U) as well as machine assembly and hardware commissioning. The Request continues to support collaborations by U.S. scientists at international facilities with unique capabilities, and research activities in AI/ML and QIS. The Request supports research activities in Materials, Fusion Nuclear Science, Advanced Manufacturing, and Enabling R&D; initiates four new integrated research centers on enabling technologies, fusion blanket/fuel cycle, advanced simulations, and structural/plasma facing materials R&D; continues to support research activities in theory and SciDAC in partnership with ASCR and data-focused activities under Advanced Computing; and continues to support research activities in both High-Energy-Density Laboratory Plasmas including LaserNetUS, and General Plasma Science including microelectronics research centers. The Request provides support for the U.S. Contributions to ITER project focusing on the design, fabrication, and delivery of in-kind hardware components, provides construction cash contributions to support the ITER Organization assembly and installation of the hardware contributions from all the ITER Members, and continues to support an ITER Research program to prepare the U.S. to take full advantage of ITER Operations. The Request provides funding for the Matter in Extreme Conditions Petawatt Laser Facility upgrade project at LCLS and supports the Material-Plasma Exposure eXperiment MIE project. The Request also continues to support research on inertial fusion energy addressing the priority research opportunities identified in the recent Basic Research Needs workshop. FES will increase its support for the RENEW and FAIR initiatives, continue to participate in the Accelerate initiative and the EPSCoR program, and focus efforts on retention of midcareer staff at the national laboratories.

- *High Energy Physics (HEP)* supports research to understand how the universe works at its most fundamental level. The HEP Request of $1,226.3 million is an increase of $60.3 million, or 5.2 percent, above the FY 2023 Enacted level, of which $75 million goes to the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) project. To support a faster completion for LBNF/DUNE, the Department has approved a new planned funding profile. To support its approved baseline, funding for the Proton Improvement Plan II project increases by $5 million. High priority areas for core research include theoretical and experimental activities in pursuit of discovery science, including hints of new physics beyond the Standard Model, such as the muon-g-2 experiment at FNAL; fostering a diverse, highly skilled workforce; graduate student traineeship programs in Accelerator Science and Engineering, HEP Instrumentation, and Computational HEP; building R&D capacity; conducting world-leading advanced technology R&D, and efforts to retain midcareer staff at the national laboratories. In partnership with SC programs, HEP promotes cross-cutting research in AL/ML, QIS, microelectronics, accelerator science and technology, and accelerating innovations in emerging technologies. Through RENEW, HEP broadens reach and increases pathways for physics and engineering students, and through FAIR, HEP invests in S&T infrastructure at MSIs. EPSCoR broadens support for universities in underrepresented regions. HEP supports the Superconducting Quantum Materials and Systems National QIS Research Center led by FNAL. Four Major Items of Equipment projects continue: Accelerator Controls Operations Research Network (ACORN), Cosmic Microwave Background Stage 4 (CMB-S4), High-Luminosity Large Hadron Collider (HL-LHC) A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) Detector Upgrade Projects. HEP supports two scientific user facilities, the Fermilab Accelerator Complex and the Facility for Advanced Accelerator Experimental Tests II (FACET-II). These facilities will operate 5,200 and 3,300 hours, respectively, while addressing critical upgrades, improvements, and deferred maintenance. HEP supports laboratory-based accelerator and detector test facilities and supports the maintenance and operations of large-scale experiments and facilities that are not based at a national laboratory, such as the U.S. LHC at CERN in Geneva, Switzerland; Sanford Underground Research Facility in Lead, South Dakota; Vera C. Rubin Observatory in Chile; and the Dark Energy Spectroscopic Instrument at the Mayall telescope in Arizona.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The NP Request of $811.4 million is an increase of $6.2 million, or 0.8 percent, above the FY 2023 Enacted level. The Request supports safe, efficient, and cost-effective operations of four NP scientific user facilities at nearly 90 percent optimal operations. To maintain U.S. leadership throughout this century and to extend well beyond current scientific capabilities, NP supports R&D and Preliminary Engineering Design for the Electron-Ion Collider (EIC) project. The Request also supports non-accelerator-based research using the nucleus as a laboratory to search for new physics by observing nature's fundamental symmetries and precision measurements to determine the properties of the neutron and whether the neutrino is its own anti-particle. The Request continues to support the construction of world-leading instrumentation, including a ton-scale detector for neutrinoless double beta decay to determine if the neutrino is its own antiparticle and the High Rigidity Spectrometer (HRS) to realize the full scientific potential of FRIB. NP is the primary steward of the nation's fundamental nuclear physics research portfolio, providing over 95 percent of the investment in the U.S. nuclear physics basic research. The Request supports this research portfolio through support for university and laboratory researchers to nurture critical core competencies and enable the highest priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science. The Request also supports the National Nuclear Data Center which collects, evaluates, curates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies for global use. Efforts on QIS, in collaboration with other SC programs, for the development of quantum sensors and quantum control techniques continue, as do efforts on AI/ML which can benefit nuclear physics research and NP accelerator operations. The Request supports continued participation in the microelectronics initiative, with an emphasis on unique devices capable of surviving in cryogenic and high radiation environments; the RENEW initiative with targeted efforts ensure a future nuclear physics workforce that is creative, innovative, and capable of meeting the Nation's needs via proactive stewardship of talent with diverse ideas and backgrounds; and efforts to retain midcareer staff at the national laboratories. The Request also continues support for efforts to broaden participation in NP research: FAIR to further enhance diversity, equity, and inclusion in nuclear physics; Accelerate to research how imaging advances within nuclear physics can apply to other fields; and EPSCoR to support universities in underrepresented regions.

- *Isotope R&D and Production (IRP) or DOE Isotope Program (DOE IP)* supports national preparedness for critical isotope production and distribution to mitigate gaps and disruptions in supply chains of isotopes even during times of national crisis; a priority is to mitigate U.S. dependence on foreign supply of key isotopes. The IRP Request is $173.1 million, an increase of $63.6 million, or 58.1 percent, above the FY 2023 Enacted level. In FY 2024, the DOE IP expects increasing demand for both radio and stable isotopes. The Russian invasion of Ukraine and subsequent impacts to isotope supply chains have highlighted the need to establish domestic supplies of critical isotopes to remove risks to the Nation's economy, national security, industrial base, and technical competitiveness. Mission readiness of isotope facilities is increased to ~92 percent and supports additional workforce to respond more efficiently as a DOE Mission Essential Function; funding supports targeted investments in infrastructure and maintenance to ensure safe and reliable operations. A core competency in stable isotope operations is strengthened to commission and prepare for operations of new capabilities. Funding supports core research teams at the production sites to improve or develop innovative approaches to isotope production and chemical separations, as well as related automation, AI/ML, and robotics. Support increases for the RENEW and FAIR initiatives providing opportunities for research, bolstered with investments in equipment and infrastructure at minority serving institutions, including attention to underserved and environmental justice regions. The Biopreparedness Research Virtual Environment (BRaVE) initiative provides increased support to tackle chemical processing of irradiated reactor targets, which has become a significant obstacle and single point failure in the program, and to provide increased isotopes for medicine and bio-medical applications. Support for microelectronics emphasizes research to establish production of isotopes needed for semiconductor manufacturing. The increase in Isotope research enables the DOE IP to proactively target fragile global isotope supply chains, investing in innovative approaches to isotope production with a focus on isotopes that are only produced in Russia. The DOE IP maintains additional efforts in the Advanced Manufacturing, Accelerate, and QIS initiatives. The FRIB Isotope Harvesting effort approaches completion, adding capabilities to extract and process rare isotopes from the beam dump of FRIB. The FY 2024 Request provides Total Estimated Cost (TEC) funding to continue the Stable Isotope Production and Research Center (SIPRC) at ORNL to restore large scale stable isotope production capacity for the Nation and remove U.S. dependency on sensitive countries. Funding supports engineering design for the ORNL Radioisotope Processing Facility (RPF) to address a lack of available radiochemical processing infrastructure to mitigate U.S. dependency on foreign supply chains of radioisotopes and meet U.S. demand for radioisotopes. Funding supports engineering design and long-lead procurements of the Clinical Alpha Radionuclide Producer (CARP) facility at BNL to address disruptions in global isotope supply chains and produce in-demand isotopes to combat cancer mortality.

- *Accelerator R&D and Production (ARDAP)* supports SC programs by working to ensure a robust pipeline of innovative accelerator technology, train an expert and diverse workforce, and reduce significant supply chain risks by reshoring critical accelerator technology. The ARDAP Request of $34.3 million, an increase of $6.8 million, or 24.9 percent, above the FY 2023 Enacted level will support cross-cutting accelerator research, operation and maintenance of a scientific user facility, and production of accelerator technologies in industry. Funded R&D will focus on transformative R&D for future generations of scientific facilities, technology transfer to industry to strengthen domestic suppliers, and encouraging community cooperation and integration by funding R&D consortia and public private partnerships. The Request supports operation of the Brookhaven National Laboratory Accelerator Test Facility for the maximum number of user hours and enables progress addressing a significant backlog of deferred maintenance, resulting in improved facility availability. Workforce development activities will address identified needs in accelerator science and engineering and foster a more diverse, inclusive workforce through continuing participation in the FAIR and RENEW initiatives. Accelerator Production will support partnerships with industry to develop the superconducting magnets, superconducting accelerators, high-intensity particle sources, radiofrequency power sources, and high-intensity laser technologies needed to build DOE's world-leading scientific facilities.

**Basic and Applied R&D Coordination**

Coordination between the Department's basic research and applied technology programs is a high priority within DOE and is facilitated through joint planning meetings, technical community workshops, annual contractor/awardee meetings, joint research solicitations, focused DOE program office working groups in targeted research areas, and collaborative program management of DOE's Small Business Innovation Research and Small Business Technology Transfer programs. Collaboration of research activities and facilities at the DOE national laboratories and partnership-encouraging funding mechanisms facilitate research integration within the basic and applied research communities. SC's R&D coordination also occurs at the interagency level. Specific collaborative activities are highlighted in the "Basic and Applied R&D Coordination" sections of each individual SC program budget justification narrative.

**High-Risk, High-Reward Research**[a]

SC incorporates high-risk, high-reward, basic research elements in all of its research portfolios; each SC research program considers a significant proportion of its supported research as high-risk, high-reward. Because advancing the frontiers of science also depends on the continued availability of state-of-the-art scientific facilities, SC constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities. SC's basic research is integrated within program portfolios, projects, and individual awards; as such, it is not possible to quantitatively separate the funding contributions of particular experiments or theoretical studies that are high-risk, high-reward from other mission-driven research in a manner that is credible and auditable. SC incorporates high-risk, high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies' studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Chemical Upcycling of Polymers,* Basic Energy Sciences report (2019)[b]; *Basic Research Needs for Microelectronics*, joint BES, ASCR, and HEP workshop (2018)[c]; *Basic Research Needs for Scientific Machine Learning; Core Technologies for Artificial Intelligence*, ASCR workshop (2018)[d]; *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context*, by the High Energy Physics Advisory Panel (2014)[e]; *From Long-distance Entanglement to Building a Nationwide Quantum Internet: Report of the DOE Quantum Internet Blueprint Workshop,* ASCR workshop report (2020)[f]; *Opportunities for Basic Research for Quantum Computing in Chemical and Materials Sciences*, Basic Energy Sciences report (2017); *Opportunities for Basic Research for Next-Generation Quantum Systems*, Basic Energy Sciences report (2017)[g]; *Basic Research Needs for Transformative Manufacturing* (2020)[h]; *Basic Research Needs Workshop on Quantum Materials for Energy Relevant Technology,* BES workshop report (2016)[i]; *Grand Challenges for Biological and Environmental Research: Progress and Future* Vision, by the BER Advisory Committee (2017)[j]; *Genome Engineering for Materials Synthesis*, BER workshop report (2018)[k]; *Plasma: at the Frontier of Scientific Discovery*, FES workshop report (2017)[l]; *Powering the Future: Fusion and Plasmas*, FES Advisory Committee Long Range Plan (2020)[m]; *FES Roundtable on QIS* (2018)[n]; *Advancing Fusion with Machine Learning,* joint FES-ASCR workshop report (2019)[o]; *Isotope Research and Production Opportunities and Priorities*, by the Nuclear Science Advisory Committee (NSAC) (2015)[p]; and *Nuclear Physics Long Range Plan*, by the Nuclear Science Advisory Committee (NSAC, 2015)[q] and *Quantum Computing and Quantum Information Sciences (QIS),* by NSAC (2019)[l]; *Office of Science User Facilities: Lessons from the COVID Era and Visions for the Future*; SC workshop report (2020)[r].

**Scientific Workforce**

For more than 60 years SC and its predecessors have fostered a vibrant ecosystem for the training of a highly skilled scientific and technological workforce. In addition to the undergraduate internships, graduate thesis research, and visiting faculty opportunities provided through SC's Office of Workforce Development for Teachers and Scientists, to sustain a strong workforce pipeline for DOE mission, the SC research program offices support undergraduates, graduate students, and postdoctoral researchers through sponsored research awards at universities and the DOE national laboratories nationwide. The research program offices also support targeted undergraduate and graduate-level training in areas

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[a] In compliance with the reporting requirements in the America COMPETES Act of 2007 (P.L. 110-69, section 1008)
[b] https://science.osti.gov/-/media/bes/pdf/BESat40/Polymer_Upcycling_Brochure.pdf
[c] https://science.osti.gov/-/media/bes/pdf/reports/2019/BRN_Microelectronics_rpt.pdf
[d] https://science.energy.gov/ascr/community-resources/program-documents/
[e] http://science.osti.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[f] https://www.osti.gov/biblio/1638794/
[g] https://science.osti.gov/~/media/bes/pdf/reports/2018/Quantum_computing.pdf
[h] https://science.osti.gov/-/media/bes/pdf/reports/2020/Transformative_Mfg_Brochure.pdf?la=en&hash=95094B9257DCFD506C04787D96EEDD942EB92EEC
[i] https://science.osti.gov/~/media/bes/pdf/reports/2016/BRNQM_rpt_Final_12-09-2016.pdf
[j] https://science.osti.gov/~/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf
[k] https://science.osti.gov/-/media/ber/pdf/community-resources/2019/GEMS_Report_2019.PDF?la=en&hash=0D7092AD5416A28207F0F95F94E00921D308A113
[l] https://science.osti.gov/~/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf
[m] https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf?la=en&hash=B404B643396D74CE7EDAB3F67317E326A891C09C
[n] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf
[o] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES_ASCR_Machine_Learning_Report.pdf
[p] https://science.osti.gov/~/media/ber/pdf/community-resources/Technologies_for_Characterizing_Molecular_and_Cellular_Systems.pdf
[q] https://science.osti.gov/np/nsac/reports/
[r] https://science.osti.gov/-/media/bes/pdf/reports/2021/SC_User_Facilities_rpt_print.pdf

critically important to DOE mission (such as those associated with scientific user facilities) but not readily available in universities, such as particle accelerator and detector physics, neutron and x-ray scattering, nuclear chemistry, instrumentation, isotope R&D, and computational sciences at the leadership computing level. To help attract critical talent for stimulating fresh ideas and forward thinking, SC supports the Early Career Research Program, which funds individual research programs to identify and award outstanding rising scientists early in their careers in the disciplines supported by SC[s]. To retain highly accomplished researchers, SC initiated the Distinguished Scientist Fellows opportunity to recognize leading DOE laboratory staff and sponsoring their innovative efforts to enrich, sustain, and promote scientific and academic excellence in SC mission research and community at large through partnership between institutions of higher education and national laboratories. SC coordinates with other DOE offices and other agencies on best practices for STEM training programs and evidence-based program evaluation efforts through internal DOE working groups and active participation in all the inter-agency working groups of the National Science and Technology Council's Committee on Science, Technology, Engineering, and Mathematics Education (CoSTEM). SC also participates in the American Association for the Advancement of Science's Science & Technology Policy Fellowships program and the Presidential Management Fellows Program to bring highly qualified scientists and professionals to DOE headquarters for a maximum term of two years. The Request continues the FAIR and RENEW activities for targeted efforts to expand participation and retention of HBCUs and other MSIs, community colleges, and individuals from underrepresented groups in SC research and workforce development activities. SC administers and/or bestows several awards to recognize talented scientists and engineers that advance DOE's missions, including the Presidential Early Career Award for Scientists and Engineers (PECASE), Ernest Orlando Lawrence Award, Enrico Fermi Award, and Distinguished Scientist Fellow opportunity. The Request continues support for these honorary awards.

**Cybersecurity**
DOE is engaged in two categories of cyber-related activities: protecting the DOE enterprise from a range of cyber threats that can adversely impact mission capabilities, and improving cybersecurity in the electric power subsector and the oil and natural gas subsector. SC's cyber program oversees ten National Science Laboratories and three other SC offices and ensures that scientific missions are accomplished while protecting all information on associated information systems. The SC Cybersecurity program enables the mission of the Office of Science by ensuring a secure platform for scientific research and safeguarding the ability to perform that scientific research.

[s] https://science. osti.gov/early-career/

**Future Year Energy Program (FYEP)**

**(dollars in millions)**

| | FY 2024 Request | FY 2025 | FY 2026 | FY 2027 | FY 2028 |
|---|---|---|---|---|---|
| **Office of Science** | 8,800 | 9,002 | 9,209 | 9,420 | 9,637 |

**Outyear Priorities and Assumptions**

In the FY 2012 Consolidated Appropriations Act (P.L. 112-74), Congress directed DOE to include a future-years energy program (FYEP) in subsequent requests that reflects the proposed appropriations for five years. This FYEP shows outyear funding for each account for FY 2025–FY 2028. The outyear funding levels use the growth rates based on the Request level and match the outyear account totals published in the FY 2024 President's Budget for both the 050 and non-050 accounts. Actual future budget request levels will be determined as part of the annual budget process.

SC priorities in the outyears include the following:

- Increase investments in Administration priorities to advance bold, transformational leaps in U.S. S&T, build a diverse workforce of the future, and ensure America remains the global S&T leader for generations to come.
- Ensure optimal operations of all scientific user facilities.
- Continue to invest in infrastructure and utility upgrades at all national laboratories.
- Invest in ongoing and new line-item construction projects and major items of equipment to ensure the United States maintain world leading and state-of-the-art scientific user facilities.

## Science
## Funding by Congressional Control

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted ($) | FY 2024 Request vs FY 2023 Enacted (%) |
|---|---|---|---|---|---|
| **Advanced Scientific Computing Research** | | | | | |
| ASCR Research | 906,000 | 991,000 | 1,110,973 | +119,973 | +12.11% |
| 17-SC-20 SC Exascale Computing Project (ECP) | 129,000 | 77,000 | 14,000 | -63,000 | -81.82% |
| **Construction** | | | | | |
| 24-SC-20 High Performance Data Facility | – | – | 1,000 | +1,000 | – |
| **Total, Construction** | **–** | **–** | **1,000** | **+1,000** | **–** |
| **Total, Advanced Scientific Computing Research** | **1,035,000** | **1,068,000** | **1,125,973** | **+57,973** | **+5.43%** |
| **Basic Energy Sciences** | | | | | |
| BES Research | 2,003,800 | 2,240,800 | 2,432,233 | +191,433 | +8.54% |
| **Construction** | | | | | |
| 24-SC-10 HFIR Pressure Vessel Replacement (PVR), ORNL | – | – | 4,000 | +4,000 | – |
| 24-SC-12 NSLS-II Experimental Tools - III (NEXT-III), BNL | – | – | 2,556 | +2,556 | – |
| 21-SC-10 Cryomodule Repair & Maintenance Facility (CRMF), SLAC | 1,000 | 10,000 | 9,000 | -1,000 | -10.00% |
| 19-SC-14 Second Target Station (STS), ORNL | 32,000 | 32,000 | 52,000 | +20,000 | +62.50% |
| 18-SC-10 Advanced Photon Source Upgrade (APS-U), ANL | 101,000 | 9,200 | – | -9,200 | -100.00% |
| 18-SC-11 Spallation Neutron Source Proton Power Upgrade (PPU), ORNL | 17,000 | 17,000 | 15,769 | -1,231 | -7.24% |
| 18-SC-12 Advanced Light Source Upgrade (ALS-U), LBNL | 75,100 | 135,000 | 57,300 | -77,700 | -57.56% |
| 18-SC-13 Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC | 50,000 | 90,000 | 120,000 | +30,000 | +33.33% |
| 13-SC-10 Linac Coherent Light Source-II (LCLS-II), SLAC | 28,100 | – | – | – | – |
| **Total, Construction** | **304,200** | **293,200** | **260,625** | **-32,575** | **-11.11%** |
| **Total, Basic Energy Sciences** | **2,308,000** | **2,534,000** | **2,692,858** | **+158,858** | **+6.27%** |
| **Biological and Environmental Research** | | | | | |

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted ($) | FY 2024 Request vs FY 2023 Enacted (%) |
|---|---|---|---|---|---|
| BER Research | 815,000 | 908,685 | 921,700 | +13,015 | +1.43% |
| **Construction** | | | | | |
| 24-SC-31 Microbial Molecular Phenotyping Capability (M2PC), PNNL | – | – | 10,000 | +10,000 | – |
| **Total, Construction** | **–** | **–** | **10,000** | **+10,000** | **–** |
| **Total, Biological and Environmental Research** | **815,000** | **908,685** | **931,700** | **+23,015** | **+2.53%** |
| **Fusion Energy Sciences** | | | | | |
| FES Research | 460,000 | 510,222 | 760,496 | +250,274 | +49.05% |
| **Construction** | | | | | |
| 20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC | 11,000 | 11,000 | 10,000 | -1,000 | -9.09% |
| 14-SC-60 U.S. Contributions to ITER | 242,000 | 242,000 | 240,000 | -2,000 | -0.83% |
| **Total, Construction** | **253,000** | **253,000** | **250,000** | **-3,000** | **-1.19%** |
| **Total, Fusion Energy Sciences** | **713,000** | **763,222** | **1,010,496** | **+247,274** | **+32.40%** |
| **High Energy Physics** | | | | | |
| HEP Research | 810,000 | 868,000 | 850,334 | -17,666 | -2.04% |
| **Construction** | | | | | |
| 18-SC-42 Proton Improvement Plan II (PIP-II), FNAL | 90,000 | 120,000 | 125,000 | +5,000 | +4.17% |
| 11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment | 176,000 | 176,000 | 251,000 | +75,000 | +42.61% |
| 11-SC-41 Muon to Electron Conversion Experiment, FNAL | 2,000 | 2,000 | – | -2,000 | -100.00% |
| **Total, Construction** | **268,000** | **298,000** | **376,000** | **+78,000** | **+26.17%** |
| **Total, High Energy Physics** | **1,078,000** | **1,166,000** | **1,226,334** | **+60,334** | **+5.17%** |
| **Nuclear Physics** | | | | | |
| NP Operation and Maintenance | 708,000 | 755,196 | 716,418 | -38,778 | -5.13% |
| **Construction** | | | | | |
| 20-SC-52 Electron Ion Collider (EIC), BNL | 20,000 | 50,000 | 95,000 | +45,000 | +90.00% |
| **Total, Construction** | **20,000** | **50,000** | **95,000** | **+45,000** | **+90.00%** |

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted ($) | FY 2024 Request vs FY 2023 Enacted (%) |
|---|---|---|---|---|---|
| **Total, Nuclear Physics** | **728,000** | **805,196** | **811,418** | **+6,222** | **+0.77%** |
| **Isotope R&D and Production** | | | | | |
| IRP Research | 70,000 | 85,451 | 142,651 | +57,200 | +66.94% |
| **Construction** | | | | | |
| 20-SC-51 U.S. Stable Isotope Production and Research Center (SIPRC), ORNL | 12,000 | 24,000 | 20,900 | -3,100 | -12.92% |
| 24-SC-92 Clinical Alpha Radionuclide Producer (CARP), BNL | – | – | 1,000 | +1,000 | – |
| 24-SC-91 Radioisotope Processing Facility, ORNL | – | – | 8,500 | +8,500 | – |
| **Total, Construction** | **12,000** | **24,000** | **30,400** | **+6,400** | **+26.67%** |
| **Total, Isotope R&D and Production** | **82,000** | **109,451** | **173,051** | **+63,600** | **+58.11%** |
| **Accelerator R&D and Production** | | | | | |
| ARDAP Research | 18,000 | 27,436 | 34,270 | +6,834 | +24.91% |
| **Total, Accelerator R&D and Production** | **18,000** | **27,436** | **34,270** | **+6,834** | **+24.91%** |
| **Workforce Development for Teachers and Scientists** | | | | | |
| WDTS | 35,000 | 42,000 | 46,100 | +4,100 | +9.76% |
| **Total, Workforce Development for Teachers and Scientists** | **35,000** | **42,000** | **46,100** | **+4,100** | **+9.76%** |
| **Science Laboratories Infrastructure** | | | | | |
| PILT | 4,820 | 4,891 | 5,004 | +113 | +2.31% |
| Oak Ridge Landlord | 6,430 | 6,559 | 6,910 | +351 | +5.35% |
| SLI F&I | 14,450 | 13,900 | 32,104 | +18,204 | +130.96% |
| SLI Laboratory Operations Apprenticeship | – | – | 3,000 | +3,000 | – |
| OR Nuclear Operations | 26,000 | 26,000 | 46,000 | +20,000 | +76.92% |
| **Construction** | | | | | |
| 22-SC-71 Critical Infrastructure Modernization Project (CIMP) - ORNL | 1,000 | 1,000 | – | -1,000 | -100.00% |
| 22-SC-72 Thomas Jefferson Infrastructure Improvements (TJII) - TJNAF | 1,000 | 1,000 | – | -1,000 | -100.00% |

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted ($) | FY 2024 Request vs FY 2023 Enacted (%) |
|---|---|---|---|---|---|
| 21-SC-71 Princeton Plasma Innovation Center (PPIC), PPPL | 7,750 | 10,000 | 15,000 | +5,000 | +50.00% |
| 21-SC-72 Critical Infrastructure Recovery & Renewal (CIRR), PPPL | 2,000 | 4,000 | 10,000 | +6,000 | +150.00% |
| 21-SC-73 Ames Infrastructure Modernization (AIM) | 2,000 | 2,000 | 8,000 | +6,000 | +300.00% |
| 20-SC-71 Critical Utilities Rehabilitation Project (CURP), BNL | 26,000 | 26,000 | – | -26,000 | -100.00% |
| 20-SC-72 Seismic and Safety Modernization (SSM), LBNL | 18,000 | 27,500 | 40,000 | +12,500 | +45.45% |
| 20-SC-73 CEBAF Renovation and Expansion (CEBAF), TJNAF | 10,000 | 15,000 | 11,000 | -4,000 | -26.67% |
| 20-SC-75 Large Scale Collaboration Center (LSCC), SLAC | 21,000 | 21,000 | – | -21,000 | -100.00% |
| 20-SC-76 Tritium System Demolition and Disposal (TSDD), PPPL | 6,400 | – | – | – | – |
| 20-SC-77 Argonne Utilities Upgrade (AU2), ANL | 10,000 | 8,000 | 8,007 | +7 | +0.09% |
| 20-SC-78 Linear Assets Modernization Project (LAMP), LBNL | 10,400 | 23,425 | 18,900 | -4,525 | -19.32% |
| 20-SC-79 Critical Utilities Infrastructure Revitalization (CUIR), SLAC | 8,500 | 25,425 | 35,075 | +9,650 | +37.95% |
| 20-SC-80 Utilities Infrastructure Project (UIP), FNAL | 10,500 | 20,000 | 45,000 | +25,000 | +125.00% |
| 19-SC-71 Science User Support Center (SUSC), BNL | 38,000 | – | – | – | – |
| 19-SC-73 Translational Research Capability (TRC), ORNL | 21,500 | – | – | – | – |
| 19-SC-74 - BioEPIC, LBNL | 35,000 | 45,000 | 38,000 | -7,000 | -15.56% |
| 17-SC-71 Integrated Engineering Research Center (IERC), FNAL | 10,250 | – | – | – | – |
| **Total, Construction** | **239,300** | **229,350** | **228,982** | **-368** | **-0.16%** |
| **Total, Science Laboratories Infrastructure** | **291,000** | **280,700** | **322,000** | **+41,300** | **+14.71%** |
| | | | | | |
| **Safeguards and Security** | | | | | |
| S&S | 170,000 | 184,099 | 200,000 | +15,901 | +8.64% |
| **Total, Safeguards and Security** | **170,000** | **184,099** | **200,000** | **+15,901** | **+8.64%** |
| | | | | | |
| **Program Direction** | | | | | |
| PD | 202,000 | 211,211 | 226,200 | +14,989 | +7.10% |
| **Total, Program Direction** | **202,000** | **211,211** | **226,200** | **+14,989** | **+7.10%** |
| | | | | | |
| **Total, Office of Science** | **7,475,000** | **8,100,000** | **8,800,400** | **+700,400** | **+8.65%** |

*Note:*

- *FY 2023 Funding does not reflect the mandated transfer of $20 million from the Office of Nuclear Energy to the Office of Science for Nuclear Facilities O&M Oak Ridge National Laboratory ORNL Operations and Maintenance.*

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $172,355,000 and STTR $24,258,000 (SC only)
- FY 2023 Enacted: SBIR $100,850,000 and STTR $14,182,000 (SC only)
- FY 2024 Request: SBIR $110,742,000 and STTR $15,580,000 (SC only)

**Science**
**Inflation Reduction Act (IRA) Investments**

The Office of Science was appropriated funds through the Inflation Reduction Act of 2022 (IRA).

(dollars in thousands)

| Appropriated Funding Organization | FY 2022 IRA Supp. | Managing Organization |
|---|---|---|
| **Advanced Scientific Computing Research** | | |
| ASCR Research | 163,791 | ASCR |
| **Total, Advanced Scientific Computing Research** | **163,791** | |
| **Basic Energy Sciences** | | |
| BES Research | 45,200 | BES |
| 21-SC-10 Cryomodule Repair & Maintenance Facility (CRMF), SLAC | 20,000 | BES |
| 19-SC-14 Second Target Station (STS), ORNL | 42,700 | BES |
| 18-SC-12 Advanced Light Source Upgrade (ALS-U), LBNL | 96,600 | BES |
| 18-SC-13 Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC | 90,000 | BES |
| **Total, Basic Energy Sciences** | **294,500** | |
| **Fusion Energy Sciences** | | |
| FES Research | 14,000 | FES |
| 20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC | 10,000 | FES |
| 14-SC-60 U.S. Contributions to ITER | 256,000 | FES |
| **Total, Fusion Energy Sciences** | **280,000** | |
| **High Energy Physics** | | |
| HEP Research | 132,633 | HEP |
| 18-SC-42 Proton Improvement Plan II (PIP-II), FNAL | 10,000 | HEP |
| 11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment | 125,000 | HEP |
| 11-SC-41 Muon to Electron Conversion Experiment, FNAL | 36,023 | HEP |
| **Total, High Energy Physics** | **303,656** | |
| **Nuclear Physics** | | |
| NP Operation and Maintenance | 88,760 | NP |
| 20-SC-52 Electron Ion Collider (EIC), BNL | 128,240 | NP |
| **Total, Nuclear Physics** | **217,000** | |
| **Isotope R&D and Production** | | |
| IRP Research | 82,813 | IRP |

(dollars in thousands)

| Appropriated Funding Organization | FY 2022 IRA Supp. | Managing Organization |
|---|---|---|
| 20-SC-51 U.S. Stable Isotope Production and Research Center (SIPRC), ORNL | 75,000 | IRP |
| **Total, Isotope R&D and Production** | **157,813** | |
| **Science Laboratories Infrastructure** | | |
| SLI F&I | 65,890 | SLI |
| 21-SC-71 Princeton Plasma Innovation Center (PPIC), PPPL | 10,000 | SLI |
| 21-SC-73 Ames Infrastructure Modernization (AIM) | 17,850 | SLI |
| 20-SC-72 Seismic and Safety Modernization (SSM), LBNL | 22,500 | SLI |
| 20-SC-73 CEBAF Renovation and Expansion (CEBAF), TJNAF | 10,000 | SLI |
| 19-SC-74 - BioEPIC, LBNL | 7,000 | SLI |
| **Total, Science Laboratories Infrastructure** | **133,240** | |
| | | |
| **Total, Office of Science IRA Supp. Coordination** | **1,550,000** | |

- **Advanced Scientific Computing Research (ASCR) Research:** The goal of these investments is to reduce the lease-financed amounts on ASCR high performance computing systems during this period of historically high inflation. By funding larger down-payments on these systems, ASCR will save funds that otherwise would have been spent on higher interest payments. The Argonne Leadership Computing Facility received $54,100,000 to reduce future lease payments on the Aurora system by increasing the down payment on the system. The National Energy Research Scientific Computing Center (NERSC) received $52,678,000 to purchase the Perlmutter Phase 2 system outright (avoiding a high interest rate lease) and pay down the lease balance on the Perlmutter Phase I system. The Oak Ridge Leadership Computing Facility received $57,013,000 to contribute to purchase of the Frontier system outright (avoiding a high interest rate lease).

- **Basic Energy Sciences (BES) Research**: The goal of this investment is to provide funding for two major items of equipment projects. 1) NEXT-II funding enables the project to bundle many procurements scattered over 3 years into few expedited packages realizing significant savings and risks reduction. FY 2024 planned activities will continue R&D, prototyping, other supporting activities, and construction/equipment procurements. FY 2024 reflects the final year of funding for the project. 2) NSRC Recapitalization funding will reduce concerns of increasing labor, materials, and supply costs, sustain forward momentum, and reduce project risks by accelerating instrument contract awards. FY 2024 planned activities will continue design, other supporting activities, and equipment procurements. FY 2024 reflects the final year of funding for the project. The goal of this investment also provides Other Project Cost funding for two construction projects: 1) Cryomodule Repair & Maintenance Facility and 2) Linac Coherent Light Source-II-High Energy.

- **Cryomodule Repair & Maintenance Facility (CRMF):** The goal of this IRA investment is to enable the project to accelerate the procurement of the architectural and engineering design services and will expedite the design. FY 2024 planned activities will support completion of the detailed design of the facility, and technical specifications for the procurement of cryogenic systems equipment.

- **Second Target Station (STS):** The goal of this IRA investment is to help address inflation-driven concerns of increasing labor, materials, and supply costs, and sustain forward momentum and reduce project risks. FY 2024 planned activities will support continued planning, R&D, design, engineering, prototyping, and testing to advance the highest priority activities. Emphasis will be on advancing the instrument prototypes, target preliminary designs and material characterization, proton beam delivery magnets, neutron beam optics and choppers, neutron moderator, and accelerator designs and controls. A potential long lead procurement for civil construction site preparation to bring in new roads and perform site grading depends on progress of the conventional facility design and DOE review and approval of the plans and use of available funding.

- **Advanced Light Source Upgrade (ALS-U):** The goal of this IRA investment is to enable the project to significantly expedite procurements taking advantage of lower pricing and mitigate inflation uncertainties as well as schedule and technical risks, accelerating the funding profile resulting in reduced funding in the outyears. FY 2024 planned activities will continue to advance the remaining procurements for the Accumulator Ring and the Storage Ring, advance installation of the Accumulator Ring in the tunnel, start pre-staging and assembly of the Storage Ring rafts and components, as the vacuum systems, magnets and diagnostics instruments are received, in preparation for the year-long dark time during which the new Storage Ring will be installed in FY 2026. FY 2024 is the final year of funding for the project.

- **Linac Coherent Light Source-II-High Energy (LCLS-II-HE):** The goal of this IRA investment is to enable the project to expedite the design and long-lead procurements, by more than a year, significantly reducing the inflation uncertainties as well as schedule and technical risks. FY 2024 planned activities will support the production of cryomodules, continue with CD-3B procurements and begin the procurement of remaining scope including vendor supported completion of design efforts associated with the cryogenic distribution system, controls systems, and the low emittance injector beamline, and continue the R&D of the superconducting radiofrequency electron gun and initiating construction/installation contracts.

- **Fusion Energy Sciences (FES) Research:** IRA funding provides $14,000,000 to the Material Plasma Exposure eXperiment (MPEX) project which is being utilized to complete the MPEX Facility Enhancements scope, which will be completed in January 2024. At the time of the IRA funding, the MPEX Facility Enhancements represented the critical path for the project. This funding has allowed the project to proceed more quickly, reducing risk and completing critical project scope as early as possible.

- **Matter in Extreme Conditions Petawatt Upgrade (MEC-U):** IRA funding will be utilized to advance the preliminary design package in support of pursuing Critical Decision (CD)-2 (Approve Performance Baseline) currently planned for FY 2025. This funding will also allow the project team to develop a more thorough plan to proceed through CD-3 (Approve Start of Construction) and project execution.

- **U.S. Contributions to ITER:** IRA funding provides $66,000,000 for Cash Contributions to fulfill U.S. agreements to the ITER Organization from previous underfunding. The remaining $190,000,000 will continue to be used to significantly enhance the design and fabrication performance of project scope in FY 2023–2024 to include the funding activities associated with the Central Solenoid Module fabrication and shipment process and the design, fabrication, and delivery of Tokomak Cooling Water System components.

- **High Energy Physics (HEP) Research:** The goal of this investment is to advance five major items of equipment (MIEs): 1) High Luminosity Large Hadron Collider (HL-LHC) Accelerator; 2) HL-LHC A Toroidal LHC Apparatus (ATLAS) Detector; 3) HL-LHC Compact Muon Solenoid (CMS) Detector; 4) Accelerator Controls Operations Research Network (ACORN); and 5) Cosmic Microwave Background Stage 4 (CMB-S4). FY 2024 planned activities will support fabrication of the HL-LHC projects' components, since all projects are past CD-3. Funding for CMB-S4 and ACORN will support the development of their respective conceptual designs.

- **Proton Improvement Plan II:** The goal of this investment is to support and accelerate the procurement of long lead items that are part of the Accelerator Complex Infrastructure contract. All IRA funds should be expended before FY 2024.

- **Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment:** The goal of this investment is to support and accelerate the Far Site Conventional Facilities - Buildings and Site Infrastructure subproject. FY 2024 planned activities will support construction of surface building and outfitting of the underground caverns with utilities.

- **Muon to Electron Conversion Experiment:** The goal of this investment is for the majority of the remaining work for approximately two years supporting: project management; accelerator; solenoids; muon beamlines; tracker; calorimeter; cosmic ray veto; and trigger and data acquisition system. FY 2024 planned activities will support all remaining activities across the project with installation being the major activity.

- **Nuclear Physics (NP) Operation and Maintenance:** The goal of this investment is to advance four MIE projects. The MOLLER experiment at the Thomas Jefferson National Accelerator facility will measure the parity-violating asymmetry in polarized electron-electron (Møller) scattering. An anomalous amount of parity violation would signal new physics beyond our current understanding. IRA funding allows for long lead procurements to start in FY 2023 once CD-3a is achieved and sets the project for establishing its performance baseline in Q1 FY2024. Gamma-Ray Energy Tracking Array (GRETA) directly supports the NP mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. IRA funding allows for acceleration of module procurements. The High Rigidity Spectrometer (HRS) at FRIB will increase the scientific potential of state-of-the-art and community-priority devices, such as GRETA, and other ancillary detectors. The HRS will allow experiments with beams of rare isotopes at the maximum production rates for fragmentation or in-flight fission. This enhancement in experimental sensitivity provides access to critical isotopes not available otherwise. IRA funding supports conceptual design and, eventually, long lead procurement activities and establishing the project performance baseline. The Ton-Scale Neutrinoless Double Beta Decay (NLDBD) Program, implemented by deploying experiments instrumenting a large volume of a specially selected isotope to detect neutrino-less nuclear beta decays (where within a single nucleus, two neutrons decay into two protons and two electrons with no neutrinos emitted), directly supports NP's mission to explore all forms of nuclear matter. IRA funding supports the three competing technology collaborations (LEGEND, nEXO, and CUPID) to reach CD-1.

- **Electron Ion Collider**: The Electron-Ion Collider (EIC) construction project will provide unprecedented ability to x-ray the proton and discover how the mass of everyday objects is dynamically generated by the interaction of quark and gluon fields inside protons and neutrons. The EIC will maintain U.S. leadership in nuclear physics and in accelerator science and technology of colliders. IRA funding supports long lead procurements and preliminary engineering design ($128,240,000) as well as OPC research and development ($10,000,000).

- **Isotope R&D and Production (IRP) Research:** The goals of this investment include: advancement of critical infrastructure and development of production capabilities of isotopes currently not available in the U.S.; enhancement of current capabilities for optimization of isotope production and forming reserves of critical isotopes; and equipment to detritiate a legacy stockpile of contaminated heavy water for semiconductor and microelectronics manufacturing and reduce dependence on foreign supply. OPC funding for Radioisotope Production Facility (RPF) is provided at planned project profile level, optimizing schedule in the near term, and avoiding reductions in force.

- **Stable Isotope Production and Research Center (SIPRC):** Funding for SIPRC restores optimal planned funding in the near term, accelerating the completion date by about one year.

- **Science Laboratories Infrastructure (SLI) Facilities & Infrastructure:** The IRA funding provided for eleven general plant projects (GPPs) at eight laboratories. Ames National Laboratory replaced the helium recovery system and the failed HVAC system in Harley Wilhelm Hall. At Argonne National Laboratory, a waste heat recovery system from the Advanced Photon Source was installed. At Brookhaven National Laboratory, the electrical distribution system in the Physics Building (B510) was upgraded and aged portions of HVAC systems in mission critical buildings were replaced. At the Fermi National Accelerator Laboratory, improvements were made to the cooling system for the laboratory's communication system in Wilson Hall. The Pacific Northwest National Laboratory installed a high efficiency electric boiler system, new high efficiency air handlers, and new system ducting in the Life Sciences Laboratory. Princeton Plasma Physics Laboratory's fire alarm system was replaced and several other life safety improvements were made. At the Stanford Linear Accelerator Laboratory, aging cooling towers were replaced. Thomas Jefferson Accelerator Facility expanded the laydown yard.

- **Princeton Plasma Innovation Center (PPIC):** PPIC will provide a multi-purpose facility with modern, flexible, efficient, and agile research laboratories and office space to conduct research activities in support of multiple SC programs. IRA funding will be used for finalizing the design of new research building, long lead procurements, and site work.

- **Ames Infrastructure Modernization (AIM):** AIM will renovate building systems that are past their life expectancy and at greatest risk of failure in support of the SC mission. IRA funding will support detailed design and construction activities including elements of plumbing, building envelopes, and electrical.

- **Seismic and Safety Modernization (SSM):** SSM is planned to deliver approximately a 47,000 square foot new building at LBNL to address the mission need for seismically safe space for cafeteria, health services, and assembly in the event of a seismic or emergency situation. IRA funding will be used to perform abatement and demolition of existing facility (B54), installation of soil retaining walls to stabilize the site after demolition, foundations, and initial portion of vertical construction.

- **Continuous Electron Beam Accelerator Facility [CEBAF] Renovation and Expansion (CRE):** CRE will construct new space and modernize existing DOE owned space for both the CEBAF Center and the newly acquired Applied Research Center to advance the Thomas Jefferson National Accelerator Facility's (TJNAF) scientific research mission by providing the infrastructure foundation composed of technically equipped and functional workspaces that are flexible and sustainable. IRA funding will be used to support the completion of this critical construction project at TJNAF by renovating about 20 percent of the Applied Research Center.

- **Biological and Environmental Program Integration Center (BioEPIC):** BioEPIC is a 72,000 square foot laboratory and office building with planned anchor tenants from the Biosciences Area and Earth and Environmental Science Area. Integration of the planned science programs in this unique laboratory facility will leverage existing strengths and emerging technologies to allow significant progress in the understanding of how microbial communities respond to and shape environmental systems, a critical DOE mission. IRA funding will be used to accelerate the enclosure of the building to a state of being weathertight.

## Advanced Scientific Computing Research

### Overview

The mission of the Advanced Scientific Computing Research (ASCR) program is to advance applied mathematics and computer science; deliver the most sophisticated computational scientific applications in partnership with disciplinary science; advance computing and networking capabilities; and develop future generations of computing hardware and software tools for science and engineering in partnership with the research community, including U.S. industry. ASCR supports state-of-the-art capabilities that enable scientific discovery through computation. ASCR's partnerships within the Office of Science (SC) and with the applied technology offices, other agencies, and industry are essential to these efforts. The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national High Performance Computing (HPC) ecosystem by focusing on long-term research to develop innovative software, algorithms, methods, tools and workflows that anticipate future hardware challenges and opportunities as well as science applications and Department of Energy (DOE) mission needs. At the same time, ASCR partners with disciplinary sciences to deliver some of the most advanced scientific computing applications in areas of strategic importance to SC, DOE and the Nation. ASCR also deploys and operates world-class, open access HPC facilities and a high-performance network infrastructure for scientific research.

For over half a century, the U.S. has maintained world-leading computing capabilities through sustained investments in research, development, and regular deployment of new advanced computing systems and networks along with the applied mathematics and software technologies to effectively use them. The benefits of U.S. computational leadership have been enormous gains in increasing workforce productivity, accelerated progress in both science and engineering, advanced manufacturing techniques and rapid prototyping, and stockpile stewardship without testing. Computational science allows researchers to explore, understand, and harness natural and engineered systems, which are too large, too complex, too dangerous, too small, or too fleeting to explore experimentally. Leadership in HPC has also played a crucial role in sustaining America's competitiveness. There is recognition that the nation that leads in Artificial Intelligence (AI) and in the integration of the computing and data ecosystem will lead the world in developing innovative clean energy technologies, medicines, industries, supply chains, and military capabilities. The U.S. will need to leverage investments in science for innovative new technologies, materials, and methods to strengthen our clean energy economy and ensure all Americans share the benefits from those investments. The next generation of breakthroughs in computational science will come from employing data-driven methods at extreme scales tightly coupled to the enormous increases in the volume and complexity of data generated by U.S. researchers and SC user facilities. The convergence of AI technologies with these existing investments creates a powerful accelerator for innovation and technology development and deployment.

Quantum Information Science (QIS)—the ability to exploit intricate quantum mechanical phenomena to create fundamentally new ways of obtaining and processing information—is opening new vistas of science discovery and technology innovation that build on decades of investment across SC. DOE envisions a future in which the cross-cutting field of QIS increasingly drives scientific frontiers and innovations toward realizing the full potential of quantum-based applications, from computing to sensing, connected through a quantum internet. However, there is a need for bold approaches that better couple all elements of the technology innovation chain and combine talents across SC, universities, national labs, and the private sector in concerted efforts to enable the U.S. to lead the world into the quantum future.

Moore's Law—the historical pace of microchip innovation whereby feature sizes reduce by a factor of two approximately every two years—is nearing an end due to limits imposed by fundamental physics and economics. As a result, numerous emerging technologies are competing to help sustain productivity gains, each with its own risks and opportunities. The challenge for ASCR is in understanding their implications for scientific computing and being ready for the potential disruptions from rapidly evolving technologies without stifling innovation or hampering scientific progress. ASCR's strategy is to focus on technologies that build on expertise and core investments across SC, continuing engagements with industry, the applied technology offices, other agencies, and the scientific community from the Exascale Computing Project (ECP); investing in small-scale testbeds; and increasing core research investments in Applied Mathematics and Computer Science.

ASCR's proposed activities will advance AI, QIS, advanced communication networks, and strategic computing at the exascale and beyond to accelerate progress in delivering a clean energy future, understanding and addressing climate change, broadening the impact of our investments in science, and increasing the competitive advantage of U.S. industry.

**Highlights of the FY 2024 Request**

The FY 2024 Request of $1,126.0 million for ASCR is well-aligned with the Administration and the Department priorities to catalyze research and innovation in critical and emerging technologies (AI, QIS, HPC, advanced communications technologies, and microelectronics), Energy Earthshots, and pandemic readiness and prevention.

Research

- The Request prioritizes foundational research in Applied Mathematics and Computer Science to ensure critical technologies from the ECP are maintained and improved so the full potential of the exascale systems can be realized. Investments will emphasize foundational research to address the combined challenges of increasingly heterogeneous and reconfigurable architectures and the changing ways in which HPC systems are used, advancing high efficiency computing, incorporating AI into simulations and data intensive applications while minimizing bias, and increasing connectivity and integration across distributed resources. The Request supports new Microelectronics Science Research Centers as authorized under the Micro Act, focusing on a multi-disciplinary co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion. Support increases for the new Energy Earthshot Research Centers (EERCs). The Computational Partnerships activity will continue to partner with other programs to infuse the latest developments in applied math and computer science into strategic applications, including areas such as accelerating the development of emerging technologies, tackling climate change, pandemic preparedness, cancer research, and efforts with DOE's applied technology programs. The Request continues support for research in states and territories with historically lower levels of Federal academic research funding through the Established Program to Stimulate Competitive Research (EPSCoR) program. ASCR funding opportunities will prioritize sustaining ECP teams, software, technologies, and applications as ECP concludes.

- The Request provides robust support for Advanced Computing Research's quantum investments and partnerships in the National Quantum Information Sciences Research Centers (NQISRCs), quantum internet, and testbeds. ASCR's regional quantum testbeds and user programs, which provide U.S. researchers with access to unique and commercial quantum computing and networking resources, and basic research in quantum information will continue to provide national leadership in quantum in coordination with relevant agencies. Support for the Computational Sciences Graduate Fellowship (CSGF) is increased. The Reaching a New Energy Sciences Workforce (RENEW) initiative expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research.

Facility Operations

- FY 2024 request supports operations and competitive allocation of the Nation's exascale computing systems at the Oak Ridge Leadership Computing Facility (OLCF), a system called Frontier deployed in calendar year 2021, and Argonne Leadership Computing Facility (ALCF), a system called Aurora that was deployed in calendar year 2022. Funding also supports operations at the National Energy Research Scientific Computing Center (NERSC) and the Energy Sciences Network (ESnet). The Request supports advanced computing and AI testbeds at the facilities with competitive, merit reviewed, open access for researchers. ASCR facilities will deploy ECP software and technologies and will prioritize sustaining ECP software and technology critical to HPC operations and users as ECP concludes. In addition, the request supports continued planning for upgrades for the Leadership Computing Facilities and the NERSC-10 upgrade, including site preparations, long lead procurements, and vendor R&D partnerships, to address rising demand for computing and U.S. competitiveness in advanced computing and computational science and a new High Performance Data Facility to provide crucial resources to SC programs to attack fundamental problems in science and engineering.

- ASCR will continue planning for SC's Integrated Research Infrastructure for state-of-the-art real-time experimental/observational workflows and to drive unique technological innovation in system architectures and services beyond what is available in the commercial cloud and will inform planning for future upgrades at the Leadership Computing Facilities (LCFs).

Projects

- The ASCR FY 2024 Request includes $14.0 million for SC's contribution to ECP project including Critical Decision (CD)-4 activities and lessons learned, focused on delivering the Key Performance Parameters (KPPs), open source publishing of ECP software and technologies, and working with vendors and other partners to transfer ECP technologies.

- The FY 2024 Request initiates the HPDF to support the next step in design and planning, advancing from pre-conceptual design to conceptual design, site selection, and alternative selection, and potentially, commencement of site preparation.

**Advanced Scientific Computing Research**
**Funding**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Advanced Scientific Computing Research** | | | | |
| Applied Mathematics Research | 50,858 | 61,035 | 76,188 | +15,153 |
| Computer Sciences Research | 49,963 | 60,667 | 86,017 | +25,350 |
| Computational Partnerships | 79,456 | 95,875 | 87,600 | -8,275 |
| Advanced Computing Research | 105,723 | 108,920 | 149,848 | +40,928 |
| Energy Earthshot Research Centers | – | 12,500 | 12,500 | – |
| **Total, Mathematical, Computational, and Computer Sciences Research** | **286,000** | **338,997** | **412,153** | **+73,156** |
| High Performance Production Computing | 120,000 | 132,003 | 142,000 | +9,997 |
| Leadership Computing Facilities | 410,000 | 430,000 | 466,607 | +36,607 |
| High Performance Network Facilities and Testbeds | 90,000 | 90,000 | 90,213 | +213 |
| **Total, High Performance Computing and Network Facilities** | **620,000** | **652,003** | **698,820** | **+46,817** |
| **17-SC-20, SC Exascale Computing Project** | **129,000** | **77,000** | **14,000** | **-63,000** |
| **Subtotal, Advanced Scientific Computing Research** | **1,035,000** | **1,068,000** | **1,124,973** | **+56,973** |
| **Construction** | | | | |
| 24-SC-20 High Performance Data Facility | – | – | 1,000 | +1,000 |
| **Subtotal, Construction** | **–** | **–** | **1,000** | **+1,000** |
| **Total, Advanced Scientific Computing Research** | **1,035,000** | **1,068,000** | **1,125,973** | **+57,973** |

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $28,194,000 and STTR $3,965,000
- FY 2023 Enacted: SBIR $10,112,000 and STTR $1,422,000
- FY 2024 Request: SBIR $12,093,000 and STTR $1,701,000

## Advanced Scientific Computing Research
## Explanation of Major Changes

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Mathematical, Computational, and Computer Sciences Research**<br>The Computer Science and Applied Mathematics activities will: continue foundational and long-term basic research efforts that explore and prepare for emerging technologies; transition critical technologies from the ECP into core research efforts; develop new scalable energy efficient algorithms and software; and address the challenges of data intensive science and emerging computing technologies such as quantum information science, as well as the development of critical tools, including AI, to enable an integrated computational and data infrastructure. Efforts to address specific basic research challenges for the EERCs are increased. Computational Partnerships continues to support partnerships across SC and interagency partnerships such as cancer and biopreparedness. The EERCs will expand basic research to address new challenges. The Advanced Computing Research activity will support the microelectronics research centers, NQISRCs, quantum testbeds, and regional quantum networking testbeds, in close coordination with the other SC programs. Support for CSGF will increase. RENEW expands its targeted efforts to increase participation and retention of underrepresented groups in SC research activities, including through a RENEW graduate fellowship. Funding opportunities will prioritize sustaining ECP teams, software, technologies, and applications as ECP concludes, as researchers shift from project funding to program funding. | **+$73,156** |
| **High Performance Computing and Network Facilities**<br>The OLCF and ALCF will provide full operations and competitive allocation of the nation’s exascale computing systems, Frontier and Aurora. Both facilities will deploy and sustain ECP software and technologies critical to operations and will provide testbed resources to explore emerging technologies. In addition, funding supports operation of the 125 petaflop NERSC-9 Perlmutter system. Planning, site preparations and project efforts for NERSC-10. Funding supports operations of all facilities—including power and cooling, equipment, staffing, testbeds, lease payments, user programs and outreach. This activity will continue implementation of SC’s Integrated Research Infrastructure, including planning for a High Performance Data Facility (HPDF). | **+$46,817** |
| **Exascale Computing**<br>The FY 2024 Request supports activities to close out and document DOE’s ECP including CD-4 and lessons learned. | **-$63,000** |
| **Construction**<br>The FY 2024 Request initiates conceptual design activities for the HPDF project. | **+$1,000** |
| **Total, Advanced Scientific Computing Research** | **+$57,973** |

**Basic and Applied R&D Coordination**

Coordination across disciplines and programs is a cornerstone of the ASCR program. Partnerships within SC are mature and continue to advance the use of HPC and scientific networks for science. New partnerships with other SC Programs have been established in QIS and in AI. ASCR continues to have a strong partnership with National Nuclear Security Administration (NNSA) for achieving the Department's goals for exascale computing. There are growing areas of collaboration across DOE and with other agencies in the area of data-intensive science, AI, and readying applications for exascale. Through the Networking and Information Technology R&D Subcommittee of the National Science and Technology Council (NSTC) Committee on Technology, ASCR also coordinates with programs across the Federal Government. Future Advanced Computing, Scientific Data, Large Scale Networking, AI, High End Computing, and QIS are coordinated with other agencies through the NSTC. In FY 2024, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

**Program Accomplishments**

*Delivering on the Exascale Computing Project*

ECP teams have successfully run mission critical science and engineering applications on the Nation's first exascale computer, Frontier, at the OLCF. Using Frontier, the ECP WarpX team won the Association for Computing Machinery's (ACM's) 2022 Gordon Bell Prize at the 2022 International Conference for High Performance Computing, Networking, Storage, and Analysis, or SC22, in Dallas, Texas, in November for their outstanding achievement in high-performance computing. WarpX, developed by researchers from Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), and the French Alternative Energies and Atomic Energy Commission (CEA), is the first mesh-refined, particle-in-cell code for kinetic plasma simulations that is optimized for parallel computing. The team produce a 3D simulation at scale of their own novel concept: a combined plasma particle injector and accelerator that focuses a high-power femtosecond (1 quadrillionth of a second) laser onto a hybrid solid/gas target. Their code ran more than 500 times faster than their original code, Warp, after six years of modernizing and optimizing as an ECP application. In addion, ORNL researchers designed a machine-learning software stack that predicts how strongly a given drug molecule will bind to a pathogen as well as the 3D structure of how it will attach to the target. These vital pieces of information can greatly shorten the usual trial-and-error process of lab experimentation to find viable drug candidates, especially for novel viruses with unknown structures. The software, TwoFold, was a finalist for the 2022 Gordon Bell Special Prize for HPC-Based COVID-19 Research.

*Broadening Participation in our Exascale Future*

Across the DOE labs and the Nation, demand greatly outpaces supply for highly skilled workers needed to realize the promise of Exascale computing. Growing this workforce requires engaging with more talented people at key stages in their career. The DOE ECP is helping to build a more vibrant, diverse, and inclusive workforce in HPC through a multipronged initiative that is reaching out to a diverse group of talented people from underrepresented communities, including people who are Black or African American, Hispanic/Latinx, American Indian, Alaska Native, Native Hawaiian, Pacific Islanders, women, persons with disabilities, first-generation scholars, and people from smaller colleges and universities. During the summer 2022, 16 faculty and 45 students representing 32 institutions (with 82 percent representing at least one element of diversity) participated in Sustainable Research Pathways for HPC. This effort, initiated by the ECP and transitioned to RENEW, is designed to connect students and faculty from underrepresented groups with DOE lab scientists to encourage lasting collaborations and jump start careers. Participants worked with ECP teams across nine DOE labs to build software technologies that power HPC discoveries and to develop advanced simulation capabilities across mission areas, with results presented by the students at the ECP Annual Meeting.

*Speeding Up Quantum Chemistry for Climate-Change Resilience*

Understanding how plants respond to drought conditions is critical to adapting to climate change in many parts of the world, and work using quantum-chemical modeling to understand how calcium is transported across cell membranes hopes to shed light on this important topic. A novel graph algorithm developed by a computer-science research project, led by Purdue University, in collaboration with researchers at Pacific Northwest National Laboratory (PNNL) working on the ExaGraph and NWChemEX efforts within the Exascale Computing Project, made a key step in the modeling of a relevant protein, four times faster and enabled the NWChemEX application to scale from using only 4,000 processors to using 14,000 processors on the Summit supercomputer at Oak Ridge National Laboratory. The algorithm, published in 2001 in the Proceedings of Society for Industrial and Applied Mathematics Applied Computational Discrete Algorithms, which computes an approximate submodular b-matching, accomplishes this feat in NWChemEX by improving the method through which computational tasks are assigned to processors.

*Moving Toward an Integrated Research Infrastructure - ESnet-6 enables Distributed Grid Simulation*
In July 2022, the ESnet upgrade project reached successful completion ahead of schedule and under budget with enhanced capability and capacity that provided the fast, predictable timing and programmable flexibility essential for reliable exchange of command-and-control information between National Renewable Energy Laboratory's (NREL) Advanced Research on Integrated Energy Systems (ARIES) platform and PNNL during a successful multi-laboratory demonstration of a complex energy system simulation. The FY 2022 multi-laboratory demonstration showed that advanced control systems in the Cordova microgrid could allow it to maintain power to critical resources like the hospital and the airport during an extreme weather event with loss of some of its hydropower resources. During this tightly coupled experiment, NREL simulated the Cordova microgrid while PNNL simulated the advanced control systems and ESnet delivered consistent, low-latency performance critical to the success of this complex, distributed experiments. The team is looking to next connect six national laboratories for experiments that use and model millions of interconnected devices. Such an integration could better identify solutions for city- and region-level problems, with experiments on outages caused by extreme weather events or a cyberattack and to help energy systems managers adopt new technologies that rely on interconnected devices.

*Advancing Reliable Fusion Reactor Design and Operation for Sustainable Clean Energy*
Nuclear fusion could provide a sustainable supply of clean energy. A critical piece of fusion reactor design is the divertor, which is the only part of the reactor where the extremely hot plasma comes into direct contact with the reactor vessel. The divertor for the multi-billion dollar international fusion experiment ITER will face heat fluxes of 10-20 MW per square meter - ten times higher than the heat load on a spacecraft re-entering Earth's atmosphere. The heat-load width of the divertor is a key design parameter which will sustain exposure to repeated hot exhaust particles. To demonstrate that the tungsten components can withstand the demanding thermal conditions of the ITER machine, researchers supported by the ECP and SciDAC, have integrated high fidelity simulations together with supervised machine learning from experimental data to make more precise predictions. The team used half of the OLCF's Summit supercomputer for two days to complete new simulations that showed that at full power ITER's divertor heat-load width would be more than six times wider than was expected. This would allow ITER to make much faster scientific progress at lower cost. The team produced a more complete prediction of ITER's divertor heat-load width by including magnetic fluctuation and electrostatic turbulence with machine learning parameters to validate the increase predicted for ITER's heat-load width at full power and produced the same results as previous experiments and simulations for existing tokamaks. The results were published in Physics of Plasmas.

*Mitigating Errors to Advance Quantum Computing*
Quantum computers have been improving rapidly over the past several years but they still exhibit error rates far higher than conventional computers. In quantum computers, noise from magnetic fields, changes in temperature, and other sources, leads to the accumulation of errors in complex quantum simulations. This limits their usefulness. To move quantum computing forward, researchers at LBNL developed a new approach to quantum error mitigation that could help make quantum computing's theoretical potential a reality: noise estimation circuits. When combined with three other error mitigation techniques, noise elimination circuits obtained reliable results for dynamic simulations of materials. The novel error mitigation approach will allow researchers to run longer, more realistic simulations and still obtain reliable results. This will broaden the potential impact of upcoming quantum computers on scientific discovery in a huge range of fields, from clean energy to artificial intelligence.

*Integrating Powerful New Tools to Accelerate Discovery Science*
Metals crack, neurons misfire, viruses mutate—all at scales of size and time we can barely fathom, let alone study. To understand how processes work or fail in the natural or mechanical world, requires the ability to probe more deeply and expose layers of detail never before observed. As our tools advance, the data generated quickly outpaces our ability to keep pace. A cross-cutting team from Argonne National Laboratory (ANL) has realized automated end-to-end analysis of data from the Advanced Photon Source (APS). The integration of APS instruments with ALCF computation and storage resources, leverages data acquisition and management software developed at the APS, the DOE-funded Globus toolkit, and ALCF knowhow to enable automated capture of data at the APS, transfer of data to the ALCF where it is analyzed, and sharing results with the scientific team—all in near real-time without human intervention. This achievement, applied at the upgraded APS in collaboration with the new ALCF Aurora supercomputer, will enable leveraging advanced Artificial

Intelligence/Machine Learning (AI/ML) methods, unlock new scientific opportunities, and enable scientific exploration at speeds and scales previously inaccessible to researchers.

## Advanced Scientific Computing Research
## Mathematical, Computational, and Computer Sciences Research

### Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports research activities to effectively meet the SC HPC and computational science mission needs, including both data intensive and computationally intensive science. Computational and data intensive sciences coupled with Artificial Intelligence and Machine Learning (AI/ML) are central to progress at the frontiers of science and to our most challenging engineering problems, particularly for the Energy Earthshots and climate science. ASCR investments are not focused on the next quarter but on the next quarter century. The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national HPC ecosystem and scientific data infrastructure by focusing on long-term research to develop intelligent software, algorithms, and methods that anticipate future hardware challenges and opportunities as well as science needs. ASCR's partnerships with disciplinary science deliver some of the most advanced scientific computing applications in areas of strategic importance to the Nation. Scientific software often has a lifecycle that spans decades, which is much longer than the lifespan of the average HPC system. Research efforts must therefore anticipate changes in hardware and rapidly developing capabilities such as AI and QIS, as well as science needs over the long term. ASCR's partnerships with vendors and discipline sciences are essential to these efforts. Within available resources, ASCR will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. In part through continued funding for the EPSCoR, RENEW and Funding for Accelerated, Inclusive Research (FAIR) initiatives, ASCR will build stronger programs with underrepresented institutions and regions, including investing in a more diverse and inclusive workforce. Accordingly, the subprogram delivers:

- new mathematics and algorithms required to more accurately model systems involving processes taking place across a wide range of time and length scales and incorporating AI and ML techniques into HPC simulations, while minimizing bias;
- the software needed to support DOE mission applications, including critical elements of the exascale software ecosystem and new paradigms of compute-intensive and data-intensive applications, AI and scientific machine learning, and scientific workflows on current and increasingly more heterogeneous future systems;
- insights about computing systems and workflow performance and usability leading to more efficient and productive use of all levels of computing, from the edge to HPC storage and networking resources;
- collaboration tools, data and compute infrastructure and partnerships to make scientific resources and data broadly available to scientists in university, national laboratory, and industrial settings;
- expertise in applying new algorithms and methods, and scientific software tools to advance scientific discovery through modeling and simulation in areas of strategic importance to SC, DOE, and the Nation; and
- long-term, basic research on future computing technologies with relevance to the DOE missions.

#### Applied Mathematics Research

The Applied Mathematics activity supports basic research leading to fundamental mathematical advances and computational breakthroughs across DOE and SC missions. Basic research in scalable algorithms and libraries, multiscale and multi-physics modeling, AI/ML, and efficient data analysis underpin all of DOE's computational and data-intensive science efforts. More broadly, this activity includes support for foundational research in problem formulation, multiscale modeling and coupling, mesh discretization, time integration, advanced solvers for large-scale linear and nonlinear systems of equations, methods that use asynchrony or randomness, uncertainty quantification, and optimization. Historically, advances in these methods have contributed as much, if not more, to gains in computational science than hardware improvements alone. Forward-looking efforts by this activity anticipate DOE mission needs from the closer coupling and integration of scientific modeling, data and scientific AI/ML with advanced computing, for enabling greater capabilities for scientific discovery, design, and decision-support in complex systems and new algorithms to support data analysis at the edge of experiments and instruments and protect the privacy of sensitive datasets. In addition, this activity will support partnerships between mathematicians and computer scientists to develop energy efficient algorithms and methods that scale from intelligent sensors to HPC to advance the Department's energy goals.

#### Computer Science Research

The Computer Science Research activity supports long-term, basic research on the software infrastructure that is essential for the effective use of the most powerful HPC and networking systems in the country as well as the tools and data infrastructure to enable the real-time exploration and understanding of extreme scale and complex data from both simulations and experiments. Through the continued development of adaptive software tools, it aims to make high performance scientific computers and networks even more productive and efficient to solve scientific challenges while attempting to reduce domain science application complexity as much as possible. ASCR Computer Science research also plays a key role in understanding gaps and future opportunities for the design of future computing systems that maintains U.S. leadership in high-performance and data-intensive computing and developing and evolving the sophisticated software required for these systems, including basic research for diverse computing architectures such as quantum computing and communication. Hardware and software vendors often use software developed with ASCR Computer Science investments and integrate it with their own software. ASCR-supported activities are entering a new paradigm driven by sharp increases in the heterogeneity and complexity of computing systems and their software ecosystems, support for large-scale data analytics, and by the incorporation of AI techniques. In partnership with the other SC programs and their scientific user facilities, the Computer Science activity supports research that addresses the need to seamlessly and intelligently integrate simulation, data analysis, and other tasks into comprehensive workflows. These workflows will gather data from the edge of experiments and connect simulation and AI at HPCs to support data analytics and visualization. This includes making research data and AI models findable, accessible, interoperable, and reusable to strengthen trust and maximize the impact of scientific research in society. In addition, this activity supports partnerships between mathematicians and computer scientists to develop energy efficient algorithms and methods that scale from intelligent sensors to HPC to advance the Department's energy goals.

Computational Partnerships

The Computational Partnerships activity supports the Scientific Discovery through Advanced Computing, or SciDAC, program, which is a recognized leader for the employment of HPC for scientific discovery. Established in 2001, SciDAC involves ASCR partnerships with the other SC programs, other DOE program offices, and other federal agencies in strategic areas with a goal to dramatically accelerate progress in scientific computing through deep collaborations between discipline scientists, applied mathematicians, and computer scientists. SciDAC does this by providing the intellectual resources in applied mathematics and computer science, expertise in algorithms and methods, and scientific software tools to advance scientific discovery through modeling, simulation, large-scale data analysis, and AI and scientific machine learning in areas of strategic importance to SC, DOE, and the Nation.

The Computational Partnerships activity also supports collaborations to enable large, distributed research teams to share data and develop tools incorporating AI/ML for real-time analysis of the massive data flows from SC scientific user facilities, as well as the research and development of software to support an integrated research infrastructure and computing environment. The activity also supports the FAIR and Accelerate initiatives, which provide focused investment on enhancing research on clean energy, climate, and related topics, including attention to underserved and environmental justice regions and Historically Black Colleges and Universities (HBCUs) and minority serving institutions (MSIs), as well as Biopreparedness Research Virtual Environment (BRaVE) that advances collaborative research for epidemiology frameworks, computational modeling, and data management/integration in support of national biopreparedness and emergency challenges. BRaVE also supports the incorporation of AI/ML and HPC in cancer research in partnership with the National Cancer Institute.

Additionally, this activity provides support for the DOE EPSCoR that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single principal investigator (PI) and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards.

Advanced Computing Research

This activity supports research focused on development of emerging computing technologies such as QIS and neuromorphic efforts as well as investments in microelectronics in partnership with the other SC program offices, Research and Evaluation Prototypes (REP), and ASCR-specific investments in cybersecurity and workforce including the CSGF and the SC-wide RENEW initiative.

REP has a long history of partnering with U.S. vendors to develop future computing technologies and testbeds that push the state-of-the-art and enabling DOE researchers to better understand the challenges and capabilities of emerging technologies. In addition to REP, this activity supports ASCR's investments in the NQISRCs, as well as quantum computing testbeds and quantum internet testbeds.

SC is fully committed to advancing a diverse, equitable, and inclusive research community, key to providing the scientific and technical expertise for U.S. scientific leadership. Toward that goal, ASCR participates in the SC-wide RENEW initiative that leverages SC's world-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. Science and Technology (S&T) ecosystem. This includes HBCUs and MSIs, typically individuals from groups historically underrepresented in Science, Technology, Engineering and Math (STEM), as well as students from communities disproportionally affected by social, economic, and health burdens of the energy system. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

This activity also provides support for the DOE EPSCoR that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single PI and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards.

Success in fostering and stewarding a highly skilled, diverse, equitable, and inclusive workforce is fundamental to SC's mission and key to also sustaining U.S. leadership in HPC and computational science. The high demand across DOE missions and the unique challenges of high-performance computational science and engineering led to the establishment of the CSGF in 1991. This program has delivered leaders in computational science both within the DOE national laboratories and across the private sector. With increasing demand for these highly skilled scientist and engineers, ASCR continues to partner with the NNSA to support the CSGF to increase the availability and diversity of a trained workforce for exascale computing, AI, and capabilities beyond Moore's Law such as QIS.

Energy Earthshot Research Centers

The Department of Energy's Energy Earthshots will accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade to address the climate crisis. The Energy Earthshots are designed to drive integrated program development across DOE's science, applied technology offices, and Advanced Research Projects Agency-Energy (ARPA-E), and take an 'all research and development (R&D) community' approach to leading science and technology innovations to address tough technological challenges and cost hurdles, and rapidly advance solutions to help achieve our climate and economic competitiveness goals. From a science perspective, many research gaps for the Energy Earthshots cut across many 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 AI and ML 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.

Toward that end, ASCR will continue to partner with SC's Basic Energy Sciences (BES) and Biological and Environmental Research (BER) programs in support of the EERCs, a new modality of research launched in FY 2023, building on the success of SC's Energy Frontier Research Centers (EFRCs) and the SciDAC program. The EERCs bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. Beyond complementing and expanding the scope of the EFRCs and SciDAC, the EERCs address the research challenges at the interface between currently supported basic research, applied research, and development activities, with support from both SC and the applied technology offices. EERCs entail co-funding of team awards involving academic, national laboratories, and industrial researchers, establishing a new era of cross-office research cooperation. Joint funding focuses efforts directly at the interfaces of current research, ensuring that directed fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied research and demonstration activities to bridge the R&D gaps and realize the stretch goals of the Energy Earthshots.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Mathematical, Computational, and Computer Sciences Research** | **+$338,997** | **+$412,153** | **+$73,156** |
| Applied Mathematics Research | $61,035 | $76,188 | +$15,153 |
| Funding continues to expand support of core research efforts in algorithms, libraries and methods that underpin high-end scientific simulations, scientific AI/ML techniques, and methods that help scientists extract insights from massive scientific datasets with an emphasis on foundational capabilities. Funding also supports the basic research needs for the EERCs and the transition of critical Applied Math efforts from the ECP into core research areas. | | The Request will continue to expand support of core research efforts in algorithms, libraries and methods that underpin high-end scientific simulations, scientific AI/ML techniques, and methods that help scientists extract insights from massive scientific datasets with an emphasis on foundational capabilities. The Request will continue partnerships between mathematicians and computer scientists to develop energy efficient algorithms and methods and investments in physics-informed, multiscale algorithms. The Request also will increase support for the basic research needs for several EERCs. Across this activity, within available resources, efforts will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. | Funding will increase support for basic research that addresses specific cross-cutting applied math challenges that support several EERCs and transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Computer Science Research $60,667 | $86,017 | +$25,350 |
| Funding continues support for core investments in software that improves the utility of HPC and advanced networks for science, including AI techniques, workflows, tools, data management, analytics and visualizations with strategic increases focused on critical tools, including AI, to enable an integrated computational and data infrastructure. Funding for this activity also continues long-term basic research efforts that explore and prepare for emerging technologies, such as quantum networking, specialized and heterogeneous hardware and accelerators, and QIS. Funding supports basic research needs of the EERCs, and transition of critical software efforts from the ECP into core research areas. | The Request will continue support for core investments in software that improves the utility of HPC and advanced networks for science, including AI techniques, workflows, tools, data management, analytics and visualizations with strategic increases focused on critical tools, including AI, to enable an integrated computational and data infrastructure. Funding for this activity will also continue long-term basic research efforts that explore and prepare for emerging technologies, such as quantum computing and networking, and other specialized and heterogeneous hardware and accelerators. Interdisciplinary quantum computing research programs previously under Computational Partnerships are moved to Computer Science to create better synergies. In addition, funding will support partnerships between mathematicians and computer scientists to develop energy efficient scalable algorithms and methods. The Request will increase support for the basic research cross-cutting needs of the EERCs. Across this activity, within available resources, efforts will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. | Funding will increase to support directed basic research in support of specific cross-cutting computer science challenges in several EERCs and transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. In addition, funding will support interdisciplinary quantum computing research programs that were previously under Computational Partnerships. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Computational Partnerships | $95,875 | $87,600 | -$8,275 |
| Funding continues support for the SciDAC Institutes and partnerships with SC and DOE applications. Partnerships on scientific data, AI, QIS, and Advanced Computing continues. The partnership with NIH continues to leverage DOE infrastructure to ensure that data is widely available for SC's AI development efforts. Efforts focused on enabling widespread use of DOE HPC resources by Federal agencies in support of emergency preparedness and response are increased. BRaVE provides the cyber infrastructure, computational platforms, and next generation experimental research capabilities within a single portal allowing distributed networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges. This includes partnering with key agencies to understand their simulation and modeling capabilities, data management and curation needs, and identify and bridge gaps necessary for DOE to provide resources on short notice, as well as transitioning ECP capabilities, such as the on-going partnership with the National Cancer Institute. Also, the funding supports the FAIR initiative with new EPSCoR awards fostering partnerships with national laboratories to leverage unique capabilities of the DOE national laboratory system. | | The Request will continue support for the SciDAC Institutes and partnerships with SC and DOE applications. Support for Advanced Computing will continue. Efforts focused on enabling widespread use of DOE HPC resources by Federal agencies in support of emergency preparedness and response will continue. BraVE will provide the cyber infrastructure, computational platforms, and next generation experimental research capabilities to allow networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges, such as the on-going partnership with the National Cancer Institute. Also, the Request will support the FAIR and Accelerate initiatives, including EPSCoR State-National Laboratory Partnership awards. Interdisciplinary quantum computing research programs are moved to Computer Science to create better synergies. Across this activity, within available resources, ASCR will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. | Decrease reflects shift of interdisciplinary quantum computing research to Computer Science. Continued support for research in EPSCoR jurisdictions. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Advanced Computing Research | $108,920 | $149,848 | +$40,928 |
| Funding continues to support the NQISRCs, quantum computing testbed efforts, and regional quantum internet testbeds. Funds allow REP to continue strategic investments in emerging technologies, microelectronics, and development of a plan to sustain the software developed under ECP. Small investments in cybersecurity continue. Funding sustains increased support for the CSGF fellowship, in partnership with NNSA, supporting increased tuition costs, in order to increase the number of fellows focused on emerging technologies, and to expand the participation of groups, fields, and institutions that are under-represented in high end computational science. The goal of CSGF is to increase availability of a trained workforce for exascale computational science, AI at scale, and beyond Moore's Law capabilities such as QIS. Funding increases support for the RENEW initiative providing undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem, including EPSCoR institutions and students, thus expanding the pipeline for ASCR research and facilities workforce needs. | | The Request will continue to support the NQISRCs, quantum computing testbed efforts, and regional quantum internet testbeds. The Request allows REP to increase strategic investments in emerging technologies, microelectronics, and development of a plan to sustain the software developed under ECP. Small investments in cybersecurity will continue. The Request will increase support for the CSGF fellowship, in partnership with NNSA, to support increased tuition costs, an increased stipend, and to increase the number of fellows focused on emerging technologies, and to expand the participation of groups, fields, and institutions that are under-represented in high end computational science. The goal of CSGF is to increase availability of a trained workforce for exascale computational science, AI at scale, and beyond Moore's Law capabilities such as QIS. The Request will also increase support for the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem to expand the pipeline for ASCR research and facilities workforce needs. Funding will support EPSCoR State-National Laboratory Partnership awards and early career awards. Within available resources, this activity will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. New Microelectronics Science Research Centers are established, as authorized under the Micro Act. | The Request supports increases for new microelectronics research centers, CSGF, and RENEW. The Request will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. Continued support for research in EPSCoR jurisdictions. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Energy Earthshot Research Centers | $12,500 | $12,500 | $ — |
| Funding supports a joint Funding Opportunity Announcement (FOA) to be released by the Office of Science (BES, ASCR, and BER) and the DOE Applied Technology Offices for the initial cohort of EERCs. Emphasis is on the current Earthshot topics and those announced by the Department prior to release of the FOA. | | The Request supports joint efforts between Office of Science program (BES, ASCR, and BER) with strong coordination the DOE Applied Technology Offices for the EERCs. Emphasis will be on the current Earthshot topics as well as those announced by the Department prior to release of the FOA. | EERC efforts will inform foundational research investments in applied mathematics and computer science that address the longer-term challenges of the Energy Earthshots. |

*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, excluding facility operations.*

**Advanced Scientific Computing Research**
**High Performance Computing and Network Facilities**

**Description**
The HPC and Network Facilities subprogram supports the operations of forefront computational and networking user facilities to meet critical mission needs. ASCR operates three HPC user facilities: the NERSC at LBNL, which provides HPC resources and large-scale storage to a broad range of SC researchers; and the two LCFs at ORNL and ANL, which provide leading-edge HPC capability to the U.S. research and industrial communities. ASCR's high performance network user facility, ESnet, delivers highly reliable data transport capabilities optimized for the requirements of large-scale science. Finally, operations of these facilities also include investments in upgrades: for the HPC user facilities, this scope includes electrical and mechanical system enhancements to ensure each remains state-of-the-art and can install future systems; for ESnet, the upgrades include rolling capacity growth to ensure no bottlenecks occur in the network.

The HPC and Network Facilities subprogram regularly gathers strategic user requirements from stakeholders across SC and DOE, including the other SC research programs, SC scientific user facilities, DOE national laboratories, and other stakeholders. ASCR gathers these user requirements through formal processes, including workshops and technical reviews, to inform planning for upgrade projects, development of services, and implementation of user programs. The insights ASCR gains from these user requirements activities are also vital to a broad spectrum of ASCR and SC strategic efforts. Examples of this insight include identification of emerging research directions, emerging trends in usage of computing and data resources, and industry innovations in computing architectures and technologies. ASCR continues to observe an accelerating pace of innovation in computing technology, through and beyond the exascale era.

Allocation of ASCR HPC resources to users follows the merit review public-access model used by other SC scientific user facilities. The Innovative and Novel Computational Impact on Theory and Experiment (INCITE) allocation program provides access to the LCFs; the ASCR Leadership Computing Challenge (ALCC) allocation program provides a path for critical DOE mission applications to access the LCFs and NERSC, and a mechanism to address urgent national emergencies and priorities.

The core strength of the ASCR facilities is the dedicated staff who work to maximize user productivity and science impact, operate and maintain world-leading computing and networking resources, while simultaneously executing major upgrade projects. None of the ASCR facilities have suffered significant operational impacts during the COVID-19 pandemic.

In FY 2024, the ASCR facilities will continue planning and begin implementation to advance DOE's Integrated Research Infrastructure (IRI) so that researchers can seamlessly and securely meld DOE's unique data, user facilities, and computing resources to accelerate discovery and innovation.

<u>High Performance Production Computing</u>
This activity supports the NERSC user facility at LBNL to deliver high-end production computing resources and data services for the SC research community. More than 10,000 computational scientists conducting over 1,000 projects use NERSC annually to perform scientific research across a wide range of disciplines including astrophysics, chemistry, earth systems modeling, materials science, engineering, high energy and nuclear physics, fusion energy, and biology. NERSC users come from nearly every state in the U.S., with about half based in universities, approximately one-third in DOE laboratories, and other users from government laboratories, non-profits, small businesses, and industry. NERSC's large and diverse user population spans a wide range of HPC experience, from world-leading experts to students. NERSC aids users entering the HPC arena for the first time, as well as those preparing leading-edge codes that harness the full potential of ASCR's HPC resources.

NERSC currently operates the 125 pf HPE/AMD/NVIDIA NERSC-9 system (Perlmutter), which came online in FY 2021. NERSC is a vital resource for the SC research community and is consistently oversubscribed, with requests exceeding capacity by a factor of 3–10. This gap between demand and capacity exists despite upgrades to the primary computing systems approximately every four to five years.

In addition, the diversity of data- and compute-intensive research workflows is expanding rapidly. The FY 2024 Request supports the NERSC-10 upgrade project, which is intended to provide SC with an innovative, flexible HPC platform to serve an even greater diversity of NERSC users. ASCR will also continue planning efforts for DOE's IRI to satisfy the unique requirements of state-of-the-art real-time experimental/observational workflows and data-integration intensive workflows across the SC user facilities. As demand for HPC resources grows and diversifies, ASCR foresees the strategic need for operational resilience and software portability across its HPC resources.

In FY 2024, the High Performance Production Computing activity will continue planning for the HPDF. Upgrades across the SC user facilities will produce unprecedented increases in data generation. SC programs and their Scientific User Facilities have proposed developing AI/ML techniques to steer experiment and facilities, as well as to speed scientific discovery by automating and streamlining interpretation of datasets. Interaction with experiments in real time requires a service type that existing facilities cannot provide such as the ability to guarantee a computing resource and quality of service throughout an experiment. Effective use of AI/ML also requires the confluence of large well-curated datasets and the compute resources to perform net training activities. Currently, most analyses of experimental and simulation data are done after the experiment or simulation has run. Controlling experiments with AI requires low-latency analysis and inference using high-volume, high-velocity data sets in real time. The proposed HPDF, serving as the foundation for the IRI, will provide a crucial resource to SC programs to attack fundamental problems in science and engineering that require nimble shared access to large data sets, increasingly aggregated from multiple sources. The facility will be designed to dynamically configure computation, network resources, and storage to access data at rest or in motion, supporting the use of well-curated datasets as well as near real-time analysis on streamed data directly from experiments or instruments.

Leadership Computing Facilities

The LCFs are national resources built to enable open scientific computational applications, including industry applications, that harness the full potential of extreme-scale leadership computing to accelerate discovery and innovation. The success of this effort is built on the gains made in the ECP, Research and Evaluation Prototypes (REP) and ASCR research efforts. The LCFs' experienced staff deploy cutting edge technologies and provide support to users including ECP teams, scaling tests, early science applications, and tool and library developers; their efforts are also critical to the success of industry and interagency partnerships.

The OLCF at ORNL currently operates and competitively allocates the Nation's first exascale computing system, an HPE-Cray/AMD exascale system (Frontier), deployed in calendar year 2021; the 200 pf IBM/NVIDIA OLCF-4 system (Summit); and other testbeds and supporting resources. Recent scientific highlights from Summit include: efforts, in partnership with the National Cancer Institute, to train privacy-preserving transformer models for clinical natural language processing of cancer records from the Surveillance, Epidemiology, and End Results (SEER) Program; prediction of synergistic drug combinations for treatment of COVID-19; quantum simulations of photosystem II and cuprate superconductivity; extreme-scale simulations for advanced seismic ground motion and hazard modeling; the world's first seasonal timescale global simulation of the Earth's atmosphere with 1 kilometer average grid spacing; exascale simulation and deep learning models for energetic particles in burning plasmas; design of novel titanium based alloys for additive manufacturing using HPC-aided large-scale phase field simulations; and high-fidelity simulations of turbulent aeroacoustics enabling sustainable aviation. OLCF staff shares its expertise with industry to broaden the benefits of exascale computing for the nation. For example, OLCF works with industry to reduce the need for costly physical prototypes and physical tests to accelerate the development of high-technology products. These efforts often prompt U.S. companies to expand their own HPC resources.

The ALCF at ANL operates and competitively allocates the Nation's second exascale system, an Intel/HPE-Cray system (Aurora) deployed in calendar year 2022. ALCF also operates and allocates a 44 PF HPE/AMD/NVIDIA testbed (Polaris) to prepare users for Aurora and to support large-scale data analytics and machine learning. The ALCF also operates a versatile AI testbed consisting of five systems, leading the investigation and sharing of novel AI accelerators and facilitating publications, and supported a 2021 COVID-19 Gordon Bell finalist with these pre-exascale systems. Recent scientific highlights from the ALCF include: the first tests of novel chiral nucleon-nucleon potentials consistent with three-nucleon interactions in a critical step in developing a first-principles description of nuclear structure; identification of an electrolyte that can be used to protect lithium-ion batteries from water damage; new geophysical dynamic rupture models to perform more accurate seismic hazard analysis; and a digital twin of the city of Chattanooga, Tennessee, to find more effective ways to improve energy efficiency for the city's buildings. The ALCF and OLCF systems are architecturally distinct, consistent with DOE's strategy to manage enterprise risk, foster diverse capabilities that provide the Nation's HPC user community with the most effective resources, and expand U.S. competitiveness.

The demand for 2022 INCITE allocations at the LCFs outpaced the available resources by a factor of three, and this is expected to increase with the availability of Aurora, and its unique capabilities. Demand for 2021–2022 ALCC allocations outpaced resources by more than a factor of five. The LCFs have begun planning for upgrades that would expand the capacity and capabilities of these unique National resources to keep pace with demand and foreign investments.

In FY 2024, the LCFs will continue planning for future upgrades, cultivate vendor partnerships to spur innovation of strategic value and drive U.S. competitiveness, and contribute to planning DOE's integrated research infrastructure.

High Performance Network Facilities and Testbeds

This activity supports ESnet, SC's high performance network user facility, providing world-leading wide-area network access for all of DOE. ESnet is widely recognized as a global leader in the research and education network community, with a multi-decade track record of developing innovative network architectures and services, and reliable operations designed for 99.9 percent uptime for connected sites. ESnet recently completed a major upgrade of its backbone network, the ESnet6 project, which commenced construction in FY 2020, launching a new era of automation, and programmability that will provide DOE science with higher performance and drive greater optimization of network resources.

ESnet is the circulatory system that enables the DOE science mission. ESnet delivers highly reliable data transport capabilities optimized for the requirements of large-scale science. ESnet continuously operates and improves one of the fastest and most reliable science networks in the world that spans the continental United States and the Atlantic Ocean. ESnet interconnects all 17 DOE National Laboratories, dozens of other DOE sites, and approximately 200 research and commercial networks around the world, enabling many tens of thousands of scientists at DOE laboratories and academic institutions across the country to transfer vast data streams and access remote research resources in real-time. ESnet also supports the data transport requirements of all SC user facilities.

ESnet's traffic continues to grow exponentially—roughly 66 percent each year since 1990—a rate more than double the commercial internet. The number of connected sites has also expanded significantly in recent years and continues to grow. Costs for ESnet are dominated by operations and maintenance, including continual efforts to maintain dozens of external connections, benchmark future needs, expand capacity, and respond to new requests for site access and specialized services. As a user facility, ESnet engages directly in efforts to improve end-to-end network performance between DOE facilities and U.S. universities. In addition, ESnet operates a network R&D Testbed user program, which is linked to the National Science Foundation's FABRIC network R&D testbed, providing the nation's academic research community a unique terabit-scale research platform for next generation internet research.

In FY 2024, ESnet will leverage the unique attributes of ESnet6 to develop advanced services to support DOE priority R&D thrusts, DOE's IRI, and cybersecurity.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| **High Performance Computing and Network Facilities** **$652,003** | **$698,820** | **+$46,817** |
| High Performance Production Computing $132,003 | $142,000 | +$9,997 |
| Funding supports operations at the NERSC user facility, including user support, power, space, system leases, and staff. Funding also supports decommissioning of the Cori system; site preparations, design and long-lead procurements for the NERSC-10 upgrade; and full operations and allocation of Perlmutter. In addition, funding supports continued design of the HPDF. | The Request will support operations at the NERSC user facility, including user support, power, space, system leases, and staff. NERSC will deploy the exascale computing software and will prioritize sustaining ECP software and technologies critical to HPC operations and users as ECP concludes. The Request will also support activities such as site preparations, design and procurements for the NERSC-10 upgrade. In addition, funding will support continued design of DOE's IRI. | The funding increase will support site preparations, design and procurements for the NERSC-10 upgrade, continued planning for DOE's IRI, and sustaining ECP software and technologies critical to HCP operations and users. |
| *National Energy Research Scientific Computing Center (NERSC)* *$130,000* | *$135,000* | *+$5,000* |
| Funding supports operations at the NERSC user facility, including user support, power, space, system leases, and staff. Funding supports decommissioning of the Cori system, site preparations, design and long-lead procurements for the NERSC-10 upgrade, and full operations and allocation of Perlmutter. In addition, funding supports continued design of the HPDF. | The Request will support operations at the NERSC user facility, including user support, power, space, system leases, and staff. NERSC will deploy the exascale computing software and will prioritize sustaining ECP software and technologies critical to HPC operations and users as ECP concludes. The Request will also support activities such as site preparations, design and procurements for the NERSC-10 upgrade, and full operations and allocation of Perlmutter. In addition, funding will also support continued design of DOE's IRI. | Funding will support site preparations, design and long-lead procurement for the NERSC-10 upgrade, continued planning for DOE's IRI, and sustaining ECP software and technologies critical to HCP operations and users. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| *High Performance Data Facility, OPC* *$2,003* | *$7,000* | *+$4,997* |
| Funding supports planning and preconceptual R&D for the HPDF, including site selection and preliminary design activities. | The Request will support pre-conceptual R&D and conceptual design for the HPDF project to support the site selection and Analysis of Alternatives processes in preparation for CD-1, and also potentially commencement of site preparation, contingent on achievement of CD-1 in FY 2024. | Increased funding will support the next step in design and planning of the HPDF project, advancing from pre-conceptual design to conceptual design, site selection, and alternative selection, and potentially, commencement of site preparation. |
| Leadership Computing Facilities $430,000 | $466,607 | +$36,607 |
| Funding supports operations at the LCF facilities at ANL and ORNL, including user support, power, space, system leases, early access systems and testbeds, and operations staff. Funding supports operations and allocation of exascale systems at OLCF and ALCF. | The Request will support operations at the LCF facilities at ANL and ORNL, including user support, power, space, system leases, early access systems and testbeds, and staff. The Request will support operations and allocation of exascale systems at OLCF and ALCF as well as planning for future upgrades, vendor partnerships, and DOE’s IRI. The LCFs will deploy and maintain ECP software and technologies critical to HPC operations and users, and support ECP applications as they complete project milestones as ECP concludes. | Funding will support increased operating costs and system leases at both OLCF and ALCF to support operation of the exascale systems. Increase also supports planning for future upgrades, vendor partnerships, and DOE’s IRI, as well as maintenance of ECP software and technologies critical to HPC operations and users. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| *Leadership Computing Facility at ANL* *$175,000* | *$219,000* | *+$44,000* |
| Funding continues support for the operation and competitive allocation of the Theta and Polaris systems. The ALCF will complete acceptance of the ALCF-3 exascale system, Aurora, which deployed in calendar year 2022 and provides access for early science applications and the Exascale Computing Project. Competitive allocation of Aurora begins through ALCC for some exascale ready teams. | The Request will support start of operations and competitive allocation of the ALCF-3 exascale system, Aurora, which will deploy and maintain ECP software and technologies critical to HPC operations and users, and support ECP applications as they complete project milestones and the completion of the Exascale Computing Project. The Request will also support continuing operation and competitive allocation of the Polaris systems and other advanced computing testbeds. The Theta system will be decommissioned at the end of calendar year 2024. Increase supports significant increases in operating costs and lease payments for the Aurora exascale system as well as planning for future upgrades, vendor partnerships, and DOE's IRI. | Funding will support significantly increased operating costs and system lease payments for the Aurora exascale system, including power, maintenance, and space costs. Increase also supports planning for future upgrades, vendor partnerships, and DOE's IRI, as well as maintenance of ECP software and technologies critical to HPC operations and users. |
| *Leadership Computing Facility at ORNL* *$255,000* | *$247,607* | *-$7,393* |
| Funding supports operations at the OLCF facility, including user support, power, space, system leases, maintenance, and staff. Funding also supports full operation and competitive allocation of the Frontier exascale system, Summit, and other testbeds. | The Request will support operations at the OLCF facility, including user support, power, space, maintenance, and staff. The Request will also support operation and competitive allocation of the Frontier exascale system and other advanced computing testbeds. OLCF will deploy and maintain ECP software and technologies critical to HPC operations and users, and support ECP applications as they complete project milestones as ECP concludes. Summit will be decommissioned at the end of calendar year 2024. Planning for OLCF-6 will begin, including vendor engagements. The Request also supports DOE's IRI. | Funding will support operating costs for the Frontier exascale system. Also, funding will support planning for future upgrades, vendor partnerships, and DOE's IRI, as well as maintenance of ECP software and technologies critical to HPC operations and users. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| High Performance Network Facilities and Testbeds $90,000 | $90,213 | +$213 |
| Funding supports operations of ESnet at 99.9 percent reliability, including user support, operations and maintenance of equipment, fiber leases, R&D testbed, and staff. Funding continues development of advanced network services at the start of operations of the recently completed ESnet6 upgrade project to build the next generation network with new equipment, increased capacity, and an advanced programmable network architecture, in accordance with the project baseline. | The Request will support operations of ESnet at 99.9 percent reliability, including user support, operations and maintenance of equipment, fiber leases, R&D testbed, and staff. Funding also supports planning and implementation of DOE's IRI. | Funding supports operations of ESnet and planning and implementation of DOE's IRI. |

*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, excluding facility operations.*

## Advanced Scientific Computing Research
## Exascale Computing Project and High Performance Data Facility

**Description**

SC and NNSA will complete the Exascale Computing Initiative (ECI), which is an effort to develop and deploy an exascale-capable computing system with an emphasis on sustained performance for relevant applications and analytic computing to support DOE missions. The deployment of exascale systems at the LCFs, beginning in CY 2021 enabled the completion of ECI. As the project completes remaining KPPs, documentation and close out activities in FY 2024, ASCR will initiate site selection for a new HPDF. The HPDF will provide a crucial resource to SC programs to attack fundamental problems in science and engineering that require nimble shared access to large data sets, increasingly aggregated from multiple sources. The facility will be designed to dynamically configure computation, network resources and storage to access data at rest or in motion, supporting the use of well-curated datasets as well as near real-time analysis on streamed data directly from experiments or instruments.

24-SC-20, High Performance Data Facility

The FY 2024 Request includes $1,000,000 in Total Estimated Cost (TEC) funding for the HPDF. The preliminary Total Project Cost (TPC) range for this project is $300,000,000 to $500,000,000. CD-0, Approve Mission Need, was approved on August 19, 2020. At that time, the scope of the project was broadly defined to include the potential for site preparation; construction or major upgrade of a data center facility; procurement of non-capital high performance computing, data storage, and local networking equipment; and non-recurring engineering activities with vendor partners to develop critical hardware and software components. Since CD-0, the scope of the project has evolved to consider a "Hub and Spoke" model of one Hub (the primary data center location) connected to several distributed Spokes located at key SC User Facilities and DOE national laboratories to address mission essential streaming data and edge applications as a critical enabler of DOE's Integrated Research Infrastructure.

As early as 2013, a subcommittee of the Advanced Scientific Computing Advisory Committee (ASCAC) cited the need for a Data Facility in its transmittal report noting that "(1) a data-intensive storage and analysis facility with common interfaces and workflows will be necessary, and that (2) building on present ASCR facilities, at least in the near-term, will provide both early successes—such as NERSC's work with Joint Genome Institute (JGI)—and considerable economies. In addition, there is often considerable synergy between analysis and visualization of large computational and observational data sets."

With the resurgence of AI/ML and explosion of data volumes and velocities at many scientific user facilities, SC programs and their Scientific User Facilities have proposed accelerating discovery by developing new techniques to steer experiments and facilities; creating computing environments that integrate heterogeneous data for novel analyses; automating and streamlining interpretation of datasets; and making data Findable, Accessible, Interoperable, and Reusable (the FAIR principles of open data). These goals require new designs of computing and data infrastructure that provide researchers with reliable, simple, seamless performance and alleviate burdens from User Facility staff.

17-SC-20, SC Exascale Computing Project

The SC Exascale Computing Project (SC-ECP) captures the research aspects of ASCR's participation in the ECI, to ensure the hardware and software R&D, including applications software, for an exascale system is completed in time to meet the scientific and national security mission needs of DOE. The SC-ECP is managed following the principles of DOE Order 413.3B, tailored for this fast-paced research effort and similar to what has been used by SC for the planning, design, and construction of all its major computing projects, including the LCFs at ANL and ORNL, and NERSC at LBNL.

SC conducts overall project management for the SC-ECP via a Project Office established at ORNL because of its considerable expertise in developing computational science and engineering applications and in managing HPC facilities, both for DOE and for other federal agencies; and its experience in managing distributed, large-scale projects, such as the Spallation Neutron Source project. A Memorandum of Agreement is in place between the six DOE national laboratories participating in the SC-ECP: LBNL, ORNL, ANL, LLNL, Los Alamos National Laboratory (LANL), and Sandia National Laboratories (SNL). The Project Office at ORNL is executing the project and coordinating among partners.

The FY 2024 Request includes $14,000,000 for the SC-ECP. These funds will provide for delivery and documentation of remaining project milestones, documentation and open source publishing of the ECP software and technologies, transferring these technologies to the DOE computing facilities and to industry partners, and project close out activities including documenting application and software results and lessons learned.

## Advanced Scientific Computing Research
## Exascale Computing Project and High Performance Data Facility

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Construction** | **$77,000** | **$15,000** | **-$62,000** |
| 17-SC-20, SC Exascale Computing Project | $77,000 | $14,000 | -$63,000 |
| Funding supports project management and final execution of applications and software technology to meet the specified KPPs that demonstrate the development of an exascale ecosystem, which is the target of the project. | | The Request will support project management to close out the project and final activities of applications and software technology to document results. FY 2024 is the last year of funding for the project. The project will focus on delivering remaining milestones and transferring ECP software and technologies to DOE computing facilities and industry partners. | FY 2023 was the final year of funding for the ECP applications and software teams. The funding will decrease to reflect the shift in focus from project execution to project close out. |
| 24-SC-20, High Performance Data Facility | $ — | $1,000 | +$1,000 |
| No funding was appropriated in FY 2023 for this project. | | The Request will support conceptual design for the HPDF project to support the site selection and Analysis of Alternatives processes in preparation for CD-1. | Funding will support the initial conceptual design activities. |

## Advanced Scientific Computing Research
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 5,000 | 5,000 | 5,000 | – |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **5,000** | **5,000** | **5,000** | **–** |

## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Total, Non-MIE Capital Equipment | N/A | N/A | 5,000 | 5,000 | 5,000 | – |
| **Total, Capital Equipment** | **N/A** | **N/A** | **5,000** | **5,000** | **5,000** | **–** |

*Note:*
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*

## Advanced Scientific Computing Research
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **24-SC-20, High Performance Data Facility** | | | | | | |
| Total Estimated Cost (TEC) | 294,000 | – | – | – | 1,000 | +1,000 |
| Other Project Cost (OPC) | 10,933 | – | 1,930 | 2,003 | 7,000 | +4,997 |
| **Total Project Cost (TPC)** | **304,933** | **–** | **1,930** | **2,003** | **8,000** | **+5,997** |
| **17-SC-20, Exascale Computing Project (ECP)** | | | | | | |
| Total Estimated Cost (TEC) | 695,376 | 517,376 | 115,000 | 63,000 | – | -63,000 |
| Other Project Cost (OPC) | 630,830 | 588,830 | 14,000 | 14,000 | 14,000 | – |
| **Total Project Cost (TPC)** | **1,326,206** | **1,106,206** | **129,000** | **77,000** | **14,000** | **-63,000** |
| | | | | | | |
| **Total, Construction** | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **115,000** | **63,000** | **1,000** | **-62,000** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **15,930** | **16,003** | **21,000** | **+4,997** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **130,930** | **79,003** | **22,000** | **-57,003** |

## Advanced Scientific Computing 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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Scientific User Facilities - Type A** | | | | | |
| **National Energy Research Scientific Computing Center** | **118,000** | **113,763** | **130,000** | **135,000** | **+5,000** |
| Number of Users | 8,500 | 9,110 | 9,200 | 9,200 | – |
| Achieved Operating Hours | – | 8,473 | – | – | – |
| Planned Operating Hours | 8,585 | 8,585 | 8,585 | 8,585 | – |
| Unscheduled Down Time Hours | – | 112 | – | – | – |
| **Argonne Leadership Computing Facility** | **160,000** | **154,233** | **175,000** | **219,000** | **+44,000** |
| Number of Users | 1,300 | 1,538 | 1,600 | 1,600 | – |
| Achieved Operating Hours | – | 6,987 | – | – | – |
| Planned Operating Hours | 7,008 | 7,008 | 7,008 | 7,008 | – |
| Unscheduled Down Time Hours | – | 21 | – | – | – |
| **Oak Ridge Leadership Computing Facility** | **250,000** | **240,911** | **255,000** | **247,607** | **-7,393** |
| Number of Users | 1,500 | 1,674 | 1,700 | 1,700 | – |
| Achieved Operating Hours | – | 6,994 | – | – | – |
| Planned Operating Hours | 7,008 | 7,008 | 7,008 | 7,008 | – |
| Unscheduled Down Time Hours | – | 14 | – | – | – |
| **Energy Sciences Network** | **90,000** | **86,715** | **90,000** | **90,213** | **+213** |
| Number of Users | – | 63 | – | – | – |
| Achieved Operating Hours | – | 8,760 | – | – | – |
| Planned Operating Hours | 8,760 | 8,760 | 8,760 | 8,760 | – |
| **Total, Facilities** | **618,000** | **595,622** | **650,000** | **691,820** | **+41,820** |
| Number of Users | 11,300 | 12,385 | 12,500 | 12,500 | – |

| | (dollars in thousands) | | | | |
|---|---|---|---|---|---|
| | **FY 2022 Enacted** | **FY 2022 Current** | **FY 2023 Enacted** | **FY 2024 Request** | **FY 2024 Request vs FY 2023 Enacted** |
| Achieved Operating Hours | – | 31,214 | – | – | – |
| Planned Operating Hours | 31,361 | 31,361 | 31,361 | 31,361 | – |
| Unscheduled Down Time Hours | – | 147 | – | – | – |

*Note:*

- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*

## Advanced Scientific Computing Research
## Scientific Employment

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 819 | 825 | 813 | -12 |
| Number of Postdoctoral Associates (FTEs) | 356 | 365 | 341 | -24 |
| Number of Graduate Students (FTEs) | 523 | 535 | 595 | +60 |
| Number of Other Scientific Employment (FTEs) | 217 | 220 | 182 | -38 |
| **Total Scientific Employment (FTEs)** | **1,915** | **1,945** | **1,931** | **-14** |

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

**24-SC-20, High Performance Data Facility**
**Undesignated Laboratory**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Office of Science (SC) High Performance Data Facility (HPDF) project is $1,000,000 of Total Estimated Cost (TEC) and $7,000,000 of Other Project Costs (OPC). The preliminary Total Project Cost (TPC) range for this project is $300,000,000 to $500,000,000. The preliminary TPC estimate for this project is $304,933,000.

The HPDF will provide a crucial resource to SC programs to attack fundamental problems in science and engineering that require nimble shared access to large data sets, increasingly aggregated from multiple sources. The facility will be designed to dynamically configure computation, network resources and storage to access data at rest or in motion, supporting the use of well-curated datasets as well as near real-time analysis on streamed data directly from experiments or instruments.

**Significant Changes**

This is a new Construction Project Data Sheet (CPDS) and this project is a new start in FY 2024. The most recent Department of Energy (DOE) Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need for a construction project with a conceptual scope and cost range, which was approved on August 19, 2020.

During FY 2023, the site for the HPDF will be selected and a Federal Project Director with the appropriate certification level will be assigned. The FY 2024 Request will support and conceptual design for the HPDF project to support the site selection and Analysis of Alternatives processes in preparation for CD-1, and also potentially commencement of site preparation, contingent on achievement of CD-1 in FY 2024.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 8/19/20 | 3Q FY 2024 | 4Q FY 2024 | 4Q FY 2025 | 3Q FY 2025 | 4Q FY 2025 | 4Q FY 2030 |

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range; Conceptual Design Complete – Actual date the conceptual design was completed (if applicable); CD-1 – Approve Alternative Selection and Cost Range; CD-2 – Approve Performance Baseline; Final Design Complete – Estimated/Actual date the project design will be/was complete(d); CD-3 – Approve Start of Construction; D&D Complete – Completion of D&D work; CD-4 – Approve Start of Operations or Project Closeout.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 4,000 | 290,000 | 294,000 | 10,933 | 10,933 | 304,933 |

*Note:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

## 2. Project Scope and Justification

**Scope**

At CD-0 the scope of the project was broadly defined to include the potential for site preparation; construction or major upgrade of a data center facility; procurement of non-capital high performance computing (HPC), data storage, and local networking equipment; and non-recurring engineering activities with vendor partners to develop critical hardware and software components. Since CD-0, the scope of the project has evolved to consider a “Hub and Spoke” model of one Hub (the primary data center location) connected to several distributed Spokes located at key SC User Facilities and Department of Energy (DOE) national laboratories to address mission essential streaming data and edge applications as a critical enabler of DOE’s Integrated Research Infrastructure.

**Justification**

As early as 2013, a subcommittee of the Advanced Scientific Computing Advisory Committee (ASCAC) cited the need for a Data Facility in its transmittal report noting that “(1) a data-intensive storage and analysis facility with common interfaces and workflows will be necessary, and that (2) building on present Advanced Scientific Computing Research facilities, at least in the near-term, will provide both early successes—such as National Energy Research Scientific Computing Center’s work with Joint Genome Institute (JGI)—and considerable economies. In addition, there is often considerable synergy between analysis and visualization of large computational and observational data sets.”

With the growth of Artificial Intelligence and Machine Learning (AI/ML) and explosion of data volumes and velocities at many scientific user facilities, SC programs and their Scientific User Facilities have proposed accelerating discovery by developing new techniques to steer experiments and facilities; creating computing environments that integrate heterogeneous data for novel analyses; automating and streamlining interpretation of datasets; and making data Findable, Accessible, Interoperable, and Reusable (the FAIR principles of open data). These goals require new designs of computing and data infrastructure that provide researchers with reliable, simple, seamless performance and alleviate burdens from User Facility staff. Recent SC workshop reports and requirements reviews cite a number of challenges: Interaction with experiments in real time requires a service type that existing facilities do not provide such as the ability to guarantee a computing resource and quality of service during an experiment. AI/ML also requires the confluence of large well-curated datasets and the compute resources to perform net training activities. Currently, most analyses of experimental and simulation data are done post hoc, after the experiment or simulation has run. Controlling either extreme-scale simulation or experimental facilities with AI requires low-latency analysis and inference using high-volume, high-velocity data sets in real time. Traditional HPC systems are designed to efficiently execute large-scale simulations and focused on minimizing users’ wait-times in batch queues. The SC Integrated Research Infrastructure Architecture Blueprint Activity, a convening of over 160 DOE laboratory subject matter experts, identified the need for new high performance data infrastructure to advance these goals as part of a DOE’s Integrated Research Infrastructure vision.

The proposed HPDF will serve as a foundational element in enabling the DOE Integrated Research Infrastructure; will provide crucial resources to Office of Science programs to attack fundamental problems in science and engineering that require nimble shared access to large data sets, increasingly aggregated from multiple sources; will partner and operate in concert with other ASCR Facilities and potentially other DOE laboratory computing resource providers to provide a high availability high performance computing ecosystem for a wide variety of applications; will serve as a “Hub” enabling “Spoke” sites to deploy and orchestrate distributed infrastructure to enable high priority DOE mission applications.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Key Performance Parameters (KPPs)
The KPPs will be determined after the site selection process and the analysis of alternatives has completed, expected around 3Q FY 2024, and upon establishment of the conceptual design prior to achievement of CD-1.

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| FY 2024 | 1,000 | 1,000 | 500 |
| Outyears | 3,000 | 3,000 | 3,500 |
| **Total, Design (TEC)** | **4,000** | **4,000** | **4,000** |
| Construction (TEC) | | | |
| Outyears | 290,000 | 290,000 | 290,000 |
| **Total, Construction (TEC)** | **290,000** | **290,000** | **290,000** |
| Total Estimated Cost (TEC) | | | |
| FY 2024 | 1,000 | 1,000 | 500 |
| Outyears | 293,000 | 293,000 | 293,500 |
| **Total, TEC** | **294,000** | **294,000** | **294,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2022 | 1,930 | 1,930 | – |
| FY 2023 | 2,003 | 2,003 | – |
| FY 2024 | 7,000 | 7,000 | 7,933 |
| Outyears | – | – | 3,000 |
| **Total, OPC** | **10,933** | **10,933** | **10,933** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2022 | 1,930 | 1,930 | – |
| FY 2023 | 2,003 | 2,003 | – |
| FY 2024 | 8,000 | 8,000 | 8,433 |
| Outyears | 293,000 | 293,000 | 296,500 |
| **Total, TPC** | **304,933** | **304,933** | **304,933** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 2,600 | N/A | **N/A** |
| Design - Contingency | 1,400 | N/A | **N/A** |
| **Total, Design (TEC)** | **4,000** | **N/A** | **N/A** |
| Construction | 188,500 | N/A | **N/A** |
| Construction - Contingency | 101,500 | N/A | **N/A** |
| **Total, Construction (TEC)** | **290,000** | **N/A** | **N/A** |
| **Total, TEC** | **294,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *102,900* | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| OPC, Except D&D | 7,106 | N/A | **N/A** |
| OPC - Contingency | 3,827 | N/A | **N/A** |
| **Total, Except D&D (OPC)** | **10,933** | **N/A** | **N/A** |
| **Total, OPC** | **10,933** | **N/A** | **N/A** |
| *Contingency, OPC* | *3,827* | *N/A* | ***N/A*** |
| **Total, TPC** | **304,933** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***106,727*** | ***N/A*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | — | — | — | 1,000 | 293,000 | 294,000 |
| | OPC | — | 1,930 | 2,003 | 7,000 | — | 10,933 |
| | TPC | — | 1,930 | 2,003 | 8,000 | 293,000 | 304,933 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2030 |
| Expected Useful Life | TBD |
| Expected Future Start of D&D of this capital asset | 4Q FY 2036 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

*Notes:*
- *The project is likely to comprise both capital assets (refurbishment or build of data center space) and non-capital assets (IT components that comprise the computational and data management infrastructure). The expected useful life of the former is potentially 10–20 years, while the latter is 5–7 years.*
- *Life-Cycle costs will be performed as part of CD-1.*

### 7. D&D Information

The scope and nature of D&D activities will be determined at CD-1.

| | Square Feet |
|---|---|
| New area being constructed by this project at [Lab] | TBD |
| Area of D&D in this project at [Lab] | TBD |
| Area at [Lab] to be transferred, sold, and/or D&D outside the project, including area previously "banked" | TBD |
| Area of D&D in this project at other sites | TBD |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | TBD |
| Total area eliminated | TBD |

### 8. Acquisition Approach

Once the site is selected, SC will work with the selected laboratory to determine if a building to house the facility will need to be constructed. All computing and storage resources, as well as, non-recurring engineering activities will be procured through open solicitations.

**17-SC-20, SC Exascale Computing Project**
**Oak Ridge National Laboratory, ORNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the SC Exascale Computing Project (SC-ECP) is $14,000,000 of Other Project Costs (OPC). The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-2/3 Approve Performance Baseline. The project achieved CD-2/3 on February 25, 2020. The Total Project Cost (TPC) of the SC portion of ECP is $1,326,206,000 with the total combined SC and National Nuclear Security Administration (NNSA) TPC of $1,812,300,000.

The FY 2017 Budget Request included funding to initiate research, development, and computer-system procurements to deliver an exascale ($10^{18}$ operations per second) computing capability by the mid-2020s. This activity, referred to as the Exascale Computing Initiative (ECI), is a partnership between SC and NNSA and addresses Department of Energy (DOE) science and national security mission requirements.

Significant Changes

This project was initiated in FY 2017. The FY 2024 Request supports investments in the ECP technical focus areas—application development, software technology and hardware and integration—to support the final close out of the activities which includes developing technical writeups, hardening software and collection of lessons learned. The funding decrease reflects the achievement, in FY 2023, of the threshold Key Performance Parameters (KPPs) as well as a subset of the objective KPPs.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-4 |
|---|---|---|---|---|---|---|
| FY 2024 | 7/28/16 | 3/22/16 | 1/3/17 | 2/25/20 | 6/6/19 | 4Q FY 2024 |

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2024 | 2/25/20 | 1/3/17 | 2/25/20 |

**CD-3A** – Approve Long Lead Time Procurements
**CD-3B** – Approve Remaining Construction Activities

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | — | 700,843 | 700,843 | 625,363 | 625,363 | 1,326,206 |
| FY 2024 | — | 695,376 | 695,376 | 630,830 | 630,830 | 1,326,206 |

## 2. Project Scope and Justification

### Scope

Four well-known challenges[a] are key to requirements and Mission Need of the SC-ECP. These challenges are:

- Parallelism: Systems must exploit the extreme levels of parallelism that will be incorporated in an exascale-capable computer;
- Resilience: Systems must be resilient to permanent and transient faults;
- Energy Consumption: System power requirements must be no greater than 20-30 MW; and
- Memory and Storage Challenge: Memory and storage architectures must be able to access and store information at anticipated computational rates.

The realization of an exascale-capable system that addresses parallelism, resilience, energy consumption, and memory/storage involves tradeoffs among hardware (processors, memory, energy efficiency, reliability, interconnectivity); software (programming models, scalability, data management, productivity); and algorithms. To address this, the scope of the SC-ECP has three focus areas:

- Hardware and Integration: The Hardware and Integration focus area supports U.S. HPC vendor-based research and the integrated deployment of specific ECP application milestones and software products on targeted systems at computing facilities, including the completion of PathForward projects transitioning to facility non-recurring engineering (where appropriate), and the integration of software and applications on pre-exascale and exascale system resources at facilities.
- Software Technology: The Software Technology focus area spans low-level operational software to programming environments for high-level applications software development, including the software infrastructure to support large data management and data science for the DOE at exascale and will deliver a high quality, sustainable product suite.
- Application Development: The Application Development focus area supports co-design activities between DOE mission critical applications and the software and hardware technology focus areas to address the exascale challenges: extreme parallelism, reliability and resiliency, deep hierarchies of hardware processors and memory, scaling to larger systems, and data-intensive science. As a result of these efforts, a wide range of applications will be ready to effectively use the exascale systems deployed in the 2021-2022 calendar year timeframe under the ECI.

### Justification

In 2015, the National Strategic Computing Initiative was established to maximize the benefits of HPC for U.S. economic competitiveness, scientific discovery, and national security. Within that initiative DOE, represented by a partnership between SC and NNSA, has the responsibility for executing a joint program focused on advanced simulation through an exascale–capable computing program, which will emphasize sustained performance and analytic computing to advance DOE missions. The objectives and the associated scientific challenges define a mission need for a computing capability of 2 – 10 ExaFLOPS (2 billion floating-point operations per second) in the early to mid-2020s. In FY 2017, SC initiated the SC-ECP within Advanced Scientific Computing Research (ASCR) to support a large research and development (R&D) co-design project between domain scientists, application and system software developers, and hardware vendors to develop an exascale ecosystem as part of the ECI.

The SC-ECP is managed in accordance with the principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, which SC uses for the planning, design, and construction of all of its major projects, including the LCFs at Argonne and Oak Ridge National Laboratories and the National Energy Research Scientific Computing Center at Lawrence Berkeley National Laboratory. Computer acquisitions use a tailored version of Order 413.3B. The first four years of SC-ECP were focused on research in software (new algorithms and methods to support application and system software development) and hardware (node and system design), and these costs will be reported as Other Project Costs. During the last three years of the project, activities will focus primarily on hardening the application and the system stack software,

[a] http://www.isgtw.org/feature/opinion-challenges-exascale-computing

and on additional hardware technology investments, and these costs will be included in the Total Estimated Costs for the project.

Key Performance Parameters (KPPs)

The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Exascale performance improvements for mission-critical challenge problems | 50 percent of selected applications achieve Figure of Merit improvement greater than or equal to 50x | 100 percent of selected applications achieve their KPP-1 stretch goal |
| Broaden exascale science and mission capability | 50 percent of the selected applications can execute their challenge problem[a] | 100 percent of selected applications can execute their challenge problem stretch goal |
| Productive and sustainable software ecosystem | 50 percent of the weighed impact goals are met | 100 percent of the weighted impact goals are met |
| Enrich the HPC Hardware Ecosystem | Vendors meet 80 percent of all the PathForward milestones | Vendors meet 100 percent of all the PathForward milestones |

[a] This KPP assesses the successful creation of new exascale science and mission capability. An exascale challenge problem is defined for every scientific application in the project. The challenge problem is reviewed annually to ensure it remains both scientifically impactful to the nation and requires exascale-level resources to execute.

## 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Construction (TEC) | | | |
| Prior Years | 517,376 | 517,376 | 257,725 |
| FY 2022 | 115,000 | 115,000 | 163,147 |
| FY 2023 | 63,000 | 63,000 | 221,745 |
| FY 2024 | – | – | 47,292 |
| Outyears | – | – | 5,467 |
| **Total, Construction (TEC)** | **695,376** | **695,376** | **695,376** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 517,376 | 517,376 | 257,725 |
| FY 2022 | 115,000 | 115,000 | 163,147 |
| FY 2023 | 63,000 | 63,000 | 221,745 |
| FY 2024 | – | – | 47,292 |
| Outyears | – | – | 5,467 |
| **Total, TEC** | **695,376** | **695,376** | **695,376** |

Note:

- The project approved a project change request to extend technical campaigns one quarter into FY 2024 to allow full access to the Aurora computer which was delayed due to supply chain issues currently prevalent since COVID. This will not impact the CD-4 baseline date.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 588,830 | 588,830 | 583,920 |
| FY 2022 | 14,000 | 14,000 | 9,171 |
| FY 2023 | 14,000 | 14,000 | 18,753 |
| FY 2024 | 14,000 | 14,000 | 13,983 |
| Outyears | – | – | 5,003 |
| **Total, OPC** | **630,830** | **630,830** | **630,830** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 1,106,206 | 1,106,206 | 841,645 |
| FY 2022 | 129,000 | 129,000 | 172,318 |
| FY 2023 | 77,000 | 77,000 | 240,498 |
| FY 2024 | 14,000 | 14,000 | 61,275 |
| Outyears | – | – | 10,470 |
| **Total, TPC** | **1,326,206** | **1,326,206** | **1,326,206** |

**4. Details of Project Cost Estimate**

The SC-ECP was baselined at CD-2. The Total Project Cost for the SC-ECP is represented in the table below.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Application Development (TEC) | 347,349 | 347,349 | 346,360 |
| Production Ready Software | 228,356 | 228,356 | 217,290 |
| Hardware Partnership | 125,138 | 125,138 | 131,726 |
| **Total, Other (TEC)** | **700,843** | **700,843** | **695,376** |
| **Total, TEC** | **700,843** | **700,843** | **695,376** |
| *Contingency, TEC* | ***N/A*** | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Planning Project Management | 89,689 | 89,689 | 89,688 |
| Application Development (OPC) | 221,050 | 221,050 | 221,050 |
| Software Research | 118,517 | 118,517 | 118,517 |
| Hardware Research | 196,107 | 196,107 | 201,575 |
| **Total, Except D&D (OPC)** | **625,363** | **625,363** | **630,830** |
| **Total, OPC** | **625,363** | **625,363** | **630,830** |
| *Contingency, OPC* | ***N/A*** | *N/A* | ***N/A*** |
| **Total, TPC** | **1,326,206** | **1,326,206** | **1,326,206** |
| ***Total, Contingency (TEC+OPC)*** | ***N/A*** | ***N/A*** | ***N/A*** |

5. **Schedule of Appropriations Requests**

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 522,843 | 115,000 | 63,000 | — | — | 700,843 |
| | OPC | 583,363 | 14,000 | 14,000 | — | 14,000 | 625,363 |
| | TPC | 1,106,206 | 129,000 | 77,000 | — | 14,000 | 1,326,206 |
| FY 2024 | TEC | 517,376 | 115,000 | 63,000 | — | — | 695,376 |
| | OPC | 588,830 | 14,000 | 14,000 | 14,000 | — | 630,830 |
| | TPC | 1,106,206 | 129,000 | 77,000 | 14,000 | — | 1,326,206 |

6. **Related Operations and Maintenance Funding Requirements**

System procurement activities for the exascale-capable computers are not part of the SC-ECP. The exascale-capable computers will become part of existing facilities and operations and maintenance funds, and will be included in the ASCR facilities' operations or research program's budget. A Baseline Change Proposal (BCP) was executed in March 2018 to reflect this change.

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2024 |
| Expected Useful Life | 7 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2031 |

7. **D&D Information**

N/A, no construction.

8. **Acquisition Approach**

The early years of the SC-ECP, approximately four years in duration, supported R&D directed at achieving system performance targets for parallelism, resilience, energy consumption, and memory and storage. The second phase of approximately three years duration will support finalizing applications and system software.

## Basic Energy Sciences

### Overview

The mission of the Basic Energy Sciences (BES) program is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels. BES research provides the scientific foundations for innovations in clean energy technologies and related national priorities, to mitigate the climate and environmental impacts of energy generation/use, and to support DOE missions in energy, environment, and national security. BES accomplishes its mission through excellence in scientific discovery and stewardship of world-class scientific user facilities that enable cutting-edge research and development.

The research disciplines that BES supports—condensed matter and materials physics, chemistry, geosciences, and aspects of biosciences—touch virtually every important aspect of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation, providing a knowledge base for achieving a secure and sustainable clean energy future. The Basic Energy Sciences Advisory Committee (BESAC) report, "A Remarkable Return on Investment in Fundamental Research,"[a] provides key examples of major technological, commercial, and national security impacts, including clean energy technologies, directly traceable to BES-supported basic research. This mission-relevance of BES research results from a long-standing strategic planning process, which encompasses BESAC reports, topical in-depth community workshops and reports, and rigorous program reviews. BES balances its research investments among discovery-oriented basic research, use-inspired basic research as exemplified by the Energy Frontier Research Centers (EFRCs), and research in support of Federal priorities and technological innovation such as the Energy Earthshot Research Centers (EERCs).

BES scientific user facilities consist of a complementary set of intense x-ray sources, neutron sources, and centers for research utilizing nanoscale science. Capabilities at BES facilities probe materials and chemical systems with ultrahigh spatial, temporal, and energy resolutions to investigate the critical functions of matter—transport, reactivity, fields, excitations, and motion—to answer some of the most challenging science questions and to provide insights on the scientific basis for energy technologies. The above-noted BESAC report recounts the central role of these shared resources in U.S. scientific and industrial leadership; a 2021 BESAC report on international benchmarking[b] outlines strategies to maintain and enhance this competitive position for facilities and key BES scientific areas. In response to the COVID-19 pandemic, BES facilities were at the forefront of the research to understand the virus, to provide therapeutics to combat it, and to combat supply chain issues for personal protective and medical equipment. BES has a long history of delivering major construction projects on time and on budget, and of providing reliable availability and support to users for operating facilities. This record of accomplishment begins with rigorous community-based processes for conceptualization, planning, and execution in construction of facilities that continues in performance assessment for operating facilities.

Key to exploiting scientific discoveries for future clean energy technological systems is the ability to create new materials using forefront synthesis and processing techniques, to precisely define the atomic arrangements, and to design chemical processes. Robust materials need improved functionality relative to today's energy materials, and new chemical processes require ever-increasing control at the level of electronic structure and dynamics. These innovations, based on principles revealed by fundamental science and using advanced computational, data science, and experimental tools, will enable better control of physical and chemical transformations and conversions of energy from one form to another for technologies including hydrogen and solar generation of fuels and electricity, long-term energy storage, geothermal energy, nuclear energy, carbon capture, and clean, lower carbon manufacturing. Working closely with the DOE technology offices, innovations and insights from BES research will evolve with awareness of technology challenges and will be disseminated to the broader research community to accelerate applied research and translate federal investments to industrial impact.

To reach the full potential of these tools and capabilities for clean energy, it is critical that the Nation bring to bear the strengths of all of its human resources, including students and institutions not currently well represented in the scientific ecosystem, and underserved and environmental justice regions. Collectively, with fully broadened participation, these new tools and capabilities convey a significant strategic advantage for the Nation to advance the scientific frontiers while laying the foundation for future clean energy innovations and economic prosperity.

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[a] https://science.osti.gov/~/media/bes/pdf/BESat40/BES_at_40.pdf
[b] https://science.osti.gov/-/media/bes/pdf/reports/2021/International_Benchmarking-Report.pdf

**Highlights of the FY 2024 Request**
The BES FY 2024 Request of $2,692.9 million is an increase of $158.9 million, or 6.3 percent, above the FY 2023 Enacted.

Research
The Request continues support for EERCs, EFRCs, the Batteries and Energy Storage and Fuels from Sunlight Energy Innovation Hub programs, and the National Quantum Information Science (QIS) Research Centers (NQISRCs). Through continued funding for the Established Program to Stimulate Competitive Research (EPSCoR) and the Reaching a New Energy Sciences Workforce (RENEW) and Funding for Accelerated, Inclusive Research (FAIR) initiatives, BES will build stronger programs with underrepresented institutions and regions, including investing in a more diverse and inclusive workforce to address environmental justice issues.

- Clean Energy and SC Energy Earthshots Initiatives: BES will increase support for research to provide understanding and foundations for clean energy, with investments across the entire portfolio to accelerate innovation to reduce impacts resulting from climate change while advancing clean energy technologies and infrastructure. Current DOE Energy Earthshots focus on aggressive goals for direct air capture of $CO_2$, carbon-neutral hydrogen, energy storage for the grid, geothermal systems, floating offshore wind, and industrial heat decarbonization, with additional topics under development. BES funding will also advance understanding of the fundamental properties of Critical Materials/Minerals and identify methodologies to reduce their use and discover substitutes, and to enhance their domestic supply.
- There are other initiatives with continued BES funding including: Fundamental Science to Transform Advanced Manufacturing, emphasizing low-carbon processes and transformative chemistry, materials, and biology for next-generation industries; and Microelectronics, focusing on a multi-disciplinary co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion including new Microelectronics Science Research Centers as authorized under the CHIPS and Science Act (Section 10731, Micro Act). Additionally, BES funding will support Accelerate Innovation in Emerging Technologies (Accelerate), to drive scientific discovery to sustainable production of new technologies across the innovation continuum, including relevant experiences for the future workforce; and Artificial Intelligence and Machine Learning (AI/ML), data science to accelerate fundamental discoveries and to apply these techniques for effective user facility operations and interpretation of massive data sets.
- BES will also support: QIS, a robust core research portfolio to complement the NQISRCs; Biopreparedness Research Virtual Environment (BRaVE), developing and expanding capabilities at user facilities for responsiveness to biological threats; Accelerator Science and Technology Initiative, to provide the world's most comprehensive and advanced accelerator-based facilities for scientific research; and Advanced Computing, with Advanced Scientific Computing Research (ASCR), including computational materials and chemical sciences to deliver shared software infrastructure, and support for efforts toward integration of computing, networking, and data storage with experimental user facilities and instruments at national labs. BES will prioritize transitioning Exascale Computing Project (ECP) researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes.
- BES will support RENEW, expanding targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research; and FAIR, improving underrepresented institutions' capability to perform and propose competitive research and building beneficial relationships with DOE national laboratories and facilities.

Facility Operations
The five BES-supported x-ray light sources, two neutron sources, and five Nanoscale Science Research Centers (NSRCs) are supported at approximately 90 percent of the funding required for re-baselined, normal operations—balancing safe operations with user access.

Projects
Support continues for the Advanced Light Source Upgrade (ALS-U), Linac Coherent Light Source-II High Energy (LCLS-II-HE), Proton Power Upgrade (PPU), Second Target Station (STS), and Cryomodule Repair and Maintenance Facility (CRMF) line-item projects and two Major Items of Equipment (MIE) projects: NSLS-II Experimental Tools-II (NEXT-II) and NSRC Recapitalization. The Request initiates design funding for the NSLS-II Experimental Tools-III (NEXT-III) and High Flux Isotope Reactor Pressure Vessel Replacement (HFIR-PVR) line-item projects. In addition, the Request initiates preliminary planning for Advanced Photon Source (APS) and Advanced Light Source (ALS) Beamline MIE projects.

## Basic Energy Sciences
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Basic Energy Sciences** | | | | |
| Scattering and Instrumentation Sciences Research | 85,675 | 105,971 | 107,713 | +1,742 |
| Condensed Matter and Materials Physics Research | 192,569 | 203,807 | 221,214 | +17,407 |
| Materials Discovery, Design, and Synthesis Research | 88,047 | 97,097 | 101,297 | +4,200 |
| Established Program To Stimulate Competitive Research EPSCoR | 25,000 | 25,000 | 25,000 | – |
| Energy Frontier Research Centers - Materials | 65,000 | 65,000 | 65,000 | – |
| Energy Earthshot Research Centers - Materials | – | 12,500 | 12,500 | – |
| Energy Innovation Hubs - Materials | 25,000 | 25,913 | 25,913 | – |
| Computational Materials Sciences | 13,492 | 13,492 | 13,492 | – |
| **Total, Materials Sciences and Engineering** | **494,783** | **548,780** | **572,129** | **+23,349** |
| Fundamental Interactions Research | 124,842 | 127,985 | 141,339 | +13,354 |
| Chemical Transformations Research | 119,725 | 129,651 | 140,158 | +10,507 |
| Photochemistry and Biochemistry Research | 106,871 | 130,877 | 139,714 | +8,837 |
| Energy Frontier Research Centers - Chemical | 65,000 | 65,000 | 65,000 | – |
| Energy Earthshot Research Centers - Chemical | – | 12,500 | 12,500 | – |
| Energy Innovation Hubs - Chemical | 20,758 | 20,758 | 20,758 | – |
| General Plant Projects - Chemical | 1,000 | 1,000 | 1,000 | – |
| Computational Chemical Sciences | 13,492 | 13,492 | 13,492 | – |
| **Total, Chemical Sciences, Geosciences, and Biosciences** | **451,688** | **501,263** | **533,961** | **+32,698** |
| X-Ray Light Sources | 538,282 | 599,498 | 704,134 | +104,636 |
| High-Flux Neutron Sources | 294,000 | 315,740 | 373,163 | +57,423 |
| Nanoscale Science Research Centers | 142,744 | 153,409 | 150,880 | -2,529 |
| Other Project Costs | 14,300 | 19,500 | 14,000 | -5,500 |
| Major Items of Equipment | 30,000 | 50,000 | 25,000 | -25,000 |

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Scientific User Facilities, Research | 38,003 | 52,610 | 58,966 | +6,356 |
| **Total, Scientific User Facilities (SUF)** | **1,057,329** | **1,190,757** | **1,326,143** | **+135,386** |
| **Subtotal, Basic Energy Sciences** | **2,003,800** | **2,240,800** | **2,432,233** | **+191,433** |
| **Construction** | | | | |
| 24-SC-10 HFIR Pressure Vessel Replacement (PVR), ORNL | – | – | 4,000 | +4,000 |
| 24-SC-12 NSLS-II Experimental Tools - III (NEXT-III), BNL | – | – | 2,556 | +2,556 |
| 21-SC-10 Cryomodule Repair & Maintenance Facility (CRMF), SLAC | 1,000 | 10,000 | 9,000 | -1,000 |
| 19-SC-14 Second Target Station (STS), ORNL | 32,000 | 32,000 | 52,000 | +20,000 |
| 18-SC-10 Advanced Photon Source Upgrade (APS-U), ANL | 101,000 | 9,200 | – | -9,200 |
| 18-SC-11 Spallation Neutron Source Proton Power Upgrade (PPU), ORNL | 17,000 | 17,000 | 15,769 | -1,231 |
| 18-SC-12 Advanced Light Source Upgrade (ALS-U), LBNL | 75,100 | 135,000 | 57,300 | -77,700 |
| 18-SC-13 Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC | 50,000 | 90,000 | 120,000 | +30,000 |
| 13-SC-10 Linac Coherent Light Source-II (LCLS-II), SLAC | 28,100 | – | – | – |
| **Subtotal, Construction** | **304,200** | **293,200** | **260,625** | **-32,575** |
| **Total, Basic Energy Sciences** | **2,308,000** | **2,534,000** | **2,692,858** | **+158,858** |

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $61,375,000 and STTR $8,643,000
- FY 2023 Enacted: SBIR $35,557,000 and STTR $5,000,000
- FY 2024 Request: SBIR $36,306,000 and STTR $5,105,000

## Basic Energy Sciences
## Explanation of Major Changes

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Materials Sciences and Engineering**<br>Research will continue to support fundamental scientific opportunities for materials innovations, including those identified in recent BESAC and Basic Research Needs workshop reports. Research priorities include clean energy (e.g., hydrogen, direct air capture of $CO_2$, energy storage, and wind), advanced manufacturing (e.g., reductions in carbon-intensive heat), microelectronics research centers, data science and AI/ML, Accelerate, critical materials, computational materials sciences, advanced computing, BRaVE, QIS, strategic accelerator technology, FAIR, and RENEW. The Request also includes funding for continued support of the EFRCs, the Batteries and Energy Storage Energy Innovation Hub program, the NQISRCs, EPSCoR, and the EERCs. | **+$23,349** |
| **Chemical Sciences, Geosciences, and Biosciences**<br>Research will continue to support fundamental scientific opportunities for innovations in chemistry, geosciences, and biosciences, including those identified in recent BESAC, Basic Research Needs, and Roundtable workshop reports. Research priorities include clean energy (e.g., energy-efficient, sustainable cycles for carbon and hydrogen, geothermal, and direct air capture of $CO_2$), advanced manufacturing, microelectronics research centers, Accelerate, critical materials/minerals, computational chemical sciences, QIS, FAIR, and RENEW. The Request also includes funding for continued support of the EFRCs, the Fuels from Sunlight Hub awards, the NQISRCs, and the EERCs. | **+$32,698** |
| **Scientific User Facilities (SUF)**<br>Five BES-supported x-ray light sources, two neutron sources, five NSRCs are supported at approximately 90 percent of the re-baselined funding level, balancing safe operation and user access. These facilities will continue to support the BRaVE initiative to maintain and enhance capabilities to tackle biological threats and the advanced computing initiative to augment integration of computing, networking, and data storage with user facilities and national labs. Continued facilities research priorities include accelerator science and technology, data science and AI/ML, and RENEW. The Request continues two MIEs: the NEXT-II beamline project for NSLS-II and the NSRC recapitalization project and initiates preliminary planning for APS and ALS Beamline MIE projects. The Request also provides Other Project Costs (OPC) to support the CRMF, HFIR-PVR, and NEXT-III projects. | **+$135,386** |
| **Construction**<br>The Request provides continuing support for the LCLS-II-HE, the STS, and the CRMF projects and provides final funding for the PPU and the ALS-U projects. The Request also initiates design funding for the NEXT-III project at Brookhaven National Laboratory (BNL) and the HFIR-PVR project at Oak Ridge National Laboratory (ORNL). | **-$32,575** |
| **Total, Basic Energy Sciences** | **+$158,858** |

**Basic and Applied R&D Coordination**
As a program that supports fundamental scientific research relevant to many DOE mission areas, BES strives to build and maintain close connections with other DOE program offices. BES coordinates with DOE R&D programs through a variety of Departmental activities, including joint participation in research workshops, strategic planning activities, solicitation development, and program review meetings, as elaborated below. BES also coordinates with DOE technology offices in the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program, including topical area planning, solicitations, reviews, and award recommendations.

BES has robust interactions with DOE technology offices through formal and informal coordination activities. Formal coordination includes Joint Strategy Teams (JSTs) and Science and Energy Technology Teams (SETTs) that draw on expertise and capabilities stewarded by multiple DOE offices to address forefront energy challenges. For example, BES participates in the newly formed Hydrogen JST (previously a SETT), engaging in activities to advance the Hydrogen Energy Earthshot aimed at accelerating breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade.[c] BES also contributes to the Carbon Dioxide Removal SETT and the Carbon Negative Earthshot to address the challenge of long-term removal of carbon dioxide from the atmosphere using a variety of approaches including direct air capture, and the Energy Storage JST and Long Duration Storage Earthshot to accelerate the development, commercialization, and utilization of next-generation energy storage technologies. In addition, BES is also participating in recently established Earthshots focused on floating offshore wind, decarbonization of heating used in manufacturing, and enhanced geothermal systems. Other coordination activities focus on fusion energy and sustainable fuels. Collectively, these BES activities impact the energy-use sectors: transportation, buildings, industrial, and electricity. Historically, co-siting of research by BES and DOE energy technology programs at the same institutions has proven to be a valuable approach to facilitate close integration of basic and applied research. In these cases, teams of researchers benefit by sharing expertise and knowledge of research breakthroughs and program needs. The DOE national laboratory system plays a crucial role in achieving this integration of basic and applied research.

Informal coordination includes participation of BES program managers in regularly scheduled intra-departmental meetings for information exchange and coordination on solicitations, program reviews, and project selections. These interactions cover a broad range of topics including biofuels derived from biomass; solar energy utilization, including solar fuels; critical minerals/materials; advanced nuclear energy systems; vehicle technologies; biotechnology; and fundamental science to transform advanced manufacturing and industrial processes. These activities facilitate cooperation and coordination between BES and the DOE energy technology offices and defense programs. Additionally, DOE technology office personnel participate in reviews of BES research, and BES personnel participate in reviews of research funded by the technology offices.

**Program Accomplishments**
*BES user facilities continue to combat the COVID-19 pandemic and to prepare for biological threats, including monkeypox.*

- Pfizer scientists used x-ray facility capabilities to determine certain structural properties of their vaccine Comirnaty, and to develop their antiviral, Paxlovid. Following on their approved therapeutic Sotrovimab, GlaxoSmithKline and Vir Biotechnology used x-ray facilities to help produce an antibody that neutralizes all known strains of SARS-CoV-2. More than 750 unique users (including most major Pharma companies), using more than 55 different beamlines at x-ray facilities, determined more than 490 structures of SARS CoV-2 proteins with/without potential antivirals or antibodies.
- X-ray light source users are also at the forefront of investigations of monkeypox, including structural biology research related to how poxviruses (including monkeypox virus) evade the host anti-viral immune response. Research includes characterization of poxvirus protein structures and interactions with antigenic proteins and antibodies, as well as therapeutics developments to combat monkeypox and related poxviridae.

*BES research and facilities advance understanding of catalysts and of key components of chemical and energy conversions for value-added chemicals and clean fuels.*

- X-ray, nanoscale science, and computational facilities were used to study a catalyst under different reaction conditions to track methanol formation. The tools helped to identify the active catalyst sites and model the kinetics of different reaction pathways. The data show that the reaction proceeds on two different pathways using two different sites of

[c] https://www.energy.gov/eere/fuelcells/hydrogen-shot.

the catalyst, yielding insights into conversion of waste methane greenhouse gases into methanol, a liquid fuel and chemical.

- Pursuing highly efficient transformations of renewable feedstocks, researchers developed molecular catalysts that are highly active and selective at low temperature for ethanol upgrading to butanol, that demonstrated a prolonged lifetime, and that could couple ethanol in tandem reactions to produce high-value industrial chemical intermediates. Conversion of ethanol to higher-order alcohols has the potential to supplement the transportation sector; higher-order alcohols feature more desirable fuel characteristics, such as higher energy densities and lower water solubility.
- Researchers developed a non-thermal plasma-excited pathway that achieved the desired conversion of the waste gas $CO_2$ and ethane to value-added oxygenated chemicals and fuels at atmospheric pressure and temperature in an energy-efficient single step. Plasma-activated reactions are more easily adaptable to renewable electricity than are large-scale thermally activated processes.
- Scientists used ultrafast attosecond-duration pulses of x-rays to map the coherent motion of electrons in a molecule, with the potential to provide a precise understanding of the fundamental role of coherent charge transfer in chemical and biological processes and energy conversions. The measurement provides a testbed for exploring the effect of electronic coherence in the photoexcitation dynamics and subsequent photochemical behavior of molecular systems.

*BES research and facilities improve materials assembly processes for advanced manufacturing.*

- Neutron scattering has been used for real-time monitoring and evaluation of residual strain during post-production heat treatment to improve 3D printing processes for metal parts. Comparison to computer simulation allows prediction of the residual stress distributions as a function of the process parameters. The results are being used to validate computer models and adjust component designs to reduce residual strain formation during additive manufacturing.
- Scientists have advanced the use of DNA for assembling new nanoscale materials into complex and prearranged structures for next-generation applications, such as nano-robots for manufacturing or innovative materials to harvest light. A hollow DNA cuboid nanochamber is formed, and the encoded DNA strands that extend from it allow precise control of the assembly pathway. Complex arrays of nanocargoes were fabricated with controlled architectures.

*BES research contributes to the potential for reduced use and increased supply of critical materials for energy storage.*

- Scientists have demonstrated that partially substituting iron for nickel in rare earth nickelates produces a change in electron transfer that makes it easier for the material to accept and donate electrons during catalysis, boosting the oxygen evolution reaction (OER). OER is a crucial process for energy conversion and storage, especially for water electrolysis to produce hydrogen. Current OER catalysts are based on precious metals. This work offers new insights into design strategies for developing low-cost, earth-abundant, and robust electrocatalysts for OER.
- Researchers developed AI/ML methods to assist the computational design of ligands for more selective and efficient solvent extraction and separation of rare-earth elements, to predict accurate distribution coefficients, and to enable higher-throughput screening of viable candidates, resulting in an extensive and shareable ligand property database for rare-earth separations.

*Scientists advance AI/ML techniques for BES science applications and develop novel materials with potential to advance quantum computation.*

- An AI/ML transfer learning approach using data from laboratory experiments is helping scientists understand and predict how natural faults respond, a critical factor in the design and control of geologic energy storage and waste sequestration reservoirs for $CO_2$ sequestration, hydrogen storage, and geothermal energy extraction.
- Researchers incorporated physics-based descriptions (quantum chemistry) directly in a deep neural network to develop chemical models that are simultaneously accurate, transferable, and interpretable for large or new chemical systems and for predicting molecular properties.
- Molecular spins are a promising class of chemically tunable quantum bits (qubits) for emerging quantum technologies; scientists addressed practical challenges by developing molecular color-center qubits with optically addressable spin. In topological materials for electronics, researchers showed that Weyl and Dirac semimetals with a topological "laser-pulse switch" can control electron motion at high speed with low energy. Researchers directly observed electrons forming a 2D Wigner crystal, in which they move collectively as a coherent system. All of these findings could be exploited for quantum computation.

## Basic Energy Sciences
## Materials Sciences and Engineering

### Description

Materials are critical to nearly every aspect of energy generation, storage, transmission, and end-use. Materials limitations are often a significant barrier to improved energy efficiencies, longer lifetimes of infrastructure and devices, or the introduction of new technologies for clean energy and to tackle climate change. The BESAC report on transformative opportunities for discovery science, coupled with the Basic Research Needs workshop reports on energy technologies and roundtable reports, provide further documentation of the importance of materials sciences in forefront research for next-generation scientific and technological advances. The Materials Sciences and Engineering subprogram supports research to provide the fundamental understanding and control of materials synthesis, properties, and performance that will enable solutions to wide-ranging challenges in clean energy generation, storage, and use as well as opening new directions that are not foreseen based on existing knowledge. The research explores 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. At the core of the subprogram is experimental, theoretical, computational, and instrumentation research that will enable the predictive design and discovery of new materials with novel structures, functions, and properties.

To accomplish these goals, the portfolio includes three integrated research activities:

- **Scattering and Instrumentation Sciences Research**—Advancing science using new tools and techniques to characterize materials structure and dynamics across multiple length and time scales, including ultrafast science, and to correlate this data with materials performance under real world and extreme conditions.
- **Condensed Matter and Materials Physics Research**—Understanding the foundations of material functionality and behavior including electronic, thermal, optical, and mechanical properties that result from material composition (including rare earths and other critical materials); understanding the impact of extreme environments on material properties and performance; and exploring materials whose properties arise from the effects of quantum mechanics.
- **Materials Discovery, Design, and Synthesis Research**—Developing the knowledge base and synthesis strategies to design and precisely assemble structures to control properties and enable discovery of new materials with unprecedented functionalities, including approaches that limit the use of rare earth and other critical materials, enable more effective polymer chemistries, and/or are learned from biological systems.

The Request continues the highest-priority fundamental research that supports the DOE mission, including research that will establish the foundational knowledge necessary to accelerate innovation to advance clean energy technologies and other national priorities. The portfolio emphasizes understanding of how to direct and control energy flow in materials systems over multiple time (femtoseconds to seconds) and length (nanoscale to mesoscale and beyond) scales, and translation of this understanding to prediction of material behavior, transformations, and processes in challenging real-world systems. This will establish a foundational knowledge base for future advanced, clean energy technologies and advanced manufacturing processes, including extremes in temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and chemical exposures. To maintain leadership in materials discovery, the research supported by this subprogram explores new frontiers of emergent materials behavior; utilization of nanoscale control; and materials systems that are metastable or far from equilibrium. This research includes investigation of the interfaces between physical, chemical, and biological sciences to explore new approaches to novel materials design and advanced sustainable manufacturing. In clean energy-related research, there is a growing emphasis on carbon dioxide removal, including direct capture of carbon dioxide from the air. Other topics in clean energy include a focus on low-carbon hydrogen research and energy storage for both transportation and the electricity grid. Also, critical materials and minerals research will provide foundational knowledge to enable secure and sustainable supply chains for key clean energy technologies.

Research activities in quantum materials emphasize the development of systems that realize unique properties for QIS. Materials science for microelectronics will provide the needed advances for future computing, sensors, detectors, and communication that are critical for national priorities in clean energy and for leadership in advanced research over a wide range of fields. An increasingly important aspect of materials research is the use of data science techniques to enhance the utility of both theoretical and experimental data for predictive design and discovery of materials. As an essential element of this research, this subprogram supports the development of advanced characterization tools, instruments, and techniques that can assess a wide range of space and time scales, especially in combination and under dynamic operando conditions to analyze non-equilibrium materials, conditions, and excited-state phenomena.

In addition to a diverse portfolio of single-investigator and small-group research projects, this subprogram supports Computational Materials Sciences, EFRCs, the Batteries and Energy Storage Hub, NQISRCs, in partnership with other SC programs, and EERCs (in partnership with ASCR, Biological and Environmental Research [BER], and with DOE energy technology offices). These research modalities support multi-investigator, multi-disciplinary research focused on forefront scientific challenges in support of the DOE clean energy mission. This subprogram supports the Accelerate initiative to ensure that science advances are rapidly transitioned to energy technologies.

This subprogram also includes the DOE EPSCoR program. The DOE EPSCoR program will strengthen investments in early-stage clean energy and climate research for U.S. states and territories that do not historically have large federally-supported academic research programs, expanding DOE research opportunities to a broad and diverse scientific community. This subprogram also supports two additional activities aimed at cultivating an equitable and expanded science, technology, engineering, and math (STEM) education, engagement, and workforce ecosystem: the RENEW and FAIR initiatives. The RENEW initiative expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research. The FAIR initiative focuses investment on enhancing research on clean energy, climate, and related topics at minority serving and under-served institutions.

Scattering and Instrumentation Sciences Research

Advanced characterization tools with very high precision in space and time are essential to understand, predict, and ultimately control matter and energy at the electronic, atomic, and nanoscale levels. Research in Scattering and Instrumentation Science supports innovative techniques and instrumentation development for advanced materials science research with scattering, spectroscopy, and imaging using electrons, neutrons, and x-rays, including development of science to understand ultrafast dynamics. These techniques provide precise and complementary information about the relationship among structure, dynamics, and properties, generating scientific knowledge that is foundational to the BES mission. The major advances in materials sciences from DOE's world-leading electron, neutron, and x-ray scattering facilities provide continuing evidence of the importance of this research field. In addition, the BESAC report on transformative opportunities for discovery science identified imaging as one of the pillars for future transformational advances. The importance of multimodal platforms to reveal the most critical features of a material has been a finding in several of the Basic Research Needs reports. These tools and techniques are also critical in advancing understanding and discovery of novel quantum materials, including materials for next-generation systems to advance microelectronics and QIS, supporting the work of NQISRCs. This program is focused on open questions in materials science and physics, but these characterization tools are broadly applicable to other fields including chemistry, biology, and geoscience, and can be a key component in preparedness for biological threats.

The unique interactions of electrons, neutrons, and x-rays with matter enable a range of complementary tools with different sensitivities and resolution for the characterization of materials at length- and time-scales spanning many orders of magnitude. A distinct aspect of this activity is the development of innovative instrumentation and techniques for scattering, spectroscopy, and imaging needed to link the microscopic and macroscopic properties of materials relevant to technologies for clean energy and mitigation of climate change. Included is the use of cryogenic environments to evaluate properties only occurring at these temperatures and to learn about processes and interfaces in materials that are damaged by the probes used to characterize them. The use of multiscale and multimodal techniques to extract heretofore unattainable information on multiple length and time scales is a growing aspect of this research, as is the development and application of cryogenic electron microscopy for challenges in physical sciences. For example, to aid in the design of transformational new materials for clean energy technologies such as batteries, *operando* experiments contribute to understanding the atomic and nanoscale changes that lead to materials failure in non-equilibrium and extreme environments (temperature, pressure, stress, radiation, magnetic fields, and electrochemical potentials). Advances in cryogenic microscopy will support the BRaVE initiative since this instrumentation is heavily used to characterize biological threats. Information from these characterization tools is the foundation for the creation of new materials that have extraordinary tolerance and can function in extreme environments without property degradation.

Condensed Matter and Materials Physics Research

This activity supports fundamental experimental and theoretical research to discover, understand, and control novel phenomena in solid materials, generating scientific knowledge that is foundational to the BES mission. These electronic, magnetic, optical, thermal, and structural materials make up the infrastructure for clean energy technologies and innovations to tackle climate change impacts, as well as accelerator and detector technologies for SC facilities. Also supported is research to understand the role of rare earth and other critical materials in determining material properties and functionality, so that they can be reduced or eliminated from key energy technology supply chains.

Experimental research in this program emphasizes discovery and characterization of materials' properties that have the potential to be exploited for new technological functionalities. Complementary theoretical research aims to explain such properties across a broad range of length and time scales. Theoretical research also includes development and integration of predictive theory and modeling for discovery of materials with targeted properties. Advanced computational and data science techniques (including AI/ML) are increasingly enabling knowledge to be extracted from large materials databases of theoretical calculations and experimental measurements. This program also supports the development of such databases as well as the computational tools that can take advantage of them.

This program continues to emphasize understanding and control of quantum materials whose properties result from interactions of the constituent electrons with each other, the atomic lattice, or light. Investigations include bulk materials as well as nanostructures and layered structures such as graphene, multilayered structures of two-dimensional materials, and studies of the electronic properties of materials at ultra-low temperatures and in high magnetic fields. The research advances the fundamental understanding of electronic, magnetic, thermal, and optical properties relevant to energy-efficient microelectronics and QIS. The focus on QIS research couples experimental and theoretical expertise in quantum materials with prototypes of quantum structures that can be used to study the science of device functionality and performance.

Activities also emphasize research to understand how materials respond to temperature, light, radiation, corrosive chemicals, and other environmental conditions. This includes electrical and optical properties of materials related to solar energy as well as the effects of defects on electronic properties, strength, deformation, and failure over a wide range of length and time scales. In FY 2024, these activities will continue to support the SC Energy Earthshots initiative. A recent focus is on extending knowledge of radiation effects to enable predictive capabilities for the extreme environments expected in future nuclear reactors and accelerators for SC facilities.

In FY 2024, BES will continue to partner with other SC programs to support the NQISRCs initiated in FY 2020. These centers focus on a set of QIS applications and cross-cutting topics that span the development space that will impact SC programs, including sensors, communication, quantum emulators/simulators, and enabling technologies that will pave the path to exploit quantum computing in the longer term. Research supported by this program will include theory of materials for quantum applications in computing, communication, and sensing; device science for next-generation QIS systems, including interface science and modeling of materials performance; and synthesis, fabrication, and characterization of quantum materials, including integration into novel device architectures to explore QIS functionality.

In partnership with the ASCR, High Energy Physics (HEP), Fusion Energy Sciences (FES), and Nuclear Physics (NP) programs, BES will continue activities begun in FY 2021 to support multi-disciplinary basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem, as called for by the Basic Research Needs for Microelectronics report.[d] Among the challenges is discovery science that can lead to low-power microelectronics for edge computing as well as for exascale computers and beyond. Such computing capabilities will be necessary to analyze the vast volumes of data that will be generated by future SC facilities. Similarly, transforming power electronics and the electricity grid into a modern, agile, resilient, and energy-efficient system requires improvements in advanced microelectronics materials, and their integration within a co-design framework.

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[d] https://science.osti.gov/-/media/bes/pdf/reports/2019/BRN_Microelectronics_rpt.pdf

Materials Discovery, Design, and Synthesis Research

The discovery and development of new materials has long been recognized as the engine that drives science frontiers, technology innovations, and advanced manufacturing. Predictive design and discovery of new forms of matter with desired properties continues to be a significant challenge for materials sciences. A strong, vibrant research enterprise in the discovery and design of new materials is critical to world leadership—scientifically, technologically, and economically. One of the goals of this activity is to grow and maintain U.S. leadership in materials discovery by investing in advanced synthesis capabilities and by coupling these with state-of-the-art user facilities and advanced computational capabilities at DOE national laboratories, generating scientific knowledge that is foundational to the BES mission, including clean energy and tackling the impacts of climate change. In FY 2024, these activities will support the SC Energy Earthshots initiative.

The BESAC report on transformative opportunities for discovery science reinforced the importance of the continued growth of synthesis science, recognizing the opportunity to realize targeted functionality in materials by controlling the synthesis and assembly of hierarchical architectures and beyond equilibrium matter. In FY 2024, this program will continue to apply materials discovery and synthesis research to understand the unique properties of rare earth and other critical materials and minerals, with the goal of reducing their use. New research directions will be inspired by BES reports related to advanced manufacturing, as well as low-carbon hydrogen and carbon dioxide removal. Understanding of synthesis science will enable design of new systems that are easier to efficiently convert into similar products with comparable or enhanced complexity, functionality, and value. Emphasis will include advancing the basic science of advanced manufacturing through innovative approaches for scalable assembly and integration of predictive modeling with characterization tools tuned to advanced manufacturing scale, complexity, and speed.

In addition to research on chemical and physical synthesis processes, an important element of this portfolio is research to understand how to use bio-mimetic and biology-inspired approaches to design and synthesize novel materials with some of the unique properties found in nature. Major research directions include the controlled synthesis and assembly of nanoscale materials into functional materials with desired properties; mimicking the low-energy synthesis approaches of biology to produce materials; bio-inspired materials that assemble autonomously and, in response to external stimuli, dynamically assemble and disassemble to form non-equilibrium structures; and adaptive and resilient materials that also possess self-repairing and self-regulating capabilities. The portfolio also supports fundamental research in solid-state chemistry to enable discovery of new functional materials and the development of new crystal growth methods and thin film deposition techniques to create complex materials with targeted structure and properties. An important element of this activity is research to understand the progression of structure and properties as a material is formed, in order to understand the underlying physical mechanisms and to gain atomic level control of material synthesis and processing, including the extraordinary challenges for synthesis of quantum materials.

Established Program to Stimulate Competitive Research (EPSCoR)

The DOE EPSCoR program funds early-stage research that supports DOE's energy mission in states and territories with historically lower levels of Federal academic research funding. Eligibility determination for the DOE EPSCoR program follows the National Science Foundation eligibility analysis. Managed by BES, the funding for the EPSCoR program is distributed among the six major research programs within SC per direction from the FY 2023 Enacted Appropriation.

The DOE EPSCoR program emphasizes research that will improve the capability of designated states and territories to conduct sustainable and nationally competitive energy-related research; jumpstart research capabilities in designated states and territories through training scientists and engineers in energy-related areas; and build beneficial relationships between scientists and engineers in the designated jurisdictions and world-class national laboratories managed by the DOE. This research leverages DOE national user facilities and takes advantage of opportunities for intellectual collaboration across the DOE system. Through broadened participation, DOE EPSCoR seeks to augment the network of energy-related research performers across the Nation.

Annual EPSCoR funding opportunities alternate between a focus on research performed in collaboration with the DOE national laboratories and a focus on implementation awards that facilitate larger team awards for the development of research infrastructure in the EPSCoR jurisdictions. The FY 2024 program will focus on EPSCoR State-National Laboratory Partnership awards promoting single-investigator and small-group interactions with the unique capabilities of the DOE national laboratory system. The technical scope will include a focus on clean energy research to tackle climate science, expanding these important research communities and supporting the SC Energy Earthshots initiative. The program will continue to support early career scientists from EPSCoR jurisdictions on an annual basis and complementary support for research grants to eligible institutions, including participation in the RENEW and FAIR initiatives.

Energy Frontier Research Centers

The EFRC program is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and enable transformative scientific advances. They allow experts from a variety of disciplines to collaborate on shared challenges, combining their strengths to uncover new and innovative solutions to the most difficult problems in materials sciences. The EFRCs also support numerous graduate students and postdoctoral researchers, educating and training a scientific workforce for the 21st century economy. The EFRCs supported in this subprogram focus on the following topics: the design, discovery, synthesis, characterization, and understanding of novel, solid-state materials that convert energy into electricity; the understanding of materials and processes that are foundational for electrical energy storage and gas separation; quantum materials and QIS; microelectronics; and materials for future nuclear energy and waste storage. After thirteen years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 15,000 peer-reviewed journal publications.

BES uses a variety of methods to regularly assess the progress of the EFRCs, including annual progress reports, monthly phone calls with the EFRC Directors, periodic Directors' meetings, and on-site visits by program managers. Each EFRC undergoes a review of its management structure and approach in the first year of the award and a midterm assessment of scientific progress compared to its scientific goals. To facilitate communication of results to other EFRCs and DOE, BES holds scientific meetings of the EFRC researchers biennially.

In FY 2024, BES plans to issue a Funding Opportunity Announcement (FOA) to recompete the four-year EFRC awards that were made in FY 2020. Emphasis will be placed on topical areas of the highest priority to the Department, including QIS, microelectronics, transformative manufacturing, and other program priorities.

Energy Earthshot Research Centers

The EERC program was launched in FY 2023, building on the success of the EFRCs. Like the EFRCs, 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 single-investigator or small-group awards. Beyond the scope of the EFRCs, EERCs will address the gap between basic research and the applied research and development activities to facilitate the exchange of knowledge between SC and the DOE energy technology offices, which is key to realizing the stretch goals of the Energy Earthshots. EERCs will support team awards involving academic, national lab, and industrial researchers with joint planning by SC and energy technology offices, establishing a new era of cross-office research cooperation. The funding will focus efforts directly at the interface, ensuring that directed 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, the Carbon Negative Shot, the Enhanced Geothermal Shot, the Floating Offshore Wind Shot, and the Industrial Heat 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 clean 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 AI/ML 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.

The FY 2024 Request continues support for the EERCs established in FY 2023 and provides additional support for Centers associated with new Energy Earthshots.

Energy Innovation Hubs

The Batteries and Energy Storage Energy Innovation Hub program was initiated by BES in 2012 and supported the Joint Center for Energy Storage Research (JCESR) for ten years. JCESR was a multi-institutional research team led by Argonne National Laboratory (ANL) in collaboration with multiple other national laboratories and universities, as well as the Army Research Laboratory and industry. JCESR focused on early-stage research to tackle forefront, basic scientific challenges for next-generation electrochemical energy storage. In FY 2024, BES will continue to support Batteries and Energy Storage Energy Innovation Hub awards initiated in FY 2023 as a result of an open recompetition of the program. Based on established best practices for managing large awards, BES will continue to require quarterly reports, frequent teleconferences, and annual progress reports and peer reviews to communicate progress, provide input on the technical directions, and ensure high-quality, impactful research.

Computational Materials Sciences

Major strides in materials synthesis, processing, and characterization, combined with concurrent advances in computational science enabled by enormous improvements in high-performance computing capabilities; also, have opened an unprecedented opportunity to design new materials with specific functions and physical properties. The opportunity is to leap beyond simple extensions of current theory and models of materials towards a paradigm shift in which specialized computational codes and software enable the design, discovery, and development of new materials or functionalities, and in turn, create new advanced, innovative technologies.

Awards in this program focus on the creation of computational codes and associated experimental/computational databases for the design of materials with new advanced functionalities. The research includes development of new ab initio theory, contributing the generated data to databases, as well as advanced characterization and controlled synthesis to validate the computational predictions. It uses the unique world-leading tools and instruments at DOE’s user facilities. The computational codes will use DOE’s leadership computational facilities and be positioned to take advantage of today’s petascale and exascale high-performance computers. This will result in open source, robust, experimentally validated, user-friendly software that captures the essential physics of relevant materials systems. These codes and generated data will be disseminated for use by the broader research community and by industry to accelerate the design of new functional materials.

BES manages the computational materials science research activities using the approaches developed for similar small and large team modalities. Management reviews by a peer review panel are held in the first year of the award for large teams. Mid-term peer reviews are held to assess scientific progress, with regular teleconferences, annual progress reports, and active oversight by BES throughout the performance period. In FY 2024, the funding associated with the four-year awards in FY 2020 will be recompeted. Within available resources, BES will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Materials Sciences and Engineering** | **$548,780** | **$572,129** | **+$23,349** |
| Scattering and Instrumentation Sciences Research | $105,971 | $107,713 | +$1,742 |
| Funding continues to focus on the development and use of advanced characterization tools to address the most challenging fundamental questions in materials science, including quantum behavior and properties. The use of multiscale and multimodal techniques to extract information on multiple length and time scales is a growing emphasis, as is the development and application of cryogenic microscopy techniques to answer open questions in physical sciences. Advanced instrumentation research can be applied to diverse national priorities, including QIS, clean energy science, advanced manufacturing, and preparedness for biological threats. Funding supports the RENEW, FAIR, and Accelerate initiatives. | | The Request will continue to focus on the development and use of advanced characterization tools to address the most challenging fundamental questions in materials science, including quantum behavior and properties. The use of multiscale and multimodal techniques to extract information on multiple length and time scales is a growing emphasis, as is the development and application of cryogenic microscopy techniques to answer open questions in physical sciences. Advanced instrumentation research can be applied to diverse national priorities, including QIS, clean energy science, tackling climate change, advanced manufacturing, and preparedness for biological threats. The RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups in SC research activities. The Request supports the FAIR and Accelerate initiatives. | Expanded investments will broaden RENEW activities, including a RENEW graduate fellowship. Investments will emphasize basic research related to clean energy and advanced manufacturing and will provide research and training opportunities for underrepresented communities and institutions. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Condensed Matter and Materials Physics Research $203,807 | $221,214 | +$17,407 |
| Funding continues to emphasize the understanding and control of the fundamental properties of materials that are central to their functionality in a wide range of clean energy-relevant technologies, including critical materials/minerals, and for reduction of climate change impacts. Exploration of quantum materials remains a high priority, and particularly the role that these materials play in microelectronics, accelerators, and the broad emerging field of QIS. The program continues to partner with other SC program offices to support the NQISRCs that were initiated in FY 2020. Additional investments support the SC Energy Earthshots initiative, including the response of materials to environmental conditions, such as temperature, light, corrosive chemicals, and radiation, particularly in the context of future clean energy technologies. | The Request will continue to emphasize the understanding and control of the fundamental properties of materials, including critical materials, that are central to their functionality in a wide range of clean energy-relevant technologies such as solar and for reduction of climate change impacts. Exploration of quantum materials remains a high priority, and particularly the role that these materials play in microelectronics, accelerators, and the broad emerging field of QIS. The program will continue to partner with other SC program offices to support the NQISRCs that were initiated in FY 2020. Additional investments will support the SC Energy Earthshots initiative, including the response of materials to environmental conditions, such as temperature, light, corrosive chemicals, and radiation, particularly in the context of future clean energy technologies. New Microelectronics Science Research Centers are established, as authorized under the CHIPS and Science Act (Section 10731, Micro Act). | Expanded investments will include support for the SC Energy Earthshots initiative including robust materials for energy/infrastructure and thermal processing innovation and new microelectronics research centers. Investments will emphasize basic research related to clean energy and advanced manufacturing, and AI/ML, and will provide research and training opportunities for underrepresented communities and institutions. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Materials Discovery, Design, and Synthesis Research $97,097 | $101,297 | +$4,200 |
| Funding continues support for the design, discovery, and synthesis of novel forms of matter with desired properties and functionalities with an emphasis on advancing the fundamental science relevant to future low-carbon manufacturing and reduction of climate change impacts, including innovative approaches to scalable assembly and integration of characterization and predictive modeling. Research continues to explore science-based solutions to materials criticality. Research on bio-mimetic and biology-inspired materials is relevant to energy technologies as well as other national priorities such as preparedness for and response to biological threats. Additional investments in these topical areas focus on support for the SC Energy Earthshots initiative. | The Request will continue support for the design, discovery, and synthesis of novel forms of matter with desired properties and functionalities with an emphasis on advancing the fundamental science relevant to future low-carbon manufacturing and clean energy technologies, including innovative approaches to scalable assembly and integration of characterization and predictive modeling. Research will continue to explore science-based solutions to materials criticality. Research on bio-mimetic and biology-inspired materials is relevant to energy technologies as well as other national priorities such as preparedness for and response to biological threats. Additional investments in these topical areas will focus on support for the SC Energy Earthshots initiative. | Expanded investments will support the SC Energy Earthshots initiative, including robust materials for energy/infrastructure. Investments will emphasize basic research related to clean energy and advanced manufacturing and will provide research and training opportunities for underrepresented communities and institutions. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Established Program to Stimulate Competitive Research (EPSCoR) $25,000 | $25,000 | $ — |
| Funding continues to support early-stage R&D, including research that underpins DOE energy technology programs, the SC Energy Earthshots initiative, and innovations for climate science. Following the previous year's focus on State-National Laboratory Partnership awards, FY 2023 emphasizes Implementation Awards to larger multiple investigator teams that develop research capabilities in EPSCoR jurisdictions. The FY 2023 funding opportunity considers new and renewal proposals. Investment continues in early career research faculty from EPSCoR-designated jurisdictions and in co-investment with other programs for awards to eligible institutions. | The Request will continue to support early-stage R&D, including research that underpins DOE energy technology programs, the SC Energy Earthshots initiative, and innovations for climate science. Following the previous year's focus on Implementation awards, FY 2024 will emphasize State-National Laboratory Partnership awards, single investigator and small group grants that promote interactions with the unique capabilities and expertise at the DOE national labs. The FY 2024 funding opportunity will consider only new proposals. Investment will continue in early career research faculty from EPSCoR-designated jurisdictions and in co-investment with other programs for awards to eligible institutions. | Funding will focus on State-National Laboratory Partnership awards promoting interactions between EPSCoR institutions and the DOE national laboratory system, with expanded investments in clean energy, climate science, and low-carbon manufacturing research as well as connections to the SC Energy Earthshots initiative. Teams will be encouraged to include institutions serving underrepresented and minority communities. EPSCoR will continue to participate in the SC-wide RENEW and FAIR initiatives to provide training and research opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. |
| Energy Frontier Research Centers $65,000 | $65,000 | $ — |
| Funding provides the fourth year of support for the four-year EFRC awards that were made in FY 2020 and the second year of support for awards that were made in FY 2022. | The Request will provide the third year of support for four-year EFRC awards that were made in FY 2022 in a broad range of topical areas relevant to clean energy, advanced manufacturing, and other national priorities such as QIS and microelectronics. In addition, BES plans to issue a solicitation in FY 2024 to recompete the EFRC awards made in FY 2020, with emphasis on QIS, microelectronics, transformative manufacturing, and other high-priority topics. | Technical emphasis for the EFRC program will continue to include research directions identified in recent strategic planning activities and aligned with program priorities, including research related to QIS, microelectronics, and low-carbon manufacturing. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Energy Earthshot Research Centers | $12,500 | $12,500 | $ — |
| Funding supports a FOA to be released by SC (BES, ASCR, BER), in coordination with the DOE Technology Offices, for the initial cohort of EERCs. EERCs will bring together the multi-investigator, multi-disciplinary teams necessary to perform energy-relevant research that bridges the gap between basic research and applied research and development activities. They emphasize the innovations at the basic-applied interface required to advance the current Energy Earthshot topics and those announced by DOE prior to release of the FOA. | | The Request will provide the second year of support for the initial cohort of EERCs that were initiated in FY 2023 and will support new EERCs for topics announced prior to FY 2024. | Technical emphasis for the EERC program will be on Energy Earthshot topics, including low-carbon hydrogen, long-duration energy storage, carbon dioxide removal, geothermal energy, offshore wind, industrial heat decarbonization, and new topics announced prior to FY 2024. |
| Energy Innovation Hubs | $25,913 | $25,913 | $ — |
| Funding supports an open re-competition of the Batteries and Energy Storage Hub program. | | The Request will support the second year of funding for one or more new Batteries and Energy Storage Hub awards initiated in FY 2023 as a result of an open competition. | Funding will continue to support next-generation batteries and energy storage research. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Computational Materials Sciences $13,492 | $13,492 | $ — |
| Funding continues research that focuses on development of computational codes and associated experimental and computational databases for the predictive design of functional materials. The research includes development of new ab initio theory, populating databases, and advanced characterization and controlled synthesis to validate the computational predictions. The goal is open source, validated software that uses today's DOE's leadership computational facilities and is poised to take advantage of tomorrow's exascale high-performance computers. BES plans to issue a FOA in FY 2023 to recompete awards made in FY 2019. | The Request will support the second year of funding for awards made in FY 2023. The Request will continue to support research aimed at the development of open source, validated software that takes advantage of DOE's leadership computational facilities. BES plans to issue a FOA in FY 2024 to recompete awards made in FY 2020. BES will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. | Funding will continue to support research focused on the development of computational codes and associated experimental and computational databases for the predictive design of functional materials. |

*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, excluding facility operations.*

## Basic Energy Sciences
## Chemical Sciences, Geosciences, and Biosciences

### Description

Development of innovative clean energy technologies relies on understanding and ultimately controlling transformations of energy among forms and conversions of matter across multiple scales starting at the atomic level. The Chemical Sciences, Geosciences, and Biosciences subprogram supports research to discover fundamental knowledge of chemical reactivity and energy conversion that is the foundation for energy-relevant chemical processes, such as catalysis, synthesis, separations, and light-driven chemical transformations. The research addresses how physical and chemical phenomena at the scales of electrons, atoms, and molecules control complex and collective behavior of macroscopic-scale energy and matter conversion systems. At the most fundamental level, research to understand quantum mechanical behavior is rapidly evolving into the ability to control and direct such behavior to achieve desired outcomes. Fundamental knowledge developed through this subprogram can enable ground-breaking science to tailor chemical transformations with atomic and molecular precision. The challenge is to achieve predictive understanding of complex chemical, geochemical, and biochemical systems at the same level of detail now known for simpler molecular systems.

To address these challenges, the portfolio includes coordinated research activities in three areas:

- **Fundamental Interactions Research**—Discover the foundational factors controlling chemical reactivity and dynamics in gas and condensed phases, and at interfaces, based on understanding quantum interactions among photons, electrons, atoms, and molecules.
- **Chemical Transformations Research**—Understand and control the mechanisms of chemical catalysis, synthesis, separation, stabilization, and transport in complex chemical and subsurface systems, from atomic to geologic scales.
- **Photochemistry and Biochemistry Research**—Elucidate the molecular mechanisms of the capture of light energy and its conversion into electrical and chemical energy through biological and chemical pathways.

The Request continues the highest-priority fundamental research, including a focus on scientific understanding to accelerate innovation that can reduce impacts of climate change and advance clean energy technologies, infrastructure, and a circular economy. Support will continue for research to discover and develop chemical processes for low-carbon, efficient, and circular approaches to advanced manufacturing. Related research emphasizes the chemistry, separations, and substitutions important for reducing dependence on critical materials and minerals and for promoting innovative and robust manufacturing supply chains. Fundamental biochemistry will discover principles that can enable biomimetic and biohybrid clean energy systems and guide new approaches in biotechnology. Research on molecular science will advance innovations for microelectronics and increase understanding of the phenomena relevant to QIS and quantum computing. Integration of data science and computational chemistry, bringing simulation and experiments together, will provide tools and infrastructure needed for shared data repositories.

Five synergistic, foundational research themes are at the intersections of multiple research focus areas in this portfolio. Ultrafast Chemistry probes electron and atom dynamics to understand energy and chemical conversions. Chemistry at Complex Interfaces advances understanding of how interfacial dynamics and structural and functional disorder influence chemical phenomena. Charge Transport and Reactivity explores how charge dynamics contribute to energy flow and chemical conversions. Reaction Pathways in Diverse Environments discovers the influence of nonequilibrium, heterogeneous, nanoscale, and extreme environments on complex reaction mechanisms. Chemistry in Aqueous Environments addresses water’s unique properties and the role it plays in energy and chemical conversions.

The subprogram supports a diverse portfolio of research efforts including single investigators, small groups, and larger multi-investigator, cross-disciplinary teams through EFRCs, the Fuels from Sunlight Energy Innovation Hub program, Computational Chemical Sciences, data science, and QIS to advance foundational science that can enable critical clean energy technologies. The subprogram also partners across SC to support the NQISRCs that were established in FY 2020 and, new in FY 2023, EERCs (in partnership with ASCR, BER, and with DOE energy technology offices). This subprogram also supports the RENEW initiative, expanding targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research; the FAIR initiative focused investment on enhancing research on clean energy, climate, and related topics at minority serving and underserved institutions; and the Accelerate initiative for scientific research to accelerate the transition of science advances to energy technologies.

Fundamental Interactions Research
This activity emphasizes structural and dynamical studies of atoms, molecules, and nanostructures, and the description of their interactions in full quantum detail. The goal is to achieve a complete understanding of reactive chemistry in the gas phase, in condensed phases, and at interfaces. This activity provides leadership for ultrafast chemistry and advances ultrafast tools and approaches to probe and control chemical processes. Research also supports theory and computation for accurate descriptions of molecular reactions and chemical dynamics. These efforts provide the foundational knowledge and the state-of-the-art experimental and computational tools necessary to advance the subprogram's research activities and the BES mission, including clean energy approaches that can reduce impacts contributing to climate change.

The principal research thrusts in this activity are atomic, molecular, and optical sciences (AMOS), gas phase chemical physics (GPCP), condensed phase and interfacial molecular science (CPIMS), and computational and theoretical chemistry (CTC). AMOS research emphasizes the fundamental interactions of atoms and molecules with electrons and photons, to characterize and control their behavior. Novel attosecond sources, x-ray free electron laser sources such as the LCLS-II, and ultrafast electron diffraction are used to image the ultrafast dynamics of electrons and charge transport. CPIMS research emphasizes foundational research at the boundary of chemistry and physics, pursuing a molecular-level understanding of chemical, physical, and electron- and photon-driven processes in liquids and at interfaces. Experimental, theoretical, and computational investigations in the condensed phase and at interfaces elucidate the molecular-scale chemical and physical properties and interactions that govern condensed phase structure and dynamics. The GPCP program supports research on fundamental gas-phase chemical processes important in energy applications. Research in this program explores chemical reactivity, kinetics, and dynamics in the gas phase at the level of electrons, atoms, molecules, and nanoparticles. The CTC program supports development, improvement, and integration of new and existing theoretical and massively parallel computational or data-driven strategies for the accurate and efficient prediction or simulation of processes and mechanisms. Research in this area is crucial to utilize emerging exascale computing facilities and to optimize use of existing leadership class computers, leveraging U.S. leadership in the development of open-source computational chemistry codes and databases. In the context of the NQISRCs, this research also lays the groundwork for applications of future quantum computers to computational quantum chemistry.

In FY 2024, BES, in partnership with other SC programs, will continue support for the multi-disciplinary multi-institutional QIS centers, initiated in FY 2020. The NQISRCs will focus on a set of QIS applications or cross-cutting topics including innovative research on sensors, quantum emulators/simulators, and enabling technologies that will pave the path to exploit quantum computing in the longer term. Research initiated in FY 2021 in microelectronics will continue with a focus on unraveling complex mechanisms of chemical reactions at interfaces to inform the design and synthesis of new materials.[e] Research in clean energy and low-carbon manufacturing will continue to address science that is foundational to novel synthesis, processing, modeling, *operando* characterization, and validation approaches for manufacturing. The Fundamental Interactions activity will continue to advance data science and computational approaches for chemical sciences with a focus on integration of databases and computational chemistry tools for the generation of scientific knowledge that is foundational to the BES mission.

Chemical Transformations Research
This activity seeks fundamental knowledge of chemical reactivity, matter and charge transport, and chemical separation and stabilization processes that are foundational for developing future clean energy and advanced manufacturing technologies, and for innovations to mitigate or adapt to climate change. Core research areas include catalysis science, separation science, heavy element chemistry, and geosciences. The research entails use of ultrafast spectroscopy to follow transient species during reactions; advances the understanding of charge transport and reactivity, which determine the kinetics of electrocatalytic, separations, and geochemical processes; explores the influence of complex interfaces on chemical transformations; develops the mechanistic insight needed to control reaction pathways in diverse catalytic, separation, and geological environments; and develops understanding of chemistry in subsurface and aqueous systems important in sustainable chemical processes.

[e] https://science.osti.gov/-/media/bes/pdf/reports/2019/BRN_Microelectronics_rpt.pdf

Catalysis science research is focused on understanding reaction mechanisms, precise synthesis, *operando* characterization, manipulation of catalytic active sites and their environments, and control of reaction conditions for efficiency and selectivity. A primary goal is the molecular-level control of chemical transformations relevant to the sustainable conversion of energy resources, with emphasis on thermal and electrochemical conversions. Separation science research seeks to understand and ultimately predict and control the atomic and molecular interactions and energy exchanges determining the efficiency and viability of chemical separations, with emphasis on critical elements and atmospheric $CO_2$. The major focus is to advance discovery of principles and predictive design of future chemical separation approaches with improved efficiencies. Heavy element chemistry provides foundational knowledge on the influence of complex environments, such as multiple phases and extreme conditions of temperature and radiation, on the dynamic behavior of actinide compounds. A primary goal is to advance understanding of the unique chemistry of f-electron systems that is required to design new ligands for actinide and rare-earth separations processes, to predict the chemical evolution of actinides in nuclear wastes and next-generation reactors, and to improve models of actinide environmental transport. Geosciences research provides the fundamental science underlying the subsurface chemistry and physics of natural substances under extreme conditions of pressure or confined environments. Areas of emphasis include the molecular-level understanding of phase equilibria, reaction mechanisms and rates associated with aqueous geochemical processes, the distribution and accumulation of elements in the earth upper mantle, and a mechanistic understanding of the origins of subsurface physical properties and the response of earth materials subject to chemo-mechanical stress.

In FY 2024, this activity will continue to support efforts central to transformative approaches to advanced manufacturing,[f] including predictive design of catalytic and separations processes for circular use of natural and synthetic resources with atom and energy efficiency, as exemplified by polymer upcycling.[g] In support of the Energy Earthshot initiative, this activity will increase focus on discovery and design of sustainable cycles for carbon and hydrogen, by means of enhanced carbon separation from both dilute and concentrated sources and clean energy cycles of hydrogen generation, storage, and use. Also supporting the Energy Earthshot initiative, research will increase the fundamental knowledge of subsurface processes across spatial and temporal scales—such as mineralization, crack propagation, and rock fracture—that is critical for developing innovative clean energy technologies for the subsurface. Support will also continue for research to address challenges in critical materials with focus on novel approaches for resource identification and extraction, selective separation, and substitution and use of critical elements. Research will continue to investigate the unique quantum phenomena enabled by f-electron elements, including rare earth elements and actinides. The use of data science and AI/ML approaches will continue to be emphasized in research across the portfolio to accelerate the generation and propagation of scientific knowledge that is foundational to the BES mission.

Photochemistry and Biochemistry Research

This activity supports research on the molecular mechanisms that capture light energy and convert it into electrical and chemical energy in both natural and man-made systems. This mechanistic understanding can inspire new strategies to control reaction pathways critical for clean energy conversions and for innovations to tackle climate change. An important component of the Photochemistry and Biochemistry activity is its leadership role in the support of basic research in both natural photosynthesis and solar photochemistry. Research explores the dynamic mechanisms of charge transport and reactivity that advances understanding of absorption, transfer, and conversion of energy across spatial and temporal scales and on redox interconversion of small molecules (e.g., carbon dioxide/methane, nitrogen/ammonia, and protons/hydrogen) important for clean fuels (e.g., solar fuels). Studies of ultrafast chemistry and photo-driven quantum coherence probe the short time-scales critical in natural photosynthesis and artificial molecular systems and can provide insights into the role of quantum phenomena in chemical and biochemical reactions. Research expands understanding of the influence of complex interfaces and aqueous environments on the dynamics and function of enzymes, natural and artificial membranes, and nano- to meso-scale structures.

This activity integrates multidisciplinary research at the interface of chemistry, physics, and biology. Research of biological systems provides insights for understanding and enhancing man-made chemical systems. In a reciprocal manner, studies of chemical (non-biological) systems provide insights on the dynamics and reactivity underlying biochemical processes.

[f] https://science.osti.gov/-/media/bes/pdf/reports/2020/Transformative_Mfg_Brochure.pdf
[g] https://science.osti.gov/-/media/bes/pdf/reports/2020/Chemical_Upcycling_Polymers.pdf

Research in natural photosynthesis advances knowledge of biological mechanisms of solar energy capture and conversion and can inspire development of bio-hybrid, biomimetic, and artificial photosynthetic systems for clean energy production and biotechnology. Studies of complex multielectron redox reactions, electron bifurcation, and quantum phenomena in biological systems can suggest innovative approaches to energy conversion and storage strategies for clean energy, biotechnology approaches, and climate change mitigation technologies. Complementary research on the elementary steps of light absorption, charge separation, and charge transport of solar energy conversion in man-made systems provides foundational knowledge for the use of solar energy for carbon-neutral fuel production and electricity generation. Research also addresses fundamental effects of ionizing radiation to understand chemical reactions in extreme environments and to provide insights for remediation, fuel-cycle separation, and design of nuclear reactors.

In FY 2024, research will continue to establish a molecular-level understanding of biochemical and photochemical processes. Efforts will build on BES biochemistry and biophysics research to discover and design chemical processes and complex structures that can enable innovations for clean energy technologies, advanced manufacturing and microelectronics, and climate change mitigation, such as bio-inspired, biohybrid, and biomimetic systems with desired functions and properties. Studies of photo-driven quantum coherence in natural photosynthesis and artificial molecular systems will continue with the goal of developing new strategies for efficient solar energy use. Research will also address challenges of reducing the use of critical and rare earth elements in light absorbers and catalysts for clean energy. In support of the Energy Earthshot initiative, this activity will increase support for research to identify new approaches for harnessing solar energy for chemical conversions, providing knowledge that could enable carbon-neutral hydrogen technologies and advance strategies for other solar fuels. This activity supports the Accelerate initiative that targets scientific research to accelerate the transition of science advances to energy technologies. This activity provides support for the ongoing SC-wide RENEW initiative and for the new FAIR initiative to build stronger programs at underrepresented institutions, including those in underserved and environmental justice communities, with a focus on enhancing research on clean energy, climate, and related topics.

<u>Energy Frontier Research Centers</u>

The EFRC program is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and accelerate basic research to enable transformative scientific advances. They allow experts from a variety of disciplines to collaborate on shared challenges, combining their strengths to uncover new and innovative solutions to the most difficult problems in chemical sciences, geosciences, and biosciences. The EFRCs also support numerous graduate students and postdoctoral researchers, educating and training a scientific workforce for the $21^{st}$-century. The EFRCs supported in this subprogram focus on the following topics: the design, discovery, characterization, and control of the chemical, biochemical, and geological processes for improved electrochemical conversion and storage of energy; the understanding of catalytic chemistry and biochemistry that are foundational for fuels, chemicals, separations, and polymer upcycling; interdependent energy-water issues; QIS; future nuclear energy and the chemistry of waste processing; and advanced interrogation and characterization of the earth's subsurface. After thirteen years of research activity, the program has produced an impressive range of scientific accomplishments, including over 15,000 peer-reviewed journal publications.

BES uses a variety of methods to regularly assess the progress of the EFRCs, including annual progress reports, monthly phone calls with the EFRC Directors, periodic Directors' meetings, and on-site visits by program managers. Each EFRC undergoes a review of its management structure and approach in the first year of the award and a mid-term assessment by outside experts of scientific progress compared to its scientific goals. To facilitate communication of results to other EFRCs and DOE, BES holds meetings of the EFRC researchers biennially.

In FY 2024, BES plans to issue a FOA to recompete the four-year EFRC awards that were made in FY 2020. Emphasis will be placed on topical areas of the highest priority to the Department, including QIS, microelectronics, transformative manufacturing, and other program priorities.

Energy Earthshot Research Centers

The EERC program was launched in FY 2023, building on the success of the EFRCs. Like the EFRCs, 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 single-investigator or small-group awards. Beyond the scope of the EFRCs, EERCs will address the gap between basic research and the applied research and development activities to facilitate the exchange of knowledge between SC and the DOE energy technology offices, which is key to realizing the stretch goals of the Energy Earthshots. EERCs will support team awards involving academic, national lab, and industrial researchers with joint planning by SC and energy technology offices, establishing a new era of cross-office research cooperation. The funding will focus efforts directly at the interface, ensuring that directed 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, the Carbon Negative Shot, the Enhanced Geothermal Shot, the Floating Offshore Wind Shot, and the Industrial Heat 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 clean 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 AI/ML 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.

The FY 2024 Request continues support for the EERCs established in FY 2023 and provides additional support for Centers associated with new Energy Earthshots.

Energy Innovation Hubs

The two multi-investigator, cross-disciplinary solar fuels research awards for the Fuels from Sunlight Hub program build on the unique accomplishments of the first Fuels from Sunlight Hub and address both new directions and long-standing challenges in the use of solar energy, water, and carbon dioxide as the only inputs for fuels production for clean energy and climate change mitigation. The FY 2024 Request will continue support for these fundamental research efforts that target innovative solutions to key scientific challenges for solar fuels (as identified in the strategic planning report from the Roundtable on Liquid Solar Fuels), including how to overcome degradation mechanisms to increase durability of solar fuel-generating components and systems, design catalytic microenvironments to selectively produce energy-rich solar fuels, take advantage of the direct coupling of light-driven phenomena and chemical processes to improve component and system performance, and tailor complex phenomena that interact and affect function of integrated multicomponent assemblies for solar fuels production.[h]

BES uses a variety of methods to regularly assess the progress of the awards, including annual progress reports, regular phone calls with the Directors, periodic Directors' meetings to ensure coordination and communication, and on-site visits and reviews. Each award undergoes a review of its management structure and approach in the first year and beginning in the second year will have an annual peer review of research progress against its scientific goals.

[h] https://science.osti.gov/-/media/bes/pdf/reports/2020/Liquid_Solar_Fuels_Report.pdf

Computational Chemical Sciences

The computational chemical sciences program (CCS) supports basic research to develop validated, open-source codes and associated experimental/computational databases for modeling and simulation of complex chemical processes and phenomena that allow full use of current and future planned DOE leadership-class computing capabilities. This research supports a publicly accessible website[i] of open source, robust, validated, user-friendly software that captures the essential physics and chemistry of relevant chemical systems. The goal is use of these codes/data by the broader research community and by industry to dramatically accelerate chemical research in the U.S.

BES uses a variety of methods to regularly assess the progress of the CCS awards, including annual progress reports, regular phone calls with the Directors, and periodic meetings of funded activities to ensure coordination and communication. Large team awards undergo a review of management structure and approach in the first year and a mid-term review by outside experts to evaluate scientific progress compared to the project's scientific goals. The FY 2024 support will continue awards from FY 2021 and FY 2022.

General Plant Projects

General Plant Projects funding provides for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems to maintain the productivity and usefulness of DOE-owned facilities and to meet requirements for safe and reliable facilities operation.

[i] https://ccs-psi.org/

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Chemical Sciences, Geosciences, and Biosciences** | **$501,263** | **$533,961** | **+$32,698** |
| Fundamental Interactions Research | $127,985 | $141,339 | +$13,354 |
| Funding continues to develop forefront ultrafast approaches, with emphasis on the use of x-ray free electron lasers, including LCLS and its upgrades. Gas-phase research continues studies of how reactive intermediates impact reaction pathways. Continued emphasis is placed on quantum phenomena underlying QIS, such as coherence and entanglement. Research expands efforts to understand and control chemical processes and quantum phenomena at the molecular level. In FY 2023, research continues to emphasize understanding and control of interfacial chemical conversion mechanisms for clean energy applications and of designing and synthesizing new materials relevant to microelectronics. This activity continues to develop advanced theoretical and computational approaches that can be scaled to operate on exascale computers. Development of data science methods increase to enable novel approaches for knowledge discovery. This activity provides continued support for the NQISRCs established in FY 2020. | | The Request will continue to develop innovative ultrafast approaches, with emphasis on use of x-ray free electron lasers; determine how reactive intermediates affect reaction pathways; and characterize quantum phenomena underlying QIS. Research will target the understanding and control of interfacial chemical conversion mechanisms and quantum phenomena at the molecular level to advance clean energy technologies, climate mitigation technologies (e.g., emissions mitigation), and design of materials relevant to microelectronics. This activity will continue generation and use of advanced theoretical and computational approaches that can take full advantage of exascale computing capabilities and the development of data science methods that enhance approaches for knowledge discovery. This activity provides continued support for the NQISRCs established in FY 2020. New Microelectronics Science Research Centers are established, as authorized under the CHIPS and Science Act (Section 10731, Micro Act). | Expanded investments will include support for new microelectronics research centers. Investments will emphasize basic research related to clean energy, climate, microelectronics, AI/ML, and advanced manufacturing. Funding will also provide research and training opportunities for underrepresented communities and institutions. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Chemical Transformations Research | $129,651 | $140,158 | +$10,507 |
| Funding continues supporting fundamental research to understand catalytic mechanisms for thermo- and electro-chemical conversions important in clean energy and advanced manufacturing technologies, including chemical upcycling of polymers, and in innovations to reduce climate change impacts. Separation science research continues to focus on innovative mechanisms for high-efficiency processes, including reactive and electro-separations, and novel solvents. Heavy element research continues to deepen understanding of actinide speciation and reactivity and fundamental theories of f-electron systems. Geosciences research continues to elucidate subsurface phenomena, such as mineralization and rock fracture propagation under extreme subsurface conditions. Areas for increased emphasis include atomically precise synthesis of new catalysts and studies of chemical processes required to develop clean energy technologies: multiscale phenomena in extreme and constrained environments in the subsurface; separations and extraction of rare earth elements from complex and dilute mixtures; and alternative approaches that reduce use of critical elements. | | The Request will continue fundamental research to understand catalytic mechanisms for thermo- and electro-chemical conversions and to develop atomically precise synthesis of catalysts important for clean energy, climate change mitigation, and advanced manufacturing technologies. Separation science research will continue to focus on innovative mechanisms for high-efficiency chemical separations and processes. Heavy element research will continue to advance understanding of actinide speciation and reactivity and fundamental theories of f-electron systems. Geosciences research will continue to reveal subsurface phenomena, such as mineralization and rock fracture propagation under extreme subsurface conditions, that can be foundational to climate mitigation strategies. Research will continue to advance the separations and extraction of rare earth elements from complex and dilute mixtures and the development of alternative approaches to reduce use of critical elements. The Request supports the SC Energy Earthshots initiative. | Expanded investments will include support for the SC Energy Earthshots initiative including innovations in catalysis, geosciences, and separations. Investments will emphasize basic research related to clean energy, climate, microelectronics, and advanced manufacturing. Funding will also provide research and training opportunities for underrepresented communities and institutions. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Photochemistry and Biochemistry Research $130,877 | $139,714 | +$8,837 |
| Funding continues support of core research to understand physical, chemical, biophysical, and biochemical processes of light energy capture and conversion. Studies of light absorption, energy transfer, charge transport, separation processes, and photocatalysis provides fundamental insights that can lead to innovations in the design of new clean energy systems and processes and in reduction of climate change impacts. Study of biochemical processes and structures provides a foundation for bio-inspired, biohybrid, and biomimetic systems with desired functions and properties, including design of efficient catalysts and reaction pathways. Solar fuels research continues to address the molecular mechanisms of photon capture, charge transport, product selectivity and separation from non-target molecules, and the reduction of critical elements in photoabsorbers and catalysts. Biological and chemical studies investigates how quantum phenomena affect energy conversion efficiency and fidelity. Funding supports the SC Energy Earthshots, FAIR, RENEW, and Accelerate initiatives. | The Request will continue research on physical, chemical, biophysical, and biochemical processes of light energy capture and conversion. Studies of light absorption, energy transfer, photocatalysis, and charge separation can lead to innovations for clean energy and climate change mitigation. Study of biochemical processes and structures will provide a foundation for bio-inspired, biohybrid, and biomimetic systems with desired functions and properties, impacting strategies for artificial photosynthesis, carbon dioxide removal, and biotechnology. Solar fuels research will address molecular mechanisms of photon capture, charge transport, product selectivity, and the reduction of critical element use in photoabsorbers and catalysts. Biological and chemical studies will examine the role of quantum phenomena in energy conversion. The RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups in SC research activities. The Request supports the SC Energy Earthshots, FAIR, and Accelerate initiatives. | Expanded investments will include support for the SC Energy Earthshots initiative including innovations in solar and bio-based fuels. Expanded investments will broaden RENEW activities, including a RENEW graduate fellowship. Investments will emphasize basic research related to clean energy, climate, and advanced manufacturing, and will provide research and training opportunities for underrepresented communities and institutions. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Energy Frontier Research Centers | $65,000 | $65,000 | $ — |
| Funding provides the final year of support for four-year EFRC awards that were made in FY 2020 and the second year of support for awards that were made in FY 2022. | | The Request will provide the third year of support for four-year EFRC awards that were made in FY 2022 in a broad range of topical areas relevant to clean energy, advanced manufacturing, and other national priorities such as QIS and microelectronics. In addition, BES plans to issue a solicitation in FY 2024 to recompete the EFRC awards made in FY 2020, with emphasis on QIS, microelectronics, transformative manufacturing, and other high-priority topics. | Technical emphasis for the EFRC program will continue to include research directions identified in recent strategic planning activities and aligned with program priorities, including research related to QIS, microelectronics, and low-carbon manufacturing. |
| Energy Earthshot Research Centers | $12,500 | $12,500 | $ — |
| Funding supports a FOA to be released by SC (BES, ASCR, BER), in coordination with the DOE Technology Offices, for the initial cohort of EERCs. EERCs will bring together the multi-investigator, multi-disciplinary teams necessary to perform energy-relevant research that bridges the gap between basic research and applied research and development activities. They emphasize the innovations at the basic-applied interface required to advance the current SC Energy Earthshot topics and those announced by DOE prior to release of the FOA. | | The Request will provide the second year of support for the initial cohort of EERCs that were initiated in FY 2023 and will support new Energy Earthshot topics announced prior to FY 2024. | Technical emphasis for the EERC program will be on Energy Earthshot topics, including low-carbon hydrogen, long-duration energy storage, carbon dioxide removal, enhanced geothermal systems, offshore wind, industrial heat decarbonization, and new topics announced prior to FY 2024. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Energy Innovation Hubs | $20,758 | $20,758 | $ — |
| Funding continues support of fundamental research to address both long-standing and emerging new scientific challenges for solar fuels generation. Research continues to focus on innovative artificial photosynthesis approaches to generate liquid fuels using only sunlight, carbon dioxide, and water as inputs. Experiment and theory are integrated for the design of processes, components, and systems for selective, stable, and efficient liquid solar fuels production for clean energy. | | The Request will continue support of fundamental research to address both long-standing and emerging new scientific challenges for solar fuels generation. Research will continue to focus on innovative artificial photosynthesis approaches to generate liquid fuels using only sunlight, carbon dioxide, and water as inputs. Integration of experiment and theory will advance the design of processes, components, and systems for selective, stable, and efficient liquid solar fuels production for clean energy, climate change mitigation, and sustainability. | Funding will continue support for prior year awards in priority research areas. |
| Computational Chemical Sciences | $13,492 | $13,492 | $ — |
| Funding continues CCS awards made in FY 2021 and FY 2022, with ongoing research to develop public, open-source codes for future exascale computer platforms. | | The Request will continue CCS awards made in FY 2021 and FY 2022, with ongoing research to develop public, validated, open-source software that takes advantage of DOE's leadership computing facilities. | Funding will continue support for prior year awards in priority research areas. |
| General Plant Projects | $1,000 | $1,000 | $ — |
| Funding supports minor facility improvements at Ames Laboratory. | | The Request will support minor facility improvements at Ames National Laboratory. | No changes. |

*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, excluding facility operations.*

## Basic Energy Sciences
## Scientific User Facilities (SUF)

### Description

The Scientific User Facilities subprogram supports the operation of a geographically diverse suite of major research facilities that provide unique tools to thousands of researchers from a wide diversity of universities, industry, and government laboratories to advance a broad range of sciences. These user facilities are operated on an open access, competitive, merit review basis, enabling scientists from every state and many disciplines from academia, national laboratories, and industry to utilize the facilities' unique capabilities and sophisticated instrumentation.

Studying matter at the level of atoms and molecules requires instruments that can probe structures that are one thousand times smaller than those detectable by the most advanced light microscopes. Thus, to characterize structures with atomic detail, researchers must use probes such as electrons, x-rays, and neutrons with wavelengths at least as small as the structures being investigated. The BES user facilities portfolio consists of a complementary set of intense x-ray sources, neutron scattering facilities, and research centers for nanoscale science. These facilities allow researchers to probe materials in space, time, and energy with the appropriate resolutions that can interrogate the inner workings of matter to answer some of the most challenging grand science questions. By taking advantage of the intrinsic charge, mass, and magnetic characteristics of x-rays, neutrons, and electrons, these tools offer unique capabilities to help understand the fundamental aspects of the natural world.

The 12 BES scientific user facilities provide unique capabilities to the scientific community and industry. Critically for U.S. scientific leadership, they provide comprehensive and advanced tools that enable fundamental discovery science and research to tackle critical challenges for national priorities in energy and other strategic areas. Collectively, they contribute to important research results that span the continuum from basic to applied research and embrace the full range of scientific and technological endeavors, including chemistry, physics, geology, materials science, environmental science, biology, and biomedical science. These capabilities enable scientific insights that can lead to the discovery and design of advanced materials and novel chemical processes with broad societal impacts, from energy applications to information technologies and biopharmaceutical discoveries.

Before the COVID-19 pandemic, more than 16,000 scientists and engineers in many fields of science and technology used BES scientific facilities annually. During the pandemic, user facilities were under curtailed user operations, available mainly through remote access for many instruments. The BES facilities supported over 15,000 users in FY 2022. Light sources and neutron sources were able to provide critical support to the development of potential therapeutic drugs and vaccines through structural studies of the proteins of the SARS-CoV-2 virus, which causes COVID-19. All BES user facilities contributed to other COVID-19 activities, including research on masks, characterization of novel manufacturing for medical equipment, and delivery of therapeutics. The BES facilities will continue to support ongoing research efforts to combat COVID-19 and evolve the tools and expertise needed for future public health challenges. In FY 2024, continued support to enhance user capabilities for research on biological threats is included in the BRaVE initiative.

At these facilities, hundreds of experiments are conducted simultaneously around the clock, generating vast quantities of raw experimental data that must be stored, transported, and then analyzed to convert the raw data into information to unlock the answers to important scientific questions. Management of the collection, transport, and analysis of data presents new and growing challenges as new capabilities and advanced detector technologies come online. Data science, artificial intelligence, and machine learning methods and advanced computing hardware are being implemented to help address these data and information challenges and needs. Challenges include speeding up high-fidelity simulations for online models, fast tuning in high-dimensional space, anomaly/breakout detection, 'virtual diagnostics' that can operate at high repetition rates, and sophisticated compression/rejection data pipelines operating at the 'edge' (next to the instrument) to save the highest-value data from user experiments.

Maintaining world-leading capabilities is crucial for competitiveness as advances in tools and instruments often drive scientific discovery. Major upgrades to BES facilities are supported through line-item construction and MIEs, including support for new instrumental capabilities such as new x-ray and neutron experimental stations with improved computational and data analysis infrastructure and forefront nanoscience instrumentation. The subprogram also supports research in accelerator and detector development to explore technology options for the next generations of x-ray and neutron sources. Keeping BES accelerator-based facilities at the forefront requires continued, transformative advances in accelerator science and technology.

The FY 2024 Request supports user facilities at 90 percent of the operational budget requirements determined by the user facilities that have redefined the meaning of optimum operations. These assessments considered funding requirements from growth in the cost of operations, evolution of the user needs for remote use, and transitioning of new capabilities from facility upgrades to operations. Funding at the 90 percent level will balance safe operations with user access.

Remote use of the facilities allows access to researchers from institutions, underserved regions, and companies that otherwise would not be able to take advantage of these resources to advance their programs and products. However, remote operations require more facility staff and expansion of computational and experimental tools. This translates to increased necessary staffing levels and staff with different expertise to support both in-person and continued growth of remote users and capabilities. In addition, increases in costs due to inflation and supply chain issues have resulted in an increase in the funding levels to ensure safe and continued operation of capabilities needed to address the challenges facing the Nation in clean energy, climate, QIS, microelectronics, and biopreparedness.

X-Ray Light Sources

X-rays are an essential tool for studying the structure of matter and have long been used to peer into material through which visible light cannot penetrate. Today's light source facilities produce x-rays that are billions of times brighter than medical x-rays. Scientists use these highly focused, intense beams of x-rays to reveal the identity and arrangement of atoms in a wide range of materials. The tiny wavelength of x-rays allows us to see things that visible light cannot resolve, such as the arrangement of atoms in metals, semiconductors, biological molecules, and other materials and chemical systems.

From their first systematic use as an experimental tool in the 1960s, large-scale light source facilities have vastly enhanced the utility of pre-existing and contemporary techniques, such as x-ray diffraction, x-ray spectroscopy, and imaging and have given rise to scores of new ways to do experiments that would not otherwise be feasible with conventional x-ray machines. Moreover, the wavelength can be selected over a broad range (from the infrared to hard x-rays) to match the needs of particular experiments. Together with additional features, such as controllable polarization, coherence, and ultrafast pulsed time structure, these characteristics make x-ray light sources an important tool for a wide range of research. The wavelengths of the emitted photons span a range of dimensions from the atom to biological cells, thereby providing incisive probes for advanced research in a wide range of areas, including materials science, physical and chemical sciences, metrology, geosciences, environmental sciences, biosciences, medical sciences, and pharmaceutical sciences. BES operates a suite of five light sources, including a free electron laser, the LCLS at SLAC, and four storage ring-based light sources—the ALS at LBNL, the APS at ANL, the Stanford Synchrotron Radiation Lightsource (SSRL) at SLAC, and the National Synchrotron Light Source-II (NSLS-II) at BNL. BES provides funding to support facility operations, technical support, and user program administration to enable cutting-edge research at these facilities, which are made available to all researchers with access determined via peer review of user proposals.

Investments at the BES light sources continue support and development of new tools for biopreparedness (under the BRaVE initiative) and to advance data science, artificial intelligence, and machine learning, as well as computing hardware, required to plan experiments, analyze data, and efficiently operate the accelerators and beamlines.

Facility upgrade projects are underway for the APS, ALS, and LCLS to ensure ongoing world leadership for these facilities. In addition, since completing construction of NSLS-II in FY 2015, the initial suite of seven beamlines has expanded to the current 28 beamlines with room for at least 30 more. To adopt the most up-to-date technologies and provide the most advanced capabilities, BES has a phased approach to new beamlines at NSLS-II, as was done for other BES facilities. The NSLS-II Experimental Tools-II (NEXT-II) MIE project, started in FY 2020, provides three best-in-class beamlines to support the needs of the U.S. research community. In FY 2024, planning and conceptual design funds are requested for NEXT-III, a line-item construction project to deliver the next cadre of beamlines.

High-Flux Neutron Sources

One of the goals of modern materials science is to understand the factors that determine the properties of matter on the atomic scale and to use this knowledge to optimize those properties or to develop new materials and functionality. This process regularly involves the discovery of fascinating new physics, which itself may lead to previously unexpected applications. Among the different probes used to investigate atomic-scale structure and dynamics, thermal neutrons have unique advantages:

- they have a wavelength similar to the spacing between atoms, allowing atomic-resolution studies of structure, and have an energy similar to the elementary excitations of atoms and magnetic spins in materials, thus allowing an investigation of material dynamics;
- they have no charge, allowing deep penetration into a bulk material;
- they are scattered to a similar extent by both light and heavy atoms but differently by different isotopes of the same element, so that different chemical sites can be uniquely distinguished via isotope substitution experiments, for example substitution of deuterium for hydrogen in organic and biological materials;
- they have a magnetic moment, and thus can probe magnetism in condensed matter systems; and
- their scattering cross-section is precisely measurable on an absolute scale, facilitating straightforward comparison with theory and computer modeling.

The High Flux Isotope Reactor (HFIR) at ORNL generates neutrons via fission in a research reactor. HFIR operates at 85 megawatts and provides state-of-the-art facilities for neutron scattering, isotope production, materials irradiation, and neutron activation analysis. It is the world's leading production source of elements heavier than plutonium for medical, industrial, and research applications. There are 12 instruments in the user program at HFIR and the adjacent cold neutron beam guide hall, which include world-class instruments for inelastic scattering, small angle scattering, powder and single crystal diffraction, neutron imaging, and engineering diffraction. In FY 2024, operations funding will support preparation work to replace the beryllium reflector at HFIR. In addition, funding is requested to continue planning, design, R&D, analysis, engineering, and prototyping to advance the replacement of the aging HFIR pressure vessel.

The Spallation Neutron Source (SNS) at ORNL uses a different approach for generating neutron beams, where an accelerator generates protons that strike a heavy-metal target such as mercury. As a result of the impact, cascades of neutrons are produced in a process known as spallation. The SNS is the world's brightest pulsed neutron facility, and presently includes 19 instruments. These world-leading instruments include very high-resolution inelastic and quasi-elastic scattering capabilities, powder and single crystal diffraction, polarized and unpolarized beam reflectometry, and spin echo and small angle scattering spectrometers. A large suite of capabilities for high and low temperature, high magnetic field, and high-pressure sample environment equipment is available for the instruments. All the SNS instruments are in high demand by researchers world-wide in a range of disciplines from biology to materials sciences and condensed matter physics. Current construction projects at SNS focus on maintaining world-leadership for neutron scattering.

Investments continue support and development of new tools for biopreparedness (under the BRaVE initiative) and to advance data science, artificial intelligence, and machine learning, as well as computing hardware, to plan experiments, analyze data, and efficiently operate the accelerator and beamlines.

Nanoscale Science Research Centers

Since the launching of the National Nanotechnology Initiative in 2000, nanoscale science has become foundational in many scientific and technology research areas. Nanoscience focuses on phenomena that occur at the nanometer scale—probing and assembling single atoms, clusters of atoms, and molecular structures. One aspect is discovery of new nanoscale materials and structures not found in nature. However, the ability to observe and understand functionality at this length scale, including interactions with physical and chemical environments, is key to many science and engineering challenges for energy, QIS, next-generation semiconductors, and biopreparedness. Developments at the nanoscale and mesoscale have the potential to make major contributions to delivering remarkable scientific discoveries that transform our understanding of energy and matter and advance national, economic, and energy security.

The NSRCs focus on interdisciplinary discovery research at the nanoscale, providing a foundation for research that encompasses technology innovations, discovery science, new tools, and new computing capabilities. Distinct from the x-ray and neutron sources, NSRCs comprise a suite of smaller unique tools and expert scientific staff. The five NSRCs are the Center for Nanoscale Materials at ANL, the Center for Functional Nanomaterials at BNL, the Molecular Foundry at LBNL, the Center for Nanophase Materials Sciences at ORNL, and the Center for Integrated Nanotechnologies at SNL and LANL. Each center has particular expertise and capabilities, such as nanomaterials synthesis and assembly; theory, modeling and simulation; imaging and spectroscopy including electron and scanning probe microscopy; and nanostructure fabrication and integration. Selected thematic areas include catalysis, electronic materials, nanoscale photonics, and soft and biological materials. Four of the centers are near or adjoining BES facilities for x-rays, neutrons, and/or SC-supported computation facilities, which complement and leverage these capabilities for the user communities. These custom-designed laboratories contain clean rooms, nanofabrication resources (crucial for semiconductor and quantum information science research), one-of-a-kind signature instruments, and other instruments generally available only at major user facilities. The NSRC electron and scanning probe microscopy capabilities provide superior atomic-scale spatial resolution and simultaneously obtain structural, chemical, and other types of information from sub-nanometer regions at short time scales. They house electron microscopes that are among the highest resolution in the world and bring unique analytical capabilities for users. Data science approaches are enabling large and fast data acquisition, real-time analysis, and autonomous experiments. Operating funds provide capabilities for cutting-edge research, technical support, and administration of the user program at these facilities, which serve academic, government, and industry researchers with access determined through external peer review of user proposals.

Since their inception, the NSRCs have played a foundational role in establishing nanoscience characterization and associated approaches as a key endeavor for energy and other national priority research areas. Going forward, the NSRCs will continue to develop infrastructure and capabilities for materials synthesis, device fabrication, metrology, modeling, and simulation. Future investments will recognize the transition from development of nanoscience as a field of research to a new phase focused on evolving these capabilities to address the most pressing national needs in clean energy and technological competitiveness. The goal is to develop a flexible and enabling infrastructure so that U.S. institutions and industry can rapidly develop and commercialize the new discoveries and innovations.

Other Project Costs

The total project cost (TPC) of DOE’s construction projects comprises two major components: the total estimated cost (TEC) and OPC. The TEC includes project costs incurred after Critical Decision (CD)-1, such as costs associated with all engineering design and inspection; the acquisition of land and land rights; direct and indirect construction/fabrication; the initial equipment necessary to place the facility or installation in operation; and facility construction costs and other costs specifically related to those construction efforts. OPC represents all other costs related to the projects that are not included in the TEC, such as costs that are incurred during the project’s initiation and definition phase for planning, conceptual design, research, and development, and those incurred during the execution phase for R&D, startup, and commissioning. OPC is always funded via operating funds.

Major Items of Equipment

BES supports MIE projects to ensure the continual development and upgrade of major scientific instrument capabilities, including fabricating new x-ray and neutron experimental stations, improving NSRC core facilities, additional beamlines for the NSLS-II, and providing new stand-alone instruments and capabilities. In FY 2024, preliminary planning support is requested for new MIEs for additional beamlines for the APS and ALS.

Research

This activity supports research from initial studies of accelerator physics and instrumentation to their translation into innovative components or techniques that improve existing or supported concepts of future BES user facilities. Production of beams with increased average flux and brightness and the detection tools capable of responding to the high beam intensity are the two major components for the advancement of light and neutron sources. The first component requires higher-repetition-rate photocathode guns and radiofrequency (RF) systems, and photon beams of enhanced temporal coherence, such as produced by improved seeding techniques or x-ray oscillators for free electron lasers (FELs). Areas of interest are techniques leading to Terawatt-power radiation, source-generated THz beams, and research on “beam on demand” techniques to support multiple beamlines simultaneously. The second component—detectors—requires higher computational capabilities per pixel, improved readout rates, radiation hardness, and better energy and temporal resolutions. Higher neutron-flux capabilities at the SNS will demand high-intensity $H^-$ currents, requiring tight control of beam losses, and detectors designed for advanced neutron imaging with very high throughput. A focus is on research that will maintain the competitiveness of BES user facilities to their counterparts in Europe and Japan. BES coordinates with the SC Office of Accelerator R&D and Production on crosscutting research and technology areas.

Investments will continue to support development of data science methods and tools to address data and information challenges at the BES user facilities, including accelerator optimization, control, prognostics, and experiment automation and real-time data analysis. Funding continues for the RENEW initiative that provides undergraduate and graduate training opportunities at DOE national laboratories and user facilities for individuals from HBCUs and MSIs. Investment will also support the BRaVE initiative, which will maintain and evolve capabilities at user facilities related to responsiveness to biological threats and development of advanced instrumentation to address these research challenges.

## Basic Energy Sciences
## Scientific User Facilities (SUF)

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Scientific User Facilities (SUF)** | **$1,190,757** | **$1,326,143** | **+$135,386** |
| X-Ray Light Sources | $599,498 | $704,134 | +$104,636 |
| Funding supports operations at five BES light sources (LCLS, APS, ALS, NSLS-II, and SSRL). | | The Request will support operations at five BES light sources (LCLS-II, APS, ALS, NSLS-II, and SSRL). Funding supports LCLS transition to LCLS-II operations, APS activities in anticipation of APS-U completion, and increased beamline support for ALS in preparation for ALS-U. | Funding will support LCLS-II, APS, ALS, NSLS-II and SSRL operations at 90 percent of optimal funding, re-baselined to account for inflation, supply chain costs, staffing support, COVID-19 and remote operations, and other costs. Development of capabilities for biopreparedness, computational techniques, and data will continue. |
| High-Flux Neutron Sources | $315,740 | $373,163 | +$57,423 |
| Funding supports operations at SNS and HFIR. | | The Request will support operations at SNS and HFIR (including partial funding for the HFIR beryllium reflector replacement procurements and planning). | Funding will support operations for SNS and HFIR at approximately 90 percent of optimal funding, re-baselined to account for inflation, supply chain costs, staffing support, COVID-19 and remote operations, and other costs. Development of capabilities for biopreparedness, computational techniques, and data will continue. |
| Nanoscale Science Research Centers | $153,409 | $150,880 | -$2,529 |
| Provides funding for five NSRCs (CFN, CNM, CNMS, MF, and CINT). The NSRCs continue to develop nanoscience and QIS-related research infrastructure and capabilities for materials synthesis, device fabrication, metrology, modeling and simulation. | | The Request will provide funding for five NSRCs (CFN, CNM, CNMS, MF, and CINT). The NSRCs will continue to develop nanoscience and QIS-related research infrastructure and capabilities for materials synthesis, device fabrication, metrology, modeling and simulation. | Funding will support operations for the five NSRCs at approximately 90 percent of optimal funding, re-baselined to account for inflation, supply chain costs, staffing support, COVID-19 and remote operations, and other costs. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Other Project Costs | $19,500 | $14,000 | -$5,500 |
| Funding supports OPC for the LCLS-II-HE project at SLAC, the STS project at ORNL, the APS-U project at ANL, and the CRMF project at SLAC. Funds also initiate OPC for the HFIR-PVR project at ORNL and the NEXT-III project at BNL. | | The Request will support OPC for the CRMF project at SLAC, the HFIR-PVR project at ORNL, and the NEXT-III project at BNL. | Funding will support planning for the CRMF project at SLAC, the HFIR-PVR project at ORNL, and the NEXT-III project at BNL. OPC will support preliminary project plans for these activities. |
| Major Items of Equipment | $50,000 | $25,000 | -$25,000 |
| Funding continues the beamline project for NEXT-II at BNL and the recapitalization project for the NSRCs. Both projects received CD-2/3 approval in FY 2022. | | The Request will provide final funding for the beamline project for NEXT-II at BNL and the recapitalization project for the NSRCs. | Funding will support the approved funding profiles for the NEXT-II and NSRC Recapitalization MIE projects. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Research $52,610 | $58,966 | +$6,356 |
| Funding supports high-priority research activities for advanced seeded FEL schemes that provide several orders of magnitude performance enhancement, detectors with high read out rate, optics that can handle high heat load and preserve the coherent wave front, and applications of data science techniques to accelerator optimization, control, prognostics, and data analysis. Research emphasizes transformative advances in accelerator science and technology that lead to significant improvements in very high brightness and high current electron sources and in high intensity proton sources. In addition, research expands to include enabling capabilities for response to biological threats and RENEW internships. | The Request will support high-priority research activities for advanced seeded FEL schemes that provide several orders of magnitude performance enhancement, detectors with high read out rate, optics that can handle high heat load and preserve the coherent wave front, and applications of data science techniques to accelerator optimization, control, prognostics, and data analysis. Research will emphasize transformative advances in accelerator science and technology that lead to significant improvements in very high brightness and high current electron sources and in high intensity proton sources. In addition, research will expand to include enabling capabilities for response to biological threats and to increase the diversity of the research performers. | Funding will support investment in future accelerator technologies to continue to provide the world's most comprehensive and advanced accelerator-based facilities for scientific research. Funding will also continue the development of data science methods and tools to address data and information challenges at the BES user facilities, including accelerator optimization, control, prognostics, and experiment automation and real time data analysis. Funding will support the BRaVE initiative to enable facility capabilities for responsiveness to biological threats. Investment will include research in underrepresented communities and institutions. Funding will support the RENEW initiative for user facility internships from HBCUs and MSIs. |

*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, excluding facility operations.*

## Basic Energy Sciences
## Construction

### Description

Accelerator-based x-ray light sources, accelerator-based pulsed neutron sources, reactor-based neutron sources, and nanoscale science research centers are essential user facilities that enable critical DOE mission-driven science, including research in support of clean energy, as well as research in response to national priorities such as the COVID-19 pandemic. These user facilities provide the academic, laboratory, and industrial research communities with the tools to fabricate, characterize, and develop new materials and chemical processes to advance basic and applied research, advancing chemistry, physics, earth science, materials science, environmental science, biology, and biomedical science. Regular investments in construction of new user facilities and upgrades to existing user facilities are essential to maintaining U.S. leadership in these research areas.

24-SC-10, HFIR Pressure Vessel Replacement (PVR), ORNL

The HFIR-PVR project will address two capability gaps. First, HFIR is no longer operating at the 100 MW design power due to the discovery of embrittlement issues and a subsequent derating of the reactor to 85 MW. Second, the design of the current pressure vessel limits the addition of new mission-driven scattering instrumentation, enhanced isotope production, and potential flexibilities such as adding a second cold source and guide hall to enhance the key missions of the reactor. Replacement of the pressure vessel and resumption of 100 MW operations meets the need for continued availability of a high-flux, steady-state neutron source that will accommodate future advances and maintain world-leading capabilities for diverse and critical missions that include: production of thermal and cold neutrons and neutrinos for the scientific user community; isotope production for research, medicine, and federal and industrial applications including NASA deep space missions; and materials irradiation and neutron activation analysis for federal and industrial partners. The project received CD-0, Approve Mission Need, on October 28, 2020, with a current Total Project Cost (TPC) range of $300,000,000–$550,000,000 and CD-1, Approve Alternative Selection and Cost Range, is expected 4Q FY 2025.

24-SC-12, NSLS-II Experimental Tools - III (NEXT-III), BNL

The NEXT-III project will provide a pathway for the construction of an additional suite of approximately 12 beamlines that will be optimized to enhance the capability of NSLS-II. NEXT-III will deliver a combination of performance and enterprise beamlines. Performance beamlines will be designed to push a given technique to or beyond the current state-of-the-art, offering extraordinary capabilities. These beamlines will enable cutting-edge research in clean sustainable energy, sustainable manufacturing, carbon sequestration and storage, materials for environmental remediation, automated structure analysis of biological macromolecules from crystals to atomic structures, drug discovery, bio-preparedness, quantum materials, and quantum information science, as well as developing novel instrumentation and tools required to maintain the global competitiveness of the U.S. light sources. Enterprise beamlines will be designed to provide capabilities and techniques that are mature and have strong, well-established user communities. These beamlines will carry out more routine measurements and are typically highly automatable with a high throughput of experiments. These beamlines can also provide a first step to gather data for complex experiments that would be fine-tuned to subsequently acquire data on a performance beamline. Enterprise beamlines will enable multimodal (remote as well as on-site) research for a larger, more diverse community to broaden industrial research and provide new avenues to introduce new users to synchrotron research, including those from under-represented institutions and regions. The project received CD-0, Approve Mission Need, on September 30, 2022, with a preliminary TPC range of $350,000,000–$500,000,000 and CD-1, Approve Alternative Selection and Cost Range, is expected 4Q FY 2024.

21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC

The CRMF project will provide a much-needed capability to maintain, repair, and test superconducting radiofrequency (SRF) accelerator components. These components include but are not limited to superconducting RF cavities and cryomodules that make up the new superconducting accelerator being constructed by the LCLS-II and LCLS-II-HE projects, high brightness electron injectors, and superconducting undulators. The facility will provide for the full disassembly and repair of the SRF cryomodule; the ability to disassemble, clean, and reassemble the SRF cavities and cavity string; testing capabilities for the full cryomodule; and separate testing capabilities for individual SRF cavities. To accomplish this, the project is envisioned to require a building up to 25,000 gross square feet to contain the necessary equipment. The building will need a concrete shielded enclosure for cryomodule testing, a control room, a vertical test stand area for testing SRF cavities and components, supplied with cryogenic refrigeration and a distribution box which is connected to a source of liquid helium and will distribute liquid helium within the CRMF building, cryomodule fixtures used to insert and remove the cold mass from the cryomodule vacuum vessel, a cleanroom partitioned into class 10 and class 1000 areas, a loading and cryomodule preparation area, storage areas, and a 15 ton bridge crane for moving equipment from one area to another within the building. The project received CD-0, Approve Mission Need, on December 6, 2019, with a current TPC range of $70,000,000–$98,000,000, and CD-1, Approve Alternative Selection and Cost Range, is expected 4Q FY 2023.

19-SC-14, Second Target Station (STS), ORNL

The STS project will expand SNS capabilities for neutron scattering research by exploiting part of the higher SNS accelerator proton beam power (2.8 MW) enabled by the PPU project. The STS will be a complementary pulsed source with a narrow proton beam which increases the proton beam power density compared to the first target station (FTS). This dense beam of protons, when deposited on a compact, rotating, water-cooled tungsten target, will create neutrons through spallation and direct them to high efficiency coupled moderators to produce an order of magnitude higher brightness cold neutrons than were previously achievable. By optimizing the design of the instruments with advanced neutron optics, optimized geometry for 15 Hz operation, and advanced detectors, the detection resolution will be up to two orders of magnitude higher, enabling new research opportunities. The project received CD-1, Approve Alternative Selection and Cost Range, on November 23, 2020, which established the approved TPC range of $1,800,000,000–$3,000,000,000 and CD-3A, Approve Long Lead Procurements, is expected 4Q FY 2024.

18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL

The PPU project will double the proton beam power capability of the SNS from 1.4 megawatts (MW) to 2.8 MW by fabricating and installing seven new superconducting radio frequency (SRF) cryomodules and supporting RF equipment, upgrade the first target station to accommodate beam power up to 2 MW, and deliver a 2 MW-qualified target. The high voltage converter modulators and klystrons for some of the existing installed RF equipment will be upgraded to handle the higher beam current. The accumulator ring will be upgraded with minor modifications to the injection and extraction areas. The improved target performance at the increased beam power of 2 MW is enabled by the addition of a new gas injection system and a redesigned mercury target vessel. The project received a combined CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on October 6, 2020, with a TPC of $271,567,000 and CD-4, Approve Project Completion, is expected 4Q FY 2028.

18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL

The ALS-U project will upgrade the existing ALS facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat lattice design, which will provide a soft x-ray source that is up to 1000 times brighter and with a significantly higher coherent flux fraction. ALS-U will leverage two decades of investments in scientific tools at the ALS by making use of the existing beamlines and infrastructure. ALS-U will ensure that the ALS facility remains a world leader in soft x-ray science. The project received CD-3, Approve Start of Construction, on November 10, 2022, with a TPC of $590,000,000 and CD-4, Approve Project Completion, is expected 4Q of FY 2029.

18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC

The LCLS-II-HE project will increase the energy of the superconducting linac currently under construction as part of the LCLS-II project from 4 giga-electronvolts (GeV) to 8 GeV and thereby expand the high repetition rate operation (1 million pulses per second) of this unique facility into the hard x-ray regime (5-12 keV). LCLS-II-HE will add new and upgraded instrumentation to augment existing capabilities and upgrade the facility infrastructure as needed. The LCLS-II-HE project will upgrade and expand the capabilities of the LCLS-II to maintain U.S. leadership in ultrafast x-ray science. The project received CD-3B, Approve Long Lead Procurements, on January 27, 2023. The project established an original TPC range of $290,000,000–$480,000,000, but due to maturing design efforts that identified additional costs across the project scope, added scope for a new superconducting electron source, and increased the project’s contingency to address several future risks, the TPC estimate has increased to $710,000,000. The LCLS-II-HE project continues to assess the impact of COVID-19 on the project’s cost and schedule. A combined CD-2/3, Approve Performance Baseline and Approve Start of Construction, is expected in 2Q FY 2024.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Construction** | **$293,200** | | **$260,625** | **-$32,575** |
| 24-SC-10, HFIR Pressure Vessel Replacement (PVR), ORNL | $ — | | $4,000 | +$4,000 |
| No funding is requested in FY 2023. | | The Request will initiate planning, design, R&D, analysis, engineering, and prototyping to advance design. | | Funding will initiate the HFIR PVR project. |
| 24-SC-12, NSLS-II Experimental Tools - III (NEXT-III), BNL | $ — | | $2,556 | +$2,556 |
| No funding is requested in FY 2023. | | The Request will initiate conceptual design activities, building on the planning activities supported in FY 2023. | | Funding will initiate the NEXT-III project. |
| 21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC | $10,000 | | $9,000 | -$1,000 |
| Funding continues the initial design effort and initiate long-lead procurements and site preparations for civil construction upon associated CD approvals. CD-1 is expected for 4Q FY 2023 and CD-3A expected for 1Q FY 2024. | | The Request will support completion of the detailed design of the facility and technical specifications of the cryogenic plant and initiate long-lead procurements upon associated CD approvals. CD-1 is expected for 4Q FY 2023 and CD-3A is expected for 1Q FY 2024. | | Funding will advance progress on the CRMF project. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| 19-SC-14, Second Target Station (STS), ORNL $32,000 | $52,000 | +$20,000 |
| The project continues the activities of planning, R&D, and engineering to mature the project's preliminary design, scope, cost, schedule, and key performance parameters. | The Request will continue planning, R&D, design, engineering, prototyping, and testing to advance the highest-priority activities. Funding will also initiate a potential long lead procurement for civil construction site preparation upon associated CD approvals. | Funding will advance progress on the STS project. |
| 18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL $9,200 | $ — | -$9,200 |
| Funding supports ongoing construction activities to include civil construction associated with the long beamline building. Dark time for installation is projected to begin 2Q FY 2023. | No funding is requested in FY 2024. | Final funding for this project is provided in FY 2023. |
| 18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL $17,000 | $15,769 | -$1,231 |
| The project supports the installation of additional cryomodules and related radiofrequency systems, operation of the second PPU test target at increased power levels, and construction of the tunnel stub that will facilitate connection to the future STS. | The Request will support construction of the tunnel stub that will facilitate connection to the future STS, install the final additional cryomodules and related radiofrequency systems, begin first target station upgrades to support high-flow target gas injection, upgrade the ring magnets, and operate the first PPU production target at increased power levels. | Final funding for this project is requested in FY 2024. |
| 18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL $135,000 | $57,300 | -$77,700 |
| The project continues to advance construction activities. | The Request will continue to advance construction activities upon associated CD approvals. | Final funding for this project is requested in FY 2024. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| 18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC $90,000 | $120,000 | +$30,000 |
| Funding supports engineering, design, R&D prototyping, continuing long lead procurements of construction items and preparation of the project baseline. Other tasks as required. A combined CD-2/3 approval is expected for 2Q FY 2024 and CD-4 is expected for 2Q FY 2030. | Funding will support production of the cryomodules, continue long lead procurements, and begin remaining scope design efforts and initiate installation/construction contracts. Other tasks as required. A combined CD-2/3 approval is expected for 2Q FY 2024. | Funding will advance progress on the LCLS-II-HE project. |

## Basic Energy Sciences
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | | |
| Capital Equipment | N/A | N/A | 55,740 | 38,500 | 80,698 | 57,394 | -23,304 |
| Minor Construction Activities | | | | | | | |
| General Plant Projects | N/A | N/A | 1,740 | – | 3,400 | 22,040 | +18,640 |
| Accelerator Improvement Projects | N/A | N/A | 23,431 | – | 14,010 | 81,169 | +67,159 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **80,911** | **38,500** | **98,108** | **160,603** | **+62,495** |

## Capital Equipment

| | (dollars in thousands) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
| **Capital Equipment** | | | | | | | |
| Major Items of Equipment | | | | | | | |
| Scientific User Facilities (SUF) | | | | | | | |
| NSLS-II Experimental Tools-II (NEXT-II), BNL | 92,283 | 13,783 | 15,000 | 18,500 | 25,000 | 20,000 | -5,000 |
| NSRC Recapitalization | 79,150 | 14,150 | 15,000 | 20,000 | 25,000 | 5,000 | -20,000 |
| Total, MIEs | N/A | N/A | 30,000 | 38,500 | 50,000 | 25,000 | -25,000 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 25,740 | – | 30,698 | 32,394 | +1,696 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **55,740** | **38,500** | **80,698** | **57,394** | **-23,304** |

*Note:*

- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*

## Minor Construction Activities

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| GPPs (greater than or equal to $5M and less than $30M) | | | | | | |
| HFIR Guide Hall Extension | 20,640 | – | 740 | 1,400 | 18,500 | +17,100 |
| HFIR Fabrication, Alignment & Manufacturing (FAM) Bldg., ORNL | 1,540 | – | – | – | 1,540 | +1,540 |
| Total GPPs (greater than or equal to $5M and less than $30M) | N/A | N/A | 740 | 1,400 | 20,040 | +18,640 |
| Total GPPs less than $5M | N/A | N/A | 1,000 | 2,000 | 2,000 | – |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **1,740** | **3,400** | **22,040** | **+18,640** |
| **Accelerator Improvement Projects (AIP)** | | | | | | |
| AIPs (greater than or equal to $5M and less than $30M) | | | | | | |
| 3rd Harmonic Cavity, National Synchrotron Light Source-II | 4,720 | – | – | – | 4,720 | +4,720 |
| Spallation Neutron Source Cold Box-Engineering | 10,500 | – | – | – | 10,500 | +10,500 |
| Cold Source Helium Refrigerator System | 21,939 | 9,339 | – | – | 12,600 | +12,600 |
| Moderator Test Stand (SNS) | 6,250 | – | 6,250 | – | – | – |
| 160kW Solid State Amplifier Hardware and Utilities - Phase 2 (APS) | 11,934 | – | – | 5,967 | 5,967 | – |
| Flexon 2nd Endstation, LBNL | 8,500 | – | – | – | 8,500 | +8,500 |
| New SAX/WAX Beamline, LBNL | 17,750 | – | – | – | 17,750 | +17,750 |
| Total AIPs (greater than or equal to $5M and less than $30M) | N/A | N/A | 6,250 | 5,967 | 60,037 | +54,070 |
| Total AIPs less than $5M | N/A | N/A | 17,181 | 8,043 | 21,132 | +13,089 |
| **Total, Accelerator Improvement Projects (AIP)** | **N/A** | **N/A** | **23,431** | **14,010** | **81,169** | **+67,159** |

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| | (dollars in thousands) | | | | | |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **25,171** | **17,410** | **103,209** | **+85,799** |

*Notes:*

- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*
- *The Total funding for the HFIR Guide Hall Extension GPP project is approximately $19,900,000. This project, originally requested in FY 2021, has been delayed. Design efforts will be fully funded in FY 2023 and the remaining funds are requested in FY 2024.*
- *The Total funding for the Cold Source Helium Refrigerator System (AIP) project is $12,600,000. This project, originally requested in FY 2021, has been deferred until FY 2024.*
- *The Total funding for the SNS Cold Box-Engineering (AIP) project is $10,500,000. This project, originally requested in FY 2023, has been deferred until FY 2024.*

## Basic Energy Sciences
## Major Items of Equipment Description(s)

Scientific User Facilities (SUF) MIEs:
In FY 2024, preliminary planning support is requested for new MIEs for additional beamlines for the APS and ALS user facilities.

*NSLS-II Experimental Tools-II (NEXT-II) Project*
The NEXT-II project will add three world-class beamlines to the NSLS-II Facility as part of a phased buildout of beamlines to provide advances in scientific capabilities for the soft x-ray user community. These beamlines will focus on the techniques of coherent diffraction imaging, soft x-ray spectromicroscopy, and nanoscale probes of electronic excitations. The project received CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on October 13, 2021. The approved total project cost is $94,500,000. The FY 2024 Request of $20,000,000 provides final funding for the project and will continue R&D, prototyping, other supporting activities, and construction/equipment procurements. The project is planning for CD-4 approval early in FY 2027.

*Nanoscale Science Research Center (NSRC) Recapitalization Project*
The NSRCs started early operations in 2006-2007 and now, over a decade later, instrumentation recapitalization is needed to continue to perform cutting edge science to support and accelerate advances in the fields of nanoscience, materials, chemistry, and biology. The recapitalization will also provide essential support for quantum information science and systems. The project received a combined CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on March 31, 2022. The approved total cost is $80,000,000. The FY 2024 Request of $5,000,000 provides final funding for the project and will continue R&D, design, engineering, prototyping, other supporting activities, and construction/equipment procurements. The project is planning for CD-4 approval early in FY 2028.

## Basic Energy Sciences
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **24-SC-10, HFIR Pressure Vessel Replacement (PVR)** | | | | | | | |
| Total Estimated Cost (TEC) | 523,000 | – | – | – | – | 4,000 | +4,000 |
| Other Project Cost (OPC) | 27,000 | – | – | – | 3,000 | 9,000 | +6,000 |
| **Total Project Cost (TPC)** | **550,000** | **–** | **–** | **–** | **3,000** | **13,000** | **+10,000** |
| **24-SC-12, NSLS-II Experimental Tools-III (NEXT-III)** | | | | | | | |
| Total Estimated Cost (TEC) | 480,000 | – | – | – | – | 2,556 | +2,556 |
| Other Project Cost (OPC) | 20,000 | – | – | – | 1,500 | 4,000 | +2,500 |
| **Total Project Cost (TPC)** | **500,000** | **–** | **–** | **–** | **1,500** | **6,556** | **+5,056** |
| **21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC** | | | | | | | |
| Total Estimated Cost (TEC) | 88,800 | 1,000 | 1,000 | 20,000 | 10,000 | 9,000 | -1,000 |
| Other Project Cost (OPC) | 5,700 | 1,000 | 2,000 | 700 | 1,000 | 1,000 | – |
| **Total Project Cost (TPC)** | **94,500** | **2,000** | **3,000** | **20,700** | **11,000** | **10,000** | **-1,000** |
| **19-SC-14, Spallation Neutron Source Second Target Station (STS), ORNL** | | | | | | | |
| Total Estimated Cost (TEC) | 2,145,000 | 50,000 | 32,000 | 42,700 | 32,000 | 52,000 | +20,000 |
| Other Project Cost (OPC) | 97,000 | 45,805 | – | – | 5,000 | – | -5,000 |
| **Total Project Cost (TPC)** | **2,242,000** | **95,805** | **32,000** | **42,700** | **37,000** | **52,000** | **+15,000** |
| **18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL** | | | | | | | |
| Total Estimated Cost (TEC) | 796,500 | 686,300 | 101,000 | – | 9,200 | – | -9,200 |
| Other Project Cost (OPC) | 18,500 | 8,500 | 5,000 | – | 5,000 | – | -5,000 |
| **Total Project Cost (TPC)** | **815,000** | **694,800** | **106,000** | **–** | **14,200** | **–** | **-14,200** |

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL** | | | | | | | |
| Total Estimated Cost (TEC) | 257,769 | 208,000 | 17,000 | – | 17,000 | 15,769 | -1,231 |
| Other Project Cost (OPC) | 13,798 | 13,798 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **271,567** | **221,798** | **17,000** | **–** | **17,000** | **15,769** | **-1,231** |
| **18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL** | | | | | | | |
| Total Estimated Cost (TEC) | 562,000 | 198,000 | 75,100 | 96,600 | 135,000 | 57,300 | -77,700 |
| Other Project Cost (OPC) | 28,000 | 28,000 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **590,000** | **226,000** | **75,100** | **96,600** | **135,000** | **57,300** | **-77,700** |
| **18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC** | | | | | | | |
| Total Estimated Cost (TEC) | 678,000 | 128,657 | 50,000 | 90,000 | 90,000 | 120,000 | +30,000 |
| Other Project Cost (OPC) | 32,000 | 14,000 | 3,000 | 6,000 | 4,000 | – | -4,000 |
| **Total Project Cost (TPC)** | **710,000** | **142,657** | **53,000** | **96,000** | **94,000** | **120,000** | **+26,000** |
| **13-SC-10, Linac Coherent Light Source II (LCLS-II), SLAC** | | | | | | | |
| Total Estimated Cost (TEC) | 1,080,200 | 1,052,100 | 28,100 | – | – | – | – |
| Other Project Cost (OPC) | 56,200 | 51,900 | 4,300 | – | – | – | – |
| **Total Project Cost (TPC)** | **1,136,400** | **1,104,000** | **32,400** | **–** | **–** | **–** | **–** |
| **Total, Construction** | | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **304,200** | **249,300** | **293,200** | **260,625** | **-32,575** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **14,300** | **6,700** | **19,500** | **14,000** | **-5,500** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **318,500** | **256,000** | **312,700** | **274,625** | **-38,075** |

*Note:*

- *The Prior Year amounts in the table above include reprogramming of funds from the APS-U project (-$3,500,000) to the LCLS-II-HE project (+$3,500,000) and the LCLS-II project (+$2,801,000) in FY 2021.*

**Basic Energy Sciences**
**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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Scientific User Facilities - Type A** | | | | | |
| **Advanced Light Source** | **70,704** | **68,672** | **74,934** | **105,289** | **+30,355** |
| Number of Users | 1,400 | 1,663 | 1,500 | 1,545 | +45 |
| Achieved Operating Hours | – | 3,957 | – | – | – |
| Planned Operating Hours | 3,885 | 3,885 | 3,880 | 3,010 | -870 |
| **Advanced Photon Source** | **146,226** | **141,638** | **173,142** | **174,920** | **+1,778** |
| Number of Users | 4,000 | 4,582 | 3,440 | 1,810 | -1,630 |
| Achieved Operating Hours | – | 4,820 | – | – | – |
| Planned Operating Hours | 4,550 | 4,550 | 3,152 | 2,071 | -1,081 |
| **National Synchrotron Light Source II** | **121,243** | **117,759** | **128,100** | **147,240** | **+19,140** |
| Number of Users | 1,600 | 1,380 | 1,500 | 1,620 | +120 |
| Achieved Operating Hours | – | 4,610 | – | – | – |
| Planned Operating Hours | 4,656 | 4,656 | 4,800 | 4,506 | -294 |
| **Stanford Synchrotron Radiation Light Source** | **45,825** | **44,989** | **48,242** | **67,035** | **+18,793** |
| Number of Users | 1,350 | 1,601 | 1,100 | 1,800 | +700 |
| Achieved Operating Hours | – | 4,833 | – | – | – |
| Planned Operating Hours | 4,850 | 4,850 | 3,316 | 4,537 | +1,221 |
| **Linac Coherent Light Source** | **154,284** | **155,273** | **175,080** | **209,650** | **+34,570** |
| Number of Users | 800 | 869 | 600 | 900 | +300 |
| Achieved Operating Hours | – | 4,598 | – | – | – |
| Planned Operating Hours | 4,655 | 4,655 | 3,200 | 5,850 | +2,650 |

| | FY 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| | (dollars in thousands) | | | | |
| **Spallation Neutron Source** | **185,081** | **172,409** | **189,727** | **180,147** | **-9,580** |
| Number of Users | 800 | 577 | 450 | 260 | -190 |
| Achieved Operating Hours | – | 3,275 | – | – | – |
| Planned Operating Hours | 3,040 | 3,040 | 2,700 | 1,444 | -1,256 |
| **High Flux Isotope Reactor** | **108,919** | **111,452** | **126,013** | **193,016** | **+67,003** |
| Number of Users | 560 | 254 | 290 | 290 | – |
| Achieved Operating Hours | – | 2,322 | – | – | – |
| Planned Operating Hours | 3,025 | 3,025 | 2,700 | 2,970 | +270 |
| **Scientific User Facilities - Type B** | | | | | |
| **Center for Nanoscale Materials** | **30,666** | **29,652** | **30,519** | **29,558** | **-961** |
| Number of Users | 480 | 756 | 730 | 700 | -30 |
| **Center for Functional Nanomaterials** | **25,690** | **25,601** | **27,114** | **26,483** | **-631** |
| Number of Users | 520 | 640 | 630 | 630 | – |
| **Molecular Foundry** | **32,226** | **31,166** | **38,051** | **37,494** | **-557** |
| Number of Users | 750 | 968 | 950 | 1,170 | +220 |
| **Center for Nanophase Materials Sciences** | **28,691** | **28,497** | **30,404** | **29,441** | **-963** |
| Number of Users | 580 | 811 | 730 | 700 | -30 |
| **Center for Integrated Nanotechnologies** | **25,471** | **24,636** | **27,321** | **27,904** | **+583** |
| Number of Users | 660 | 906 | 870 | 850 | -20 |
| **Total, Facilities** | **975,026** | **951,744** | **1,068,647** | **1,228,177** | **+159,530** |
| Number of Users | 13,500 | 15,007 | 12,790 | 12,275 | -515 |
| Achieved Operating Hours | – | 28,415 | – | – | – |
| Planned Operating Hours | 28,661 | 28,661 | 23,748 | 24,388 | +640 |

*Note:*

- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*

**Basic Energy Sciences**
**Scientific Employment**

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 5,280 | 5,840 | 6,190 | +350 |
| Number of Postdoctoral Associates (FTEs) | 1,520 | 1,670 | 1,740 | +70 |
| Number of Graduate Students (FTEs) | 2,380 | 2,620 | 2,730 | +110 |
| Number of Other Scientific Employment (FTEs) | 3,190 | 3,550 | 3,810 | +260 |
| **Total Scientific Employment (FTEs)** | **12,370** | **13,680** | **14,470** | **+790** |

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

**24-SC-10, HFIR Pressure Vessel Replacement (PVR), ORNL**
**Oak Ridge National Laboratory, ORNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the HFIR Pressure Vessel Replacement (PVR), ORNL is $4,000,000 of Total Estimated Cost (TEC) funding and $9,000,000 of Other Project Costs (OPC) funding. The preliminary total project cost (TPC) range is $300,000,000 to $550,000,000. This preliminary cost range encompasses the most feasible preliminary alternatives at this time. The current preliminary TPC is $550,000,000.

**Significant Changes**

This is a new Construction Project Data Sheet (CPDS) and this project is a new start in FY 2024.

The HFIR started initial operations in 1965 at 100 Mega Watts (MW) but has been operating since 1990 at 85 MW to extend the lifetime of the reactor pressure vessel by slowing radiation-induced embrittlement. In 2019, the Basic Energy Sciences Advisory Committee (BESAC) was charged with assessing the long-term strategy for HFIR and the scientific justification for a U.S. domestic high-performance reactor-based research facility. A key recommendation from the resulting July 2020 report, *The Scientific Justification for a U.S. Domestic High-Performance Reactor-Based Research Facility,* is to replace the pressure vessel with one made with modern materials better able to withstand the harsh radiation environment. After the PVR upgrade, HFIR can resume operations at 100 MW, maintaining reliable access to the world's most intense source of neutrons and ensuring continued support for a variety of high-impact missions in science, isotope production, energy, environment, and national security.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, approved on October 28, 2020. The FY 2023 Enacted Appropriations include $3,000,000 in OPC funding to initiate the alternatives analysis and conceptual design activities required for CD-1. The FY 2024 Request will support planning, design, R&D, analysis, engineering, and prototyping to advance the design.

A Federal Project Director with the appropriate level of certification will be assigned to this project prior to CD-1.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2024 | 10/28/20 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2026 | 4Q FY 2029 | 4Q FY 2027 | 4Q FY 2034 | 4Q FY 2034 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 4Q FY 2026 | 4Q FY 2025 |

**CD-3A** – Approve Long-Lead Procurements, to reduce schedule and technical risk by procuring specialty radiation and corrosion resistant nuclear reactor materials early in the project lifecycle that can have a long-lead time from procurement to receipt.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 177,000 | 346,000 | 523,000 | 27,000 | 27,000 | 550,000 |

**2. Project Scope and Justification**

**Scope**

The HFIR-PVR project will replace the existing HFIR reactor pressure vessel, enabling HFIR to continue providing world-class brightness and flux for a variety of critical mission objectives for decades to come.

**Justification**

The BES mission is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security. BES accomplishes its mission in part by operation of large-scale user facilities consisting of a complementary set of intense x-rays sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

Maintaining world-class user facilities for neutron scattering research and other national priorities requiring neutron sources are an important component of the user facility portfolio enabled by the Spallation Neutron Source (SNS) for pulsed neutrons and the HFIR for reactor-based high-flux neutrons. The HFIR, completed in 1965, has the highest thermal neutron flux in the western world but is at risk of falling behind the 100 MW PIK reactor in Gatchina, Russia (completed in 2021) and the 150 MW MBIR reactor in Dmitrovgrad, Russia (planned for completion in 2027). The HFIR-PVR project reduces the risk of needing to rely on foreign research reactors for critical isotope production and scientific research needs in the long term.

The HFIR-PVR project will address two capability gaps. First, HFIR is no longer operating at the 100 MW design power due to the discovery of embrittlement issues and a subsequent derating of the reactor to 85 MW. Second, the design of the current pressure vessel limits the addition of new mission-driven scattering instrumentation, enhanced isotope production, and potential flexibilities such as adding a second cold source and guide hall to enhance the key missions of the reactor. Replacement of the pressure vessel and resumption of 100 MW operations meets the need for continued availability of a high-flux, steady-state neutron source that will accommodate future advances and maintain world leading capabilities for diverse and critical missions that include: production of thermal and cold neutrons and neutrinos for the scientific user community, isotope production for research, medicine, and federal and industrial applications including NASA deep space missions; and materials irradiation and neutron activation analysis for federal and industrial partners.

The July 2020 BESAC subcommittee report, *The Scientific Justification for a U.S. Domestic High-Performance Reactor-Based Research Facility,* recommends fabricating and replacing the pressure vessel with one made with modern materials better able to withstand the harsh radiation environment. This upgrade will resume operations at 100 MW, maintaining reliable access to HFIR, the world's most intense source of neutrons, ensuring continued support for a variety of high-impact missions including neutron science, materials irradiation, neutron activation analysis, neutrino research, and radioisotope production for research, medicine, and federal and industrial applications. Potential capability and capacity enhancements benefiting the scientific community include: an immediate ~20 percent increase in neutron flux from 100 MW operations; flexibility for a second guide providing the opportunity to increase the number of instruments from the current 12 to 20; the option for a new cold source that provides a ~50 percent boost to cold neutron brightness; and improved beam systems that increase the available flux at cold and thermal instruments by factors of two or more. Additionally, an improved reactor vessel head that allows introduction and removal of capsules during reactor operations will increase isotope production and enable a significant increase in instrumented materials irradiation experiments.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)
The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Pressure Vessel Power Level Capability | 85 MW | 100 MW |
| Instrument ports available for future expansion beyond the current facility | 2 | 8 |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| FY 2024 | 4,000 | 4,000 | – |
| Outyears | 173,000 | 173,000 | 177,000 |
| **Total, Design (TEC)** | **177,000** | **177,000** | **177,000** |
| Construction (TEC) | | | |
| Outyears | 346,000 | 346,000 | 346,000 |
| **Total, Construction (TEC)** | **346,000** | **346,000** | **346,000** |
| Total Estimated Cost (TEC) | | | |
| FY 2024 | 4,000 | 4,000 | – |
| Outyears | 519,000 | 519,000 | 523,000 |
| **Total, TEC** | **523,000** | **523,000** | **523,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2023 | 3,000 | 3,000 | 2,400 |
| FY 2024 | 9,000 | 9,000 | 8,000 |
| Outyears | 15,000 | 15,000 | 16,600 |
| **Total, OPC** | **27,000** | **27,000** | **27,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2023 | 3,000 | 3,000 | 2,400 |
| FY 2024 | 13,000 | 13,000 | 8,000 |
| Outyears | 534,000 | 534,000 | 539,600 |
| **Total, TPC** | **550,000** | **550,000** | **550,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 137,000 | N/A | **N/A** |
| Design - Contingency | 40,000 | N/A | **N/A** |
| **Total, Design (TEC)** | **177,000** | **N/A** | **N/A** |
| Construction | 247,500 | N/A | **N/A** |
| Construction - Contingency | 98,500 | N/A | **N/A** |
| **Total, Construction (TEC)** | **346,000** | **N/A** | **N/A** |
| **Total, TEC** | **523,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *138,500* | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| **Total, D&D** | **5,600** | **N/A** | **N/A** |
| Conceptual Design | 14,000 | N/A | **N/A** |
| Start-up | 2,400 | N/A | **N/A** |
| OPC - Contingency | 5,000 | N/A | **N/A** |
| **Total, Except D&D (OPC)** | **21,400** | **N/A** | **N/A** |
| **Total, OPC** | **27,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *5,000* | *N/A* | ***N/A*** |
| **Total, TPC** | **550,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***143,500*** | ***N/A*** | ***N/A*** |

5. **Schedule of Appropriations Requests**

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | — | — | — | 4,000 | 519,000 | 523,000 |
| | OPC | — | — | 3,000 | 9,000 | 15,000 | 27,000 |
| | TPC | — | — | 3,000 | 13,000 | 534,000 | 550,000 |

6. **Related Operations and Maintenance Funding Requirements**

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2034 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2084 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

7. **D&D Information**

At this stage of project planning and development, SC anticipates that there will be no new area being constructed in the construction project.

8. **Acquisition Approach**

The acquisition approach will be developed and matured as part of the acquisition strategy and alternatives analysis required for CD-1. DOE has determined that ORNL will acquire the HFIR-PVR project under the existing DOE Management and Operations (M&O) contract.

A Conceptual Design Report for the project will identify key design activities, requirements, and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. Project management systems are fully up to date, operating, and are maintained as an ORNL-wide resource.

ORNL will design and procure the key technical subsystem components. Some technical system designs may require research and development activities. Preliminary cost estimates for these components and systems will likely be based on operating experience of HFIR and vendor estimates, while some first-of-a-kind components may be based on expert judgement. Vendors and/or partner labs with the necessary capabilities will fabricate the technical equipment. ORNL will competitively bid and award all subcontracts based on best value to the government. The M&O contractor's performance will be evaluated through the annual laboratory performance appraisal process.

Lessons learned from other Office of Science projects and other similar facilities will be exploited fully in planning and executing the HFIR-PVR project.

**24-SC-12, NSLS-II Experimental Tools - III (NEXT-III), BNL**
**Brookhaven National Laboratory, BNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the NSLS-II Experimental Tools - III (NEXT-III) Project is $2,556,000 of Total Estimated Cost (TEC) funding and $4,000,000 of Other Project Cost (OPC) funding. The current preliminary total project cost (TPC) range is $350,000,000 to $500,000,000. The preliminary cost range encompasses the most feasible preliminary alternatives at this time. The current preliminary TPC for this project is $500,000,000.

**Significant Changes**

This is a new Construction Project Data Sheet (CPDS) and this project is a new start in FY 2024.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, approved on September 30, 2022. The FY 2023 Enacted Appropriations included $1,500,000 in OPC funding for planning activities for this project. The FY 2024 Request continues planning activities including development of plans for CD-1, any required R&D and the future CD-3A package, and initiates conceptual design activities, building on the activities planned in FY 2023.

A Level III certified Federal Project Director will be assigned to this project prior to CD-1.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 9/30/22 | 3Q FY 2024 | 4Q FY 2024 | 2Q FY 2026 | 3Q FY 2027 | 4Q FY 2027 | 1Q FY 2036 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2024 | 2Q FY 2026 | 3Q FY 2025 | 2Q FY 2026 |

**CD-3A** – Approve Long-Lead Procurements, plan to acquire long lead items and assembly for the 1st group of instruments.
**CD-3B** – Approve Long-Lead Procurements, plan to acquire long lead items and assembly for the 2nd group of instruments.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 38,000 | 442,000 | 480,000 | 20,000 | 20,000 | 500,000 |

## 2. Project Scope and Justification

**Scope**

The NEXT-III project will provide for the construction of approximately 12 performance and enterprise beamlines that will be optimized to enhance the capability of NSLS-II to support multimodal research. Performance beamlines will be designed to push a given technique to or beyond, current state-of-the-art, offering extraordinary capabilities. These beamlines, together with complementary results from the enterprise beamlines, will enable cutting-edge research in clean sustainable energy, sustainable manufacturing, carbon sequestration and storage, materials for environmental remediation, automated structure-analysis of biological macromolecules from crystals to atomic structures, drug discovery, bio-preparedness, quantum material and quantum information science, as well as developing novel instrumentation and tools required to maintain the global competitiveness of the U.S. light sources such as adaptive x-ray optics and ultrafast detectors.

The enterprise beamlines will be designed to provide capabilities and techniques that are mature and have strong, well-established user communities. These beamlines will carry out more routine measurements and are typically highly automatable with a high throughput of experiments. These beamlines are also very useful for providing supporting information for projects which would also take data on a performance beamline. The enterprise beamlines will enable multimodal (remote as well as on-site) research for a larger more diverse community including researchers from under-represented communities.

**Justification**

SC has a mission to deliver the scientific discoveries and major scientific tools that transform our understanding of nature and advance the energy, economic, and national security of the United States. SC accomplishes this mission through direct support of research, construction, and operation of national scientific user facilities, and the stewardship of ten world-class national laboratories. The SC national laboratories collectively comprise a preeminent federal research system that develops unique, often multidisciplinary, scientific capabilities beyond the scope of academic and industrial institutions, to benefit the nation's researchers and national strategic priorities.

The mission of BES is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels to provide the foundations for new energy technologies and to support DOE's missions in energy, environment, and national security. To accomplish its mission, BES continually strives to enhance our ability to observe, measure, and understand the structure and properties of materials and the evolution of chemical and physical processes within them. International competition in these research areas is fierce and scientific breakthroughs are often driven by the availability of novel tools and techniques.

A significant fraction of researchers world-wide who use storage-ring sources use low- and medium-energy x-rays in their research because of their great importance in characterization for the fields of energy, the environment, new or improved materials, and biological studies. Low- and medium-energy x-rays can be used to determine the structure of materials at the atomic resolution scales, can provide images at the nanometer spatial resolution, are sensitive to features on the surface and in the bulk, and can operate in extremes of temperature, pressure, and applied magnetic field. However, performance limitations of the U.S. low- and medium-energy x-ray sources had prevented measurements with the necessary resolution and sensitivity in space, energy, and time. Those types of measurements are essential for understanding and controlling energy conversion in materials used in alternative energy technologies. To address these limitations and to further the accomplishment of its mission, the BES program constructed the NSLS-II storage ring light source at Brookhaven National Laboratory to provide one of the world's brightest storage ring synchrotron sources of low- and medium-energy x-rays. NSLS-II has a total capacity of 60 beamlines, with only 28 beamlines (about 47 percent of the capacity) constructed and in current operation.

The NEXT-III project will significantly close the current capability gap by constructing an additional suite of state-of-the-art beamlines. These capabilities are at the core of the NSLS-II User Facility mission to support identified needs of the U.S. research community and the DOE mission to tackle the discoveries and transformational solutions needed for the next generation of sustainable energy technologies. Implementation of this state-of-the-art suite of instrumentation will significantly improve the scientific quality and productivity from the U.S. research community. The remaining open beamlines will allow future opportunities for as yet unforeseen science needs and technology developments.

Because of the importance of the development of new materials and sustainable manufacturing processes, failure to acquire the suite of new advanced tools made possible by the NEXT-III project would have serious repercussions on the competitiveness of U.S. science and engineering. Constructing major scientific user facilities and tools that lead the world in cutting edge research is one of the most important strategic activities of SC. As a result, BES has made the design and fabrication of synchrotron light source beamlines a high priority in order to keep the U.S. at the forefront of energy research.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The KPPs listed are conceptual and will be revised for CD-1 (as preliminary) and finalized at CD-2. Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Performance beamlines | At least 3 or more beamlines capable of operating in the range of 0.1 to 20 KeV Energy Range with tunable spatial resolutions. | At least 5 or more beamlines capable of delivering 0.1-30 KeV energy range with tunable spatial resolutions. |
| Enterprise beamlines | At least 5 or more beamlines capable of micron to submicron spatial resolution for tomography and high-resolution diffraction and crystallography, all with multi-modal capabilities. | At least 7 or more beamlines capable of micron to submicron spatial resolution for tomography, high-resolution diffraction and crystallography, full-field x-ray imaging, high-energy x-ray scattering and imaging, all with multi-modal capabilities. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| FY 2024 | 2,556 | 2,556 | 1,500 |
| Outyears | 35,444 | 35,444 | 36,500 |
| **Total, Design (TEC)** | **38,000** | **38,000** | **38,000** |
| Construction (TEC) | | | |
| Outyears | 442,000 | 442,000 | 442,000 |
| **Total, Construction (TEC)** | **442,000** | **442,000** | **442,000** |
| Total Estimated Cost (TEC) | | | |
| FY 2024 | 2,556 | 2,556 | 1,500 |
| Outyears | 477,444 | 477,444 | 478,500 |
| **Total, TEC** | **480,000** | **480,000** | **480,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2023 | 1,500 | 1,500 | 1,300 |
| FY 2024 | 4,000 | 4,000 | 3,800 |
| Outyears | 14,500 | 14,500 | 14,900 |
| **Total, OPC** | **20,000** | **20,000** | **20,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2023 | 1,500 | 1,500 | 1,300 |
| FY 2024 | 6,556 | 6,556 | 5,300 |
| Outyears | 491,944 | 491,944 | 493,400 |
| **Total, TPC** | **500,000** | **500,000** | **500,000** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 28,500 | N/A | **N/A** |
| Design - Contingency | 9,500 | N/A | **N/A** |
| **Total, Design (TEC)** | **38,000** | **N/A** | **N/A** |
| Construction | 115,200 | N/A | **N/A** |
| Equipment | 172,800 | N/A | **N/A** |
| Construction - Contingency | 154,000 | N/A | **N/A** |
| **Total, Construction (TEC)** | **442,000** | **N/A** | **N/A** |
| **Total, TEC** | **480,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *163,500* | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | 4,000 | N/A | **N/A** |
| Conceptual Planning | 3,000 | N/A | **N/A** |
| Conceptual Design | 10,000 | N/A | **N/A** |
| OPC - Contingency | 3,000 | N/A | **N/A** |
| **Total, Except D&D (OPC)** | **20,000** | **N/A** | **N/A** |
| **Total, OPC** | **20,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *3,000* | *N/A* | ***N/A*** |
| **Total, TPC** | **500,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***166,500*** | ***N/A*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | — | — | — | 2,556 | 477,444 | 480,000 |
| | OPC | — | — | 1,500 | 4,000 | 14,500 | 20,000 |
| | TPC | — | — | 1,500 | 6,556 | 491,944 | 500,000 |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2036 |
| Expected Useful Life | 15 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2051 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

## 7. D&D Information

At this stage of project planning and development, SC anticipates that there will be no new area being constructed in the construction project.

## 8. Acquisition Approach

NEXT-III will be acquired by the BNL under the existing M&O contract managed by the Brookhaven Science Associates. Since completion of NSLS-II User Facility in 2015, the BNL team has constructed many beamlines at the facility and have all the requisite expertise and experience to deliver the project. Project acquisition will be implemented through a combination of sub-contracts for purchase of turn-key systems, and specific instruments and components. Installations will be accomplished by utilizing in-house labor as well as subcontractors.

Lessons learned from other SC projects and other similar facilities are being exploited fully in planning and executing NEXT-III.

**21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC**
**SLAC National Accelerator Laboratory, SLAC**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Cryomodule Repair and Maintenance Facility (CRMF) project at SLAC National Accelerator Laboratory is $9,000,000 of Total Estimated Cost (TEC) funding and $1,000,000 of Other Project Costs (OPC) funding. This project has a preliminary Total Project Cost (TPC) range of $70,000,000 to $98,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. As the conceptual design of this project has matured, the current preliminary TPC estimate for this project has increased from $94,000,000 to $94,500,000.

**Significant Changes**

CRMF was initiated in FY 2021. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, approved on December 6, 2019. This Construction Project Data Sheet (CPDS) is an update of the FY 2023 CPDS and does not include a new start for FY 2024.

In FY 2022, funding supported analysis of alternatives and matures the conceptual design with expertise from an architectural and engineering (AE) firm in preparation for the CD-1 planned in FY 2023. Also in FY 2022, CRMF received $20,700,000 in Inflation Reduction Act (IRA) supplemental funding that will enable the project to accelerate the procurement of the AE design services and will expedite the design. FY 2023 funding supports the design of building infrastructure and technical systems and finalizing the design guidelines and specifications for cryogenics capabilities as part of the proposed CD-3A, approval of long lead procurements. The FY 2024 Request will support completion of the detailed design of the facility, and technical specifications for the procurement of cryogenic systems/equipment.

A Federal Project Director, certified to Level I, has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 12/6/19 | 4Q FY 2023 | 4Q FY 2023 | 1Q FY 2025 | 4Q FY 2024 | 1Q FY 2025 | 4Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 1Q FY 2025 | 1Q FY 2024 |

**CD-3A** – Approve Long-Lead Procurements

As the project planning and design matures, long lead procurement may be requested to mitigate cost and schedule risk to the project. Pending the final design, the long lead items may include the components for CRMF cryogen capabilities.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 5,600 | 84,700 | 90,300 | 3,700 | 3,700 | 94,000 |
| FY 2024 | 5,600 | 83,200 | 88,800 | 5,700 | 5,700 | 94,500 |

*Note:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

**2. Project Scope and Justification**

**Scope**
The preliminary scope of the CRMF project is to construct a building to support the repair, maintenance, and testing of superconducting radiofrequency (SRF) LCLS-II and LCLS-II-HE accelerator components. These components may include but are not limited to SRF cavities and cryomodules, future capabilities for high brightness electron injectors, and superconducting undulators. The requirements will be refined as the project matures. The initial concept includes a building with a concrete shielded enclosure for cryomodule testing, a control room, a vertical test stand area for testing SRF cavities and components, supplied with cryogenic refrigeration and a distribution box, cryomodules handling tools and fixtures used to insert and remove the cold mass from the cryomodule vacuum vessel, a cleanroom partitioned into class 10 and class 1000 areas, a loading and cryomodule preparation area, storage areas, and a 15 ton bridge crane for moving equipment from one area to another within the building.

The building is sized to enable future upgrades of capabilities including installation of a dedicated SRF electron injector development and test area, a 40 mega-electronvolt (MeV) SRF linac to provide the equipment and diagnostics necessary for an integrated injector test stand, and equipment to refurbish and test the niobium SRF cavities. The project is pre-CD-2; the scope included in the alternative selection and cost range will be refined at CD-1.

**Justification**
SC, through the two current BES construction projects, LCLS-II and LCLS-II-HE, is making over a $1,800,000,000 capital investment in an SRF linac at SLAC to support the science mission of DOE. The LCLS-II project is providing a 4 GeV SRF-based linear accelerator capable of providing 1 megahertz (MHz) electron pulses to create a free electron, x-ray laser. This machine contains 35 SRF cryomodules to accelerate the electrons to 4 GeV. The LCLS-II-HE will increase the energy of the LCLS-II linac to 8 GeV by providing an additional 20-23 SRF cryomodules of a similar design to the LCLS-II ones but operating at a higher accelerating gradient. SLAC has partnered with Fermi National Accelerator Laboratory (FNAL) and the Thomas Jefferson National Accelerator Facility (TJNAF) to provide the accelerating cryomodules. FNAL and TJNAF produce the cryomodules making use of specialized fabrication, assembly, and test capabilities available there. To make any repairs, the facilities must currently send the cryomodules back to either FNAL or TJNAF at an increased risk of damage, cost, and schedule delays.

The initial assumption was that cryomodules could be shipped back to the partner laboratories as needed for maintenance at a rate of 1 to 2 cryomodules per year. However, during construction of the LCLS-II facility it was determined that multi-million dollar cryomodules could be damaged during transportation; transportation of cryomodules for repairs during operations would pose a risk to reliable facility operations and scientific productivity. This approach also assumed that either FNAL or TJNAF would have the maintenance capabilities available when needed. At this time, the two partner laboratories have informed SLAC that they will need 6 to 12 months of advance notice to schedule maintenance or repairs to the SLAC hardware.

The proposed CRMF is designed to meet these challenges and will provide the capability to repair, maintain, and test SRF accelerator components, primarily the SRF cryomodules that make up the new superconducting accelerator being constructed by the LCLS-II and LCLS-II-HE construction projects. The facility will provide for the full disassembly and repair of the SRF cryomodule; the ability to disassemble, clean, and reassemble the SRF cavities and cavity string; testing capabilities for the full cryomodule; and separate testing capabilities for individual SRF cavities.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)
The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be part of the approved performance baseline. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Conventional Facilities Building Area | 19,000 gross square feet | 25,000 gross square feet |
| Electron Beam Energy | 50 MeV | 128 MeV |
| Cryogenic Cooling Capacity at 2K | 100 Watts | 250 Watts |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 1,000 | 1,000 | – | – |
| FY 2022 | 1,000 | 1,000 | – | – |
| FY 2022 - IRA Supp. | 300 | 300 | – | – |
| FY 2023 | 1,600 | 1,600 | – | – |
| FY 2024 | 1,000 | 1,000 | 4,600 | 300 |
| Outyears | 700 | 700 | 700 | – |
| **Total, Design (TEC)** | **5,600** | **5,600** | **5,300** | **300** |
| Construction (TEC) | | | | |
| FY 2022 - IRA Supp. | 19,700 | 19,700 | – | – |
| FY 2023 | 8,400 | 8,400 | – | – |
| FY 2024 | 8,000 | 8,000 | – | 11,000 |
| Outyears | 47,100 | 47,100 | 63,500 | 8,700 |
| **Total, Construction (TEC)** | **83,200** | **83,200** | **63,500** | **19,700** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 1,000 | 1,000 | – | – |
| FY 2022 | 1,000 | 1,000 | – | – |
| FY 2022 - IRA Supp. | 20,000 | 20,000 | – | – |
| FY 2023 | 10,000 | 10,000 | – | – |
| FY 2024 | 9,000 | 9,000 | 4,600 | 11,300 |
| Outyears | 47,800 | 47,800 | 64,200 | 8,700 |
| **Total, TEC** | **88,800** | **88,800** | **68,800** | **20,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 1,000 | 1,000 | 59 | – |
| FY 2022 | 2,000 | 2,000 | 1,398 | – |
| FY 2022 - IRA Supp. | 700 | 700 | – | – |
| FY 2023 | 1,000 | 1,000 | 2,400 | 700 |
| FY 2024 | 1,000 | 1,000 | 193 | – |
| Outyears | – | – | 950 | – |
| **Total, OPC** | **5,700** | **5,700** | **5,000** | **700** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 2,000 | 2,000 | 59 | – |
| FY 2022 | 3,000 | 3,000 | 1,398 | – |
| FY 2022 - IRA Supp. | 20,700 | 20,700 | – | – |
| FY 2023 | 11,000 | 11,000 | 2,400 | 700 |
| FY 2024 | 10,000 | 10,000 | 4,793 | 11,300 |
| Outyears | 47,800 | 47,800 | 65,150 | 8,700 |
| **Total, TPC** | **94,500** | **94,500** | **73,800** | **20,700** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 4,000 | 4,000 | **N/A** |
| Design - Contingency | 1,600 | 1,600 | **N/A** |
| **Total, Design (TEC)** | **5,600** | **5,600** | **N/A** |
| Construction | 28,700 | N/A | **N/A** |
| Site Preparation | 5,800 | 8,800 | **N/A** |
| Equipment | 24,400 | 26,160 | **N/A** |
| Other Construction | N/A | 25,500 | **N/A** |
| Construction - Contingency | 24,300 | 24,240 | **N/A** |
| **Total, Construction (TEC)** | **83,200** | **84,700** | **N/A** |
| **Total, TEC** | **88,800** | **90,300** | **N/A** |
| *Contingency, TEC* | *25,900* | *25,840* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 500 | 500 | **N/A** |
| Conceptual Design | 3,100 | 1,700 | **N/A** |
| Start-up | 1,100 | 500 | **N/A** |
| OPC - Contingency | 1,000 | 1,000 | **N/A** |
| **Total, Except D&D (OPC)** | **5,700** | **3,700** | **N/A** |
| **Total, OPC** | **5,700** | **3,700** | **N/A** |
| *Contingency, OPC* | *1,000* | *1,000* | ***N/A*** |
| **Total, TPC** | **94,500** | **94,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***26,900*** | ***26,840*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 1,000 | 1,000 | — | 10,000 | — | 78,300 | 90,300 |
| | OPC | 1,000 | 2,000 | — | — | — | 700 | 3,700 |
| | TPC | 2,000 | 3,000 | — | 10,000 | — | 79,000 | 94,000 |
| FY 2024 | TEC | 1,000 | 1,000 | 20,000 | 10,000 | 9,000 | 47,800 | 88,800 |
| | OPC | 1,000 | 2,000 | 700 | 1,000 | 1,000 | — | 5,700 |
| | TPC | 2,000 | 3,000 | 20,700 | 11,000 | 10,000 | 47,800 | 94,500 |

*Note:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2054 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations, Maintenance and Repair | 5,500 | 5,500 | 137,500 | 137,500 |

The estimate will be updated and additional details will be provided after CD-1, Approve Alternative Selection and Cost Range.

## 7. D&D Information

At this stage of project planning and development, SC is planning to construct a new building up to 25,000 gross square feet as part of this project.

| | Square Feet |
|---|---|
| New area being constructed by this project at SLAC .......... | 19,000 – 25,000 |
| Area of D&D in this project at SLAC .......... | — |
| Area at SLAC to be transferred, sold, and/or D&D outside the project, including area previously "banked" .......... | 19,000 – 25,000 |
| Area of D&D in this project at other sites .......... | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" .......... | — |
| Total area eliminated .......... | — |

## 8. Acquisition Approach

The CRMF Project will be sited at the SLAC and is being acquired by Stanford University under the existing DOE Management and Operations contract.

SLAC is preparing a Conceptual Design Report for the CRMF project and has the requisite construction and project management systems and expertise to execute the project.

Preliminary cost estimates are based on similar facilities at other national laboratories, to the extent practicable. The project will fully exploit recent cost data from similar operating facilities in planning and budgeting. SLAC or partner laboratory staff may assist with completing the design of the technical systems. The selected contractor and/or subcontracted vendors with the necessary capabilities will fabricate technical equipment. All subcontracts will be competitively bid and awarded based on best value to the government.

Lessons learned from other SC projects and other similar facilities will be exploited fully in planning and executing CRMF.

**19-SC-14, Second Target Station (STS), ORNL**
**Oak Ridge National Laboratory, ORNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History


**Summary**

The FY 2024 Request for the STS project is $52,000,000 of Total Estimated Cost (TEC) funding. This project has a preliminary Total Project Cost (TPC) range of $1,800,000,000 to $3,000,000,000. This cost range encompasses the most feasible preliminary alternatives. The current preliminary TPC estimate is $2,242,000,000.


**Significant Changes**

STS was initiated in FY 2019. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, approved on November 23, 2020. This Construction Project Data Sheet (CPDS) is an update of the FY 2023 CPDS and does not include a new start for FY 2024.

In FY 2022, funding supported continued planning, R&D, design, engineering, prototyping, and testing to assist in maturing the project design, scope, cost, schedule, and key performance parameters with emphasis on advancing the preliminary design, incorporating the eight selected instruments into the project plan, and evaluating proposals for the construction manager/general contractor. FY 2022 Inflation Reduction Act (IRA) funds of $42,700,000 will help address inflation-driven concerns of increasing labor, materials, and supply costs, and sustain forward momentum and reduce project risks. FY 2023 funds will continue planning, R&D, design, engineering, prototyping, and testing to advance the highest priority R&D and design activities. Emphasis will be on advancing the neutron detectors and velocity selectors, proton beam optics, target assemblies, instrument optics and choppers, integrated controls systems, safety systems, target material characterization and site characterization in preparation for civil construction. FY 2024 funding will support continued planning, R&D, design, engineering, prototyping, and testing to advance the highest priority activities. Emphasis will be on advancing the instrument prototypes, target preliminary designs and material characterization, proton beam delivery magnets, neutron beam optics and choppers, neutron moderator, and accelerator designs and controls. A potential long lead procurement for civil construction site preparation to bring in new roads and perform site grading depends on progress of the conventional facility design and DOE review and approval of the plans and use of available funding.

A Federal Project Director, certified to level III, has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 1/7/09 | 4/30/21 | 11/23/20 | 4Q FY 2026 | 4Q FY 2029 | 4Q FY 2026 | 2Q FY 2037 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 4Q FY 2026 | 4Q FY 2024 |

**CD-3A** – Approve Long-Lead Procurements for the Construction Management/General Contractor (CM/GC) to create roads for site access and perform site grading and preparation for conventional civil construction.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 332,757 | 1,810,243 | 2,143,000 | 99,000 | 99,000 | 2,242,000 |
| FY 2024 | 294,250 | 1,850,750 | 2,145,000 | 97,000 | 97,000 | 2,242,000 |

*Note:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

**2. Project Scope and Justification**

**Scope**
To address the gap in advanced neutron sources and instrumentation, the STS project will design, build, install, and test the equipment necessary to provide the four primary elements of the new facility: the neutron target and moderators; the accelerator systems; the instruments; and the conventional facilities. Costs for acceptance testing, integrated testing, and initial commissioning to demonstrate achievement of the KPPs are included in the STS scope. The STS will be located in unoccupied space east of the existing First Target Station (FTS). The project requires approximately 375,000 $ft^2$ of new buildings, making conventional facility construction a major contributor to project costs.

**Justification**
The BES mission is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security. BES accomplishes its mission in part by operation of large-scale user facilities consisting of a complementary set of intense x-rays sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

In the area of neutron science, the scientific community conducted numerous studies since the 1970's that have established the scientific justification and need for a very high-intensity pulsed neutron source in the U.S. Since 2007, when it began its user program at ORNL, the FTS at the SNS has been fulfilling this need. In accordance with the 1996 BESAC (Russell Panel) Report recommendation, SNS has many technical margins built into its systems to facilitate a power upgrade into the 2-4 megawatt (MW) range to maintain its position of scientific leadership in the future.

The STS would enable many advances in the opportunities described in the 2015 BESAC report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science." ORNL held four workshops to assess the neutron scattering needs in quantum condensed matter, soft matter, biology, and the frontiers in materials discovery. These four areas encompass and directly map to the transformative opportunities identified in the BES Grand Challenges update. Quantum materials map most directly to harnessing coherence in light and matter, while soft matter and biology are aligned primarily with mastering hierarchical architectures and beyond-equilibrium matter, and frontiers in materials discovery explored many of the topics in beyond ideal materials and systems: understanding the critical roles of heterogeneity, interfaces, and disorder. As an example, while neutrons already play an important role in the areas of biology and soft matter, step change improvements in capability will be required to make full use of the unique properties of neutrons to meet challenges in mastering hierarchical architectures and beyond-equilibrium matter and understanding the critical roles of heterogeneity and interfaces. The uniform conclusion from all workshops was that in the areas of science covered, neutrons play a unique and pivotal role in understanding structure and dynamics in materials required to develop future technologies.

The STS will feature a very high-density beam of protons that strikes a rotating solid tungsten target. The produced neutron beam illuminates moderators located above and below the target that will feed experimental beamlines (eight within the

STS project scope) with neutron beams conditioned for specific instruments. The small-volume cold neutron moderator system is geometrically optimized to deliver higher peak brightness neutrons.

The SNS PPU project, requested separately, will double the power of the SNS accelerator complex to 2.8 MW so that the STS can use one out of every four proton pulses to produce cold neutron beams with the highest peak brightness of any current or projected neutron sources. The high-brightness pulsed source optimized for cold neutron production will operate at 15 Hz (as compared to FTS, which currently operates at 60 Hz, but will operate at 45 pulses/second when the STS is operating) to provide the large time-of-flight intervals corresponding to the broad time and length scales required to characterize complex materials. The project will provide a series of kicker magnets to divert every fourth proton pulse away from the FTS to a new line feeding the STS. Additional magnets will further deflect the beam into the transport line to the new target. A final set of quadrupole magnets will tailor the proton beam shape and distribution to match the compact source design.

An initial set of eight best-in-class instruments, developed with input from the user community, are largely built on known and demonstrated technologies but will need some research and development to deliver unprecedented levels of performance. Advanced neutron optics designs are needed for high alignment and stability requirements. The lower repetition rate of the STS pushes the chopper design to larger diameter rotating elements with tighter limits on allowed mechanical vibration. The higher peak neutron production of the STS will put a greater demand on neutron detector technology.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Demonstrate independent control of the proton beam on the two target stations | Operate beam to FTS at 45 pulses/s, with no beam to STS. Operate beam to STS at 15 Hz, with no beam to FTS. Operate with beam to both target stations 45 pulses/s at FTS and 15 Hz at STS. | Operate beam to FTS at 45 pulses/s, with no beam to STS. Operate beam to STS at 15 Hz, with no beam to FTS. Operate with beam to both target stations 45 pulses/s at FTS and 15 Hz at STS. |
| Demonstrate proton beam power on STS at 15 Hz | 100 kW beam power | 700 kW beam power |
| Measure STS neutron brightness | peak brightness of $2 \times 10^{13}$n/cm$^2$/sr/Å/s at 5 Å | peak brightness of $2 \times 10^{14}$n/cm$^2$/sr/Å/s at 5 Å |
| Beamlines transitioned to operations | 8 beamlines successfully passed the integrated functional testing per the transition to operations parameters acceptance criteria. | ≥ 8 beamlines successfully passed the integrated functional testing per the transition to operations parameters acceptance criteria. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 50,000 | 50,000 | 20,360 | – |
| FY 2022 | 32,000 | 32,000 | 30,082 | – |
| FY 2022 - IRA Supp. | 42,700 | 42,700 | – | – |
| FY 2023 | 32,000 | 32,000 | 22,300 | 32,700 |
| FY 2024 | 37,000 | 37,000 | 62,000 | 10,000 |
| Outyears | 100,550 | 100,550 | 116,808 | – |
| **Total, Design (TEC)** | **294,250** | **294,250** | **251,550** | **42,700** |
| Construction (TEC) | | | | |
| FY 2024 | 15,000 | 15,000 | 10,000 | – |
| Outyears | 1,835,750 | 1,835,750 | 1,840,750 | – |
| **Total, Construction (TEC)** | **1,850,750** | **1,850,750** | **1,850,750** | **–** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 50,000 | 50,000 | 20,360 | – |
| FY 2022 | 32,000 | 32,000 | 30,082 | – |
| FY 2022 - IRA Supp. | 42,700 | 42,700 | – | – |
| FY 2023 | 32,000 | 32,000 | 22,300 | 32,700 |
| FY 2024 | 52,000 | 52,000 | 72,000 | 10,000 |
| Outyears | 1,936,300 | 1,936,300 | 1,957,558 | – |
| **Total, TEC** | **2,145,000** | **2,145,000** | **2,102,300** | **42,700** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 45,805 | 45,805 | 29,232 | – |
| FY 2022 | – | – | 3,540 | – |
| FY 2023 | 5,000 | 5,000 | 14,500 | – |
| FY 2024 | – | – | 2,500 | – |
| Outyears | 46,195 | 46,195 | 47,228 | – |
| **Total, OPC** | **97,000** | **97,000** | **97,000** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 95,805 | 95,805 | 49,592 | – |
| FY 2022 | 32,000 | 32,000 | 33,622 | – |
| FY 2022 - IRA Supp. | 42,700 | 42,700 | – | – |
| FY 2023 | 37,000 | 37,000 | 36,800 | 32,700 |
| FY 2024 | 52,000 | 52,000 | 74,500 | 10,000 |
| Outyears | 1,982,495 | 1,982,495 | 2,004,786 | – |
| **Total, TPC** | **2,242,000** | **2,242,000** | **2,199,300** | **42,700** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 256,000 | 258,000 | **N/A** |
| Design - Contingency | 38,250 | 74,757 | **N/A** |
| **Total, Design (TEC)** | **294,250** | **332,757** | **N/A** |
| Construction | 1,477,000 | 1,290,000 | **N/A** |
| Construction - Contingency | 373,750 | 520,243 | **N/A** |
| **Total, Construction (TEC)** | **1,850,750** | **1,810,243** | **N/A** |
| **Total, TEC** | **2,145,000** | **2,143,000** | **N/A** |
| *Contingency, TEC* | *412,000* | *595,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | 29,546 | 22,875 | **N/A** |
| Conceptual Design | 26,454 | 24,750 | **N/A** |
| Start-up | 22,000 | 20,250 | **N/A** |
| OPC - Contingency | 19,000 | 31,125 | **N/A** |
| **Total, Except D&D (OPC)** | **97,000** | **99,000** | **N/A** |
| **Total, OPC** | **97,000** | **99,000** | **N/A** |
| *Contingency, OPC* | *19,000* | *31,125* | ***N/A*** |
| **Total, TPC** | **2,242,000** | **2,242,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***431,000*** | ***626,125*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 50,000 | 32,000 | — | 32,000 | — | 2,029,000 | 2,143,000 |
| | OPC | 45,805 | — | — | 5,000 | — | 48,195 | 99,000 |
| | TPC | 95,805 | 32,000 | — | 37,000 | — | 2,077,195 | 2,242,000 |
| FY 2024 | TEC | 50,000 | 32,000 | 42,700 | 32,000 | 52,000 | 1,936,300 | 2,145,000 |
| | OPC | 45,805 | — | — | 5,000 | — | 46,195 | 97,000 |
| | TPC | 95,805 | 32,000 | 42,700 | 37,000 | 52,000 | 1,982,495 | 2,242,000 |

*Note:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2Q FY 2037 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 2Q FY 2062 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations, Maintenance and Repair | 59,000 | 59,000 | 1,475,000 | 1,475,000 |

The numbers presented are the incremental operations and maintenance costs above the existing SNS facility without escalation. The estimate will be updated and additional details will be provided after CD-2, Approve Performance Baseline.

## 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at ORNL | ~375,000 |
| Area of D&D in this project at ORNL | — |
| Area at ORNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | ~375,000 |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | — |
| Total area eliminated | — |

## 8. Acquisition Approach

Based on the DOE determination at CD-1, ORNL is acquiring the STS project under the existing DOE Management and Operations (M&O) contract.

The M&O contractor prepared a Conceptual Design Report for the STS project and identified key design activities, requirements, and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up to date, operating, and are maintained as an ORNL-wide resource.

ORNL will design and procure the key technical subsystem components. Some technical system designs will require research and development activities. Preliminary cost estimates for most of these systems are based on SNS operating experience and vendor estimates, while some first-of-a-kind systems are based on expert judgement. Vendors and/or partner labs with the necessary capabilities will fabricate the technical equipment. ORNL will competitively bid and award all subcontracts based on best value to the government. The M&O contractor's performance will be evaluated through the annual laboratory performance appraisal process.

Lessons learned from other Office of Science projects and other similar facilities are being exploited fully in planning and executing the STS.

**18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL**
**Oak Ridge National Laboratory, ORNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**
The FY 2024 Request for the PPU project is $15,769,000 of Total Estimated Cost (TEC) funding. The Total Project Cost (TPC) is $271,567,000.

**Significant Changes**
PPU was initiated in FY 2018. The most recent DOE Order 413.3B Critical Decision (CD) is a combined CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, approved on October 6, 2020. CD-4, Approve Project Completion, is anticipated in 4Q FY 2028. This Construction Project Data Sheet (CPDS) is an update of the FY 2023 CPDS and does not include a new start for FY 2024.

In FY 2022, the project continued R&D, engineering, prototyping, preliminary and final design, testing, fabrication, procurement of baseline and spare hardware, and component integration and installation and civil construction, focused on completion of initial cryomodules, advancing the target knowledge base by running the first PPU target during Spallation Neutron Source (SNS) operations, and continued radiofrequency (RF) equipment procurement, and initial equipment installation in the klystron gallery. In FY 2023, funding supports remaining R&D, engineering, final design, testing, fabrication, procurement of baseline and spare hardware, component integration and installation, and civil construction site activities, with priority on continuing RF equipment installation in the klystron gallery, assembly, installation, and use of new cryomodules, magnet fabrication, and operation of the second PPU test target at increased power levels. The FY 2024 Request reflects the final year of funding for the project and will start construction of the tunnel stub that will facilitate connection to the future Second Target Station, install the final additional cryomodules and related radiofrequency systems, begin first target station upgrades to support high-flow target gas injection, upgrade the ring magnets, and operate the first PPU production target at increased power levels.

A Federal Project Director, certified to Level III, has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 1/7/09 | 8/1/17 | 4/4/18 | 10/6/20 | 2/9/22 | 10/6/20 | 4Q FY 2028 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2024 | 10/6/20 | 10/5/18 | 9/3/19 |

**CD-3A** – Approve Long-Lead Procurements for niobium material, cryomodule cavities, and related cryomodule procurements to reduce project technical and schedule risk.

**CD-3B** – Approve Long-Lead Procurements for klystron gallery buildout, RF procurements, and cryomodule hardware to reduce project technical and schedule risk.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 45,300 | 212,469 | 257,769 | 13,798 | 13,798 | 271,567 |
| FY 2024 | 47,800 | 209,969 | 257,769 | 13,798 | 13,798 | 271,567 |

**2. Project Scope and Justification**

**Scope**

The PPU project will design, build, install, and test the equipment necessary to double the accelerator power from 1.4 megawatts (MW) to 2.8 MW, upgrade the existing SNS target system to accommodate beam power up to 2 MW, and deliver a 2 MW qualified target. PPU includes the provision for a stub-out in the SNS transport line to the existing target to facilitate rapid connection to a new proton beamline. The project also includes utility infrastructure upgrades in the klystron gallery building needed for the new accelerator equipment.

**Justification**

The BES mission is to “support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security.” BES accomplishes its mission in part by operating large-scale user facilities consisting of a complementary set of intense x-ray sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

In the area of neutron science, numerous studies by the scientific community since the 1970s have established the scientific justification and need for a very high-intensity pulsed neutron source in the U.S. The SNS, which began its user program at ORNL in 2007, currently fulfills the need. The SNS was designed to be upgradeable so as to maintain its position of scientific leadership in the future, in accordance with the 1996 BESAC (Russell Panel) Report recommendation, and many technical margins were built into the SNS systems to facilitate a power upgrade into the 2 - 4 MW range with the ability to extract some of that power to a second target station.

An upgraded SNS will enable many advances in the opportunities described in the 2015 BESAC report “Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science.” Four workshops were held by ORNL to assess the neutron scattering needs in quantum condensed matter, soft matter, biology, and the frontiers in materials discovery. These four areas encompass and directly map to the transformative opportunities identified in the BES Grand Challenges update. Quantum materials map most directly to harnessing coherence in light and matter, while soft matter and biology align primarily with mastering hierarchical architectures and beyond-equilibrium matter, and frontiers in materials discovery explored many of the topics in beyond ideal materials and systems: understanding the critical roles of heterogeneity, interfaces, and disorder. As an example, while neutrons already play an important role in the areas of biology and soft matter, step change improvements in capability will be required to make full use of the unique properties of neutrons to meet challenges in mastering hierarchical architectures and beyond-equilibrium matter and understanding the critical roles of heterogeneity and interfaces. The uniform conclusion from all of the workshops was that, in the areas of science covered, neutrons play a unique and pivotal role in understanding structure and dynamics in materials required to develop future technologies.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Beam power on target | 1.7 MW at 1.25 giga-electron volts (GeV) | 2.0 MW at 1.3 GeV |
| Beam energy | 1.25 GeV | 1.3 GeV |
| Target reliability lifetime without target failure | 1,250 hours at 1.7 MW | 1,250 hours at 2.0 MW |
| Stored beam intensity in ring | ≥ $1.6 \times 10^{14}$ protons at 1.25 GeV | ≥ $2.24 \times 10^{14}$ protons at 1.3 GeV |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| Prior Years | 45,300 | 45,300 | 40,020 |
| FY 2022 | 2,500 | 2,500 | 7,668 |
| FY 2023 | – | – | 112 |
| **Total, Design (TEC)** | **47,800** | **47,800** | **47,800** |
| Construction (TEC) | | | |
| Prior Years | 162,700 | 162,700 | 79,625 |
| FY 2022 | 14,500 | 14,500 | 36,137 |
| FY 2023 | 17,000 | 17,000 | 36,050 |
| FY 2024 | 15,769 | 15,769 | 21,815 |
| Outyears | – | – | 36,342 |
| **Total, Construction (TEC)** | **209,969** | **209,969** | **209,969** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 208,000 | 208,000 | 119,645 |
| FY 2022 | 17,000 | 17,000 | 43,805 |
| FY 2023 | 17,000 | 17,000 | 36,162 |
| FY 2024 | 15,769 | 15,769 | 21,815 |
| Outyears | – | – | 36,342 |
| **Total, TEC** | **257,769** | **257,769** | **257,769** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 13,798 | 13,798 | 9,814 |
| FY 2023 | – | – | 501 |
| FY 2024 | – | – | 555 |
| Outyears | – | – | 2,928 |
| **Total, OPC** | **13,798** | **13,798** | **13,798** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 221,798 | 221,798 | 129,459 |
| FY 2022 | 17,000 | 17,000 | 43,805 |
| FY 2023 | 17,000 | 17,000 | 36,663 |
| FY 2024 | 15,769 | 15,769 | 22,370 |
| Outyears | – | – | 39,270 |
| **Total, TPC** | **271,567** | **271,567** | **271,567** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 47,800 | 36,960 | 32,000 |
| Design - Contingency | N/A | 8,340 | 8,000 |
| **Total, Design (TEC)** | **47,800** | **45,300** | **40,000** |
| Construction | 173,242 | 168,502 | 163,466 |
| Construction - Contingency | 36,727 | 43,967 | 54,303 |
| **Total, Construction (TEC)** | **209,969** | **212,469** | **217,769** |
| **Total, TEC** | **257,769** | **257,769** | **257,769** |
| *Contingency, TEC* | *36,727* | *52,307* | *62,303* |
| **Other Project Cost (OPC)** | | | |
| R&D | 2,500 | 2,408 | 2,408 |
| Conceptual Design | 7,220 | 7,250 | 7,250 |
| Other OPC Costs | 1,150 | 3,480 | 3,480 |
| OPC - Contingency | 2,928 | 660 | 660 |
| **Total, Except D&D (OPC)** | **13,798** | **13,798** | **13,798** |
| **Total, OPC** | **13,798** | **13,798** | **13,798** |
| *Contingency, OPC* | *2,928* | *660* | *660* |
| **Total, TPC** | **271,567** | **271,567** | **271,567** |
| ***Total, Contingency (TEC+OPC)*** | ***39,655*** | ***52,967*** | ***62,963*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 208,000 | 17,000 | 17,000 | — | 15,769 | 257,769 |
| | OPC | 13,798 | — | — | — | — | 13,798 |
| | TPC | 221,798 | 17,000 | 17,000 | — | 15,769 | 271,567 |
| FY 2024 | TEC | 208,000 | 17,000 | 17,000 | 15,769 | — | 257,769 |
| | OPC | 13,798 | — | — | — | — | 13,798 |
| | TPC | 221,798 | 17,000 | 17,000 | 15,769 | — | 271,567 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2028 |
| Expected Useful Life | 40 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2068 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations, Maintenance and Repair | 9,325 | 9,325 | 373,000 | 373,000 |

**7. D&D Information**

The new area being constructed in this project is not replacing existing facilities.

| | **Square Feet** |
|---|---|
| New area being constructed by this project at ORNL ........ | 3,000-4,000 |
| Area of D&D in this project at ORNL ........ | — |
| Area at ORNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | 3,000-4,000 |
| Area of D&D in this project at other sites ........ | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | — |
| Total area eliminated ........ | — |

**8. Acquisition Approach**

Based on the DOE determination at CD-1, the PPU project is being acquired by ORNL under the existing DOE Management and Operations (M&O) contract.

The M&O contractor has completed a Conceptual Design Report for the PPU project and identified key design activities, requirements, and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up-to-date, operating, and are maintained as an ORNL-wide resource.

ORNL is partnering with other laboratories for design and procurement of key technical subsystem components. Some technical system designs will require research and development activities. Cost estimates for these systems are based on operating experience of SNS and vendor quotes. ORNL, partner laboratory staff, and/or vendors will complete the design of the technical systems. Vendors and/or partner labs with the necessary capabilities will fabricate technical equipment. All subcontracts will be competitively bid and awarded based on best value to the government.

Lessons learned from other Office of Science projects and other similar facilities have been sought and are being applied as appropriate in planning and executing PPU. The M&O contractor's performance will be evaluated through the annual laboratory performance appraisal process.

**18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL**
**Lawrence Berkeley National Laboratory, LBNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the ALS-U project is $57,300,000 of Total Estimated Cost (TEC) funding. The project has a Total Project Cost (TPC) of $590,000,000.

**Significant Changes**

The ALS-U was initiated in FY 2018. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, approved on November 10, 2022. This Construction Project Data Sheet (CPDS) is an update of the FY 2023 CPDS and does not include a new start for FY 2024.

In FY 2022, the project continued planning, engineering, design, R&D, prototyping, and procurements of both long-lead components for the accumulator ring installation as well as start of major procurements for the storage ring systems and components. In addition, the ALS-U received $96,600,000 in FY 2022 Inflation Reduction Act (IRA) supplemental funding that will enable the project to significantly expedite procurements taking advantage of lower pricing and mitigate inflation uncertainties as well as schedule and technical risks, accelerating the funding profile resulting in reduced funding in the outyears. FY 2023 funding supports post CD-3 procurements and continuation of the Accumulator Ring installation. The FY 2024 Request reflects the final year of funding for the project and will continue to advance the remaining procurements for the Accumulator Ring and the Storage Ring, advance installation of the Accumulator Ring in the tunnel, start pre-staging and assembly of the Storage Ring rafts and components, as the vacuum systems, magnets and diagnostics instruments are received, in preparation for the year-long dark time during which the new Storage Ring will be installed in FY 2026.

With the departure of the previous Federal Project Director (FPD), a new FPD certified to Level II has been assigned to this project, with Level III certification in progress.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 9/27/16 | 4/30/18 | 9/21/18 | 4/2/21 | 11/10/22 | 11/10/22 | 4Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 4/2/21 | 12/19/19 |

**CD-3A** – Approve Long-Lead Procurements scope included the equipment required for the electron accumulator ring. CD-3A, approved in December of 2019, enables completion of the new Accumulator Ring installation, which is on the ALS-U critical path, ahead of the year-long down time (the period during which the new storage ring will be installed) thereby, accelerating project completion by more than a year.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 134,340 | 427,660 | 562,000 | 28,000 | 28,000 | 590,000 |
| FY 2024 | 134,340 | 427,660 | 562,000 | 28,000 | 28,000 | 590,000 |

### 2. Project Scope and Justification

**Scope**

The ALS-U project will upgrade the existing ALS facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat (MBA) lattice design to provide a soft x-ray source that is orders of magnitude brighter—a 10-1000 times increase in brightness over the current ALS—and to provide a significantly higher fraction of coherent light in the soft x-ray region (approximately 50-2,000 electronvolts [eV]) than is currently available at ALS. The project will replace the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a nine-bend achromat design. In addition, the project will add a low-emittance, full-energy accumulator ring to the existing tunnel inner shield wall to enable on- and off-axis, swap-out injection and extraction into and from the new storage ring using fast kicker magnets. The new source will require upgrading x-ray optics on existing beamlines with some beamlines being realigned or relocated. The project adds two new undulator beamlines that are optimized for the novel science made possible by the beam's new high coherent flux. The project intends to reuse the existing building, utilities, electron gun, linac, and booster synchrotron equipment currently at ALS. Prior to CD-2, the scope was increased to include radiation shielding and safety-mandated seismic structural upgrades to the ALS facility. With an aggressive accelerator design, ALS-U will provide the highest coherent flux of any existing or planned storage ring facility worldwide, up to a photon energy of about 3.5 keV. This range covers the entire soft x-ray regime.

**Justification**

At this time, our ability to observe and understand materials and material phenomena in real-time and as they emerge and evolve is limited. Soft x-rays (approximately 50 to 2,000 eV) are ideally suited for revealing the chemical, electronic, and magnetic properties of materials, as well as the chemical reactions that underpin these properties. This knowledge is crucial for the design and control of new advanced materials that address the challenges of new energy technologies.

Existing storage ring light sources lack a key attribute that would revolutionize x-ray science: stable, nearly continuous soft x-rays with high brightness and high coherent flux—that is, smooth, well organized soft x-ray wave fronts. Such a stable, high brightness, high coherent flux source would enable 3D imaging with nanometer resolution and the measurement of spontaneous nanoscale motion with nanosecond resolution—all with electronic structure sensitivity.

Currently, BES operates advanced ring-based light sources that produce soft x-rays. The NSLS-II, commissioned in 2015, is the brightest soft x-ray source in the U.S. The ALS, completed in 1993, is competitive with NSLS-II for x-rays below 200 eV but not above that. NSLS-II is somewhat lower in brightness than the new Swedish light source, MAX-IV, which began user operations in 2017 and represents the first use of a MBA lattice design in a light source facility. Neither NSLS-II nor ALS make use of the newer MBA lattice design. Switzerland's SLS-2 (an MBA-based design in the planning stage) will be a brighter soft x-ray light source than both NSLS-II and MAX-IV when it is built and brought into operation. These international light sources, and those that follow, will present a significant challenge to the U.S. light source community to provide competitive x-ray sources to domestic users. Neither NSLS-II nor ALS soft x-ray light sources possess sufficient brightness or coherent flux to provide the capability to meet the mission need in their current configurations.

BES is currently supporting two major light source upgrade projects, the APS-U and LCLS-II. These two projects will upgrade existing x-ray facilities in the U.S. and will provide significant increases in brightness and coherent flux. These upgrades will not address the specific research needs that demand stable, nearly continuous soft x-rays with high brightness and high coherence.

APS-U, which is under construction at ANL, will deploy the MBA lattice design optimized for its higher 6 GeV electron energy and to produce higher energy (hard) x-rays in the range of 10-100 keV. Because the ring will be optimized for high energy, the soft x-ray light it produces will not be sufficiently bright to meet the research needs described above.

LCLS-II, which is under construction at SLAC, is a high repetition rate (up to 1 MHz) free electron laser (FEL) designed to produce high brightness, coherent x-rays, but in extremely short bursts rather than as a nearly continuous beam. Storage rings offer higher stability than FELs. In addition, there is a need for a facility that can support a larger number of concurrent experiments than is possible with LCLS-II in its current configuration. This is critical for serving the large and expanding soft x-ray research community. LCLS-II will not meet this mission need.

The existing ALS is a 1.9 GeV storage ring operating at 500 milliamps (mA) of beam current. It is optimized to produce intense beams of soft x-rays, which offer spectroscopic contrast, nanometer-scale resolution, and broad temporal sensitivity. The ALS facility includes an accelerator complex and photon delivery system that can provide the foundations for an upgrade that will achieve world-leading soft x-ray coherent flux. The existing ALS provides a ready-made foundation, including conventional facilities, a $500,000,000 scientific infrastructure investment and a vibrant user community of over 2,500 users per year already attuned to the potential scientific opportunities an upgrade offers. The facility also includes extensive (up to 40) simultaneously operating beamlines and instrumentation, an experimental hall, computing resources, ancillary laboratories, offices, and related infrastructure that will be heavily utilized in an upgrade scenario. Furthermore, the upgrade leverages the ALS staff, who are experts in the scientific and technical aspects of the proposed upgrade.

In summary, the capabilities at our existing x-ray light source facilities are insufficient to develop the next generation of tools that combine high resolution spatial imaging together with precise energy resolving spectroscopic techniques in the soft x-ray range. To enable these cutting-edge experimental techniques, ALS-U is designed and being constructed to be a world-leading facility in soft x-ray science by delivering ultra-bright source of light in soft x-ray regime with high coherent x-ray flux required to resolve nanometer-scale features and interactions, and to allow the real-time observation and understanding of materials and phenomena as they emerge and evolve. Developing such a light source will ensure the U.S. has the tools to maintain its leadership in soft x-ray science and will significantly accelerate the advancement of the fundamental sciences that underlie a broad range of emerging and future energy applications.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The Threshold KPPs approved at CD-2 represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Storage Ring Energy | ≥ 1.9 GeV | 2.0 GeV |
| Beam Current | > 25 mA | 500 mA |
| Horizontal Emittance | < 150 pm-rad | < 85 pm-rad |
| Brightness @ 1 keV[a] | > $2 \times 10^{19}$ | ≥ $2 \times 10^{21}$ |
| New MBA Beamlines | 2 | ≥ 2 |

[a]Units = photons/sec/0.1% BW/mm2/mrad2

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 114,340 | 114,340 | 85,215 | – |
| FY 2022 | 20,000 | 20,000 | 28,947 | – |
| FY 2023 | – | – | 14,681 | – |
| FY 2024 | – | – | 2,132 | – |
| Outyears | – | – | 3,365 | – |
| **Total, Design (TEC)** | **134,340** | **134,340** | **134,340** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 83,660 | 83,660 | 18,675 | – |
| FY 2022 | 55,100 | 55,100 | 25,076 | – |
| FY 2022 - IRA Supp. | 96,600 | 96,600 | – | 4 |
| FY 2023 | 135,000 | 135,000 | 12,464 | 72,450 |
| FY 2024 | 57,300 | 57,300 | 108,121 | 24,146 |
| Outyears | – | – | 166,724 | – |
| **Total, Construction (TEC)** | **427,660** | **427,660** | **331,060** | **96,600** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 198,000 | 198,000 | 103,890 | – |
| FY 2022 | 75,100 | 75,100 | 54,023 | – |
| FY 2022 - IRA Supp. | 96,600 | 96,600 | – | 4 |
| FY 2023 | 135,000 | 135,000 | 27,145 | 72,450 |
| FY 2024 | 57,300 | 57,300 | 110,253 | 24,146 |
| Outyears | – | – | 170,089 | – |
| **Total, TEC** | **562,000** | **562,000** | **465,400** | **96,600** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 28,000 | 28,000 | 23,560 | – |
| Outyears | – | – | 4,440 | – |
| **Total, OPC** | **28,000** | **28,000** | **28,000** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 226,000 | 226,000 | 127,450 | – |
| FY 2022 | 75,100 | 75,100 | 54,023 | – |
| FY 2022 - IRA Supp. | 96,600 | 96,600 | – | 4 |
| FY 2023 | 135,000 | 135,000 | 27,145 | 72,450 |
| FY 2024 | 57,300 | 57,300 | 110,253 | 24,146 |
| Outyears | – | – | 174,529 | – |
| **Total, TPC** | **590,000** | **590,000** | **493,400** | **96,600** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 117,778 | 101,098 | 92,967 |
| Design - Contingency | 16,562 | 33,242 | 38,778 |
| **Total, Design (TEC)** | **134,340** | **134,340** | **131,745** |
| Construction | 159,338 | 150,093 | 142,165 |
| Equipment | 172,938 | 171,743 | 161,449 |
| Construction - Contingency | 95,384 | 105,824 | 126,641 |
| **Total, Construction (TEC)** | **427,660** | **427,660** | **430,255** |
| **Total, TEC** | **562,000** | **562,000** | **562,000** |
| *Contingency, TEC* | *111,946* | *139,066* | *165,419* |
| **Other Project Cost (OPC)** | | | |
| R&D | N/A | 4,971 | 8,241 |
| Conceptual Planning | 10,261 | 2,000 | 2,000 |
| Conceptual Design | 14,100 | 12,100 | 12,100 |
| Start-up | 1,000 | 2,000 | 2,000 |
| OPC - Contingency | 2,639 | 6,929 | 3,659 |
| **Total, Except D&D (OPC)** | **28,000** | **28,000** | **28,000** |
| **Total, OPC** | **28,000** | **28,000** | **28,000** |
| *Contingency, OPC* | *2,639* | *6,929* | *3,659* |
| **Total, TPC** | **590,000** | **590,000** | **590,000** |
| ***Total, Contingency (TEC+OPC)*** | ***114,585*** | ***145,995*** | ***169,078*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 198,000 | 75,100 | — | 135,000 | — | 153,900 | 562,000 |
| | OPC | 28,000 | — | — | — | — | — | 28,000 |
| | TPC | 226,000 | 75,100 | — | 135,000 | — | 153,900 | 590,000 |
| FY 2024 | TEC | 198,000 | 75,100 | 96,600 | 135,000 | 57,300 | — | 562,000 |
| | OPC | 28,000 | — | — | — | — | — | 28,000 |
| | TPC | 226,000 | 75,100 | 96,600 | 135,000 | 57,300 | — | 590,000 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2054 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| FY 2018 Estimates | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations, Maintenance and Repair | — | 71,500 | — | 2,597,500 |

### 7. D&D Information

At this stage of project planning and development, SC anticipates that there will be no new area being constructed in the construction project.

### 8. Acquisition Approach

Based on the DOE determination at CD-1, LBNL is acquiring the ALS-U project under the existing DOE Management and Operations (M&O) contract.

The ALS-U project identified key design activities, requirements, and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up-to-date, operating, and are maintained as a LBNL-wide resource.

LBNL has partnered with BNL for design and procurement of all required power supplies. Technical system designs required research and development and prototyping activities that are now near completion. Cost estimates for the remaining work have been updated by acquiring recent vendor quotes as part of CD-3 approval. All subcontracts are being competitively bid and awarded based on best value to the government. The M&O contractor's performance is being evaluated through the annual laboratory performance appraisal process.

Lessons learned from other SC projects and other similar facilities are being exploited fully in planning and executing ALS-U.

**18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC**
**SLAC National Accelerator Laboratory, SLAC**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**
The FY 2024 Request for the LCLS-II-HE project is $120,000,000 of Total Estimated Cost (TEC) funding. At CD-1, this project established a preliminary Total Project Cost (TPC) range of $290,000,000 to $480,000,000. This cost range encompassed the most feasible preliminary alternatives at that time. For the pending CD-2 reviews, the project's TPC estimate has exceeded the prior point estimate of $660,000,000 and now has reached $710,000,000, based on COVID-driven cost and schedule growth and additional risks.

**Significant Changes**
The LCLS-II-HE project was initiated in FY 2019. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3B, Approve Long-Lead Procurements, which was approved on January 27, 2023. The LCLS-II-HE project is continuing to assess the impact of COVID-19 on the project's cost, schedule, and project milestones. A combined CD-2/3 approval is projected for 2Q FY 2024; CD-4 is now projected for 2Q FY 2030. This Construction Project Data Sheet (CPDS) is an update of the FY 2023 CPDS and does not include a new start for FY 2024.

FY 2022 funding supported engineering, design, R&D, prototyping, continuing CD-3A long-lead procurements, and advancing the preliminary and final designs. LCLS-II-HE received $96,000,000 in FY 2022 Inflation Reduction Act (IRA) supplemental funding that will enable the project to expedite the design and long-lead procurements, by more than a year, significantly reducing the inflation uncertainties as well as schedule and technical risks. FY 2023 funding supports finalizing the design and the performance baseline, continues with engineering, R&D, injector gun prototyping, initiates CD-3B long-lead procurements of cryogenic system components and transfer lines for the new superconducting electron gun, and cryomodule production at the partner labs. The FY 2024 Request will support the production of cryomodules, continue with CD-3B procurements and begin the procurement of remaining scope including vendor supported completion of design efforts associated with the cryogenic distribution system, controls systems, and the low emittance injector beamline, and continue the R&D of the superconducting radiofrequency electron gun and initiating construction/installation contracts.

A Federal Project Director, certified to Level IV, has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 12/15/16 | 3/23/18 | 9/21/18 | 2Q FY 2024 | 2Q FY 2026 | 2Q FY 2024 | 2Q FY 2030 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2024 | 2Q FY 2024 | 5/12/20 | 1/27/23 |

**CD-3A** – Approve Long-Lead Procurements for cryomodule associated parts and equipment.
**CD-3B** – Approve Long-Lead Procurements for SRF Injector cryogenic systems, Cryo Distribution Box, Optics for Experimental Systems, Controls Systems.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 39,000 | 589,000 | 628,000 | 32,000 | 32,000 | 660,000 |
| FY 2024 | 80,400 | 597,600 | 678,000 | 32,000 | 32,000 | 710,000 |

**2. Project Scope and Justification**

**Scope**
The LCLS-II-HE project's scope includes increasing the superconducting linac energy from 4 giga-electronvolts (GeV) to 8 GeV by installing additional cryomodules in the first kilometer of the existing linac tunnel. The electron beam, generated by a superconducting electron source, will be transported to the existing undulator hall to extend the x-ray energy to 12 keV and beyond. The project will also modify or upgrade existing infrastructure (process cooling water, power, electrical) in the last sector of the Linac tunnel and x-ray transport, optics, and diagnostics system, and provide new or upgraded instrumentation to augment existing and planned capabilities. Additional scope is being considered to address several risks associated with the linac performance, operation reliability and scientific mission capability.

**Justification**
The leadership position of LCLS-II will be challenged by the European x-ray free electron laser (XFEL) at DESY in Hamburg, Germany, which began operations in 2017. The European XFEL has a higher electron energy, which allows production of shorter (i.e., harder) x-ray wavelength pulses compared to LCLS-II. More recent plans emerging from DESY have revealed how the European XFEL could be extended from a pulsed operation mode to continuous operation, which would create a profound capability gap compared to LCLS-II. The continuous operation improves the stability of the electron beam and provides uniformly spaced pulses of x-rays or, if desired, the ability to customize the sequence of x-ray pulses provided to experiments to optimize the measurements being made.

In the face of this challenge to U.S. scientific leadership, extending the energy reach of x-rays beyond the upper limit of LCLS-II (5 keV) is a high priority. 12 keV x-rays correspond to an x-ray wavelength of approximately 1 Ångstrom, which is particularly important for high resolution structural determination experiments since this is the characteristic distance between bound atoms in matter. Expanding the photon energy range beyond 5 keV will allow U.S. researchers to probe earth-abundant elements that will be needed for large-scale deployment of photo-catalysts for electricity and fuel production; it allows the study of strong spin-orbit coupling that underpins many aspects of quantum materials; and it reaches the biologically important selenium k-edge, used for protein crystallography.

There is also a limited ability to observe and understand the structural dynamics of complex matter at the atomic scale with hard x-rays, at ultrafast time scales, and in operational environments. Overcoming this capability gap is crucial for the design, control and understanding of new advanced materials necessary to develop new energy technologies. To achieve this objective, the Department needs a hard x-ray source capable of producing high energy ultrafast bursts, with full spatial and temporal coherence, at high repetition rates. Possession of a hard x-ray source with a photon energy range from 5- 12 keV and beyond would enable spectroscopic analysis of additional key elements in the periodic table, deeper penetration into materials, and enhanced resolution. This capability cannot be provided by any existing or planned light source.

The LCLS-II project at SLAC, which is currently under construction and will begin operations in 2022–2024 is the first step to address this capability gap. LCLS-II will be the premier XFEL facility in the world at energies ranging from 200 eV up to approximately 5 keV. The cryomodule technology that underpins LCLS-II is a major advance from prior designs that will allow continuous operation up to 1 megahertz (MHz).

When completed, LCLS-II will be powered by SLAC's 4 GeV superconducting electron linear accelerator (linac). Over the past years, the cryomodule design for LCLS-II has performed beyond expectations, providing the technical basis to double the electron beam energy. It is therefore conceivable to add additional acceleration capacity at SLAC to double the electron beam energy from 4 GeV to 8 GeV. Calculations indicate that an 8 GeV linac will deliver a hard x-ray photon beam with peak energy of 12.8 keV, which will meet the mission need.

The LCLS-II-HE project will upgrade the LCLS-II to fully address the capability gaps and maintain U.S. leadership in XFEL science. The upgrade will provide world leading experimental capabilities for the U.S. research community by extending the x-ray energy of LCLS-II from 5 keV to 12 keV and beyond. The flexibility and detailed pulse structure associated with the proposed LCLS-II-HE facility will not be matched by other facilities under development worldwide.

Based on the factors described above, the most effective and timely approach for DOE to meet the Mission Need and realize the full potential of the facility is by upgrading the LCLS-II, currently under construction at SLAC, by increasing the energy of the superconducting accelerator and upgrading the existing infrastructure and instrumentation.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Superconducting linac electron beam energy | ≥ 7 GeV | ≥ 8 GeV |
| Electron bunch repetition rate | 93 kHz | 929 kHz |
| Superconducting linac charge per bunch | 0.02 nC | 0.1 nC |
| Photon beam energy range | 200 to ≥ 8,000 eV | 200 to ≥ 12,000 eV |
| High repetition rate capable, hard X-ray end stations | ≥ 3 | ≥ 5 |
| FEL photon quantity ($10^{-3}$ BW) | $5x10^8$ (50x spontaneous @ 8 keV) | > $10^{11}$ @ 8 keV (200 μJ) or<br>> $10^{10}$ @ 12.8 keV (20 μJ) |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 28,000 | 28,000 | 12,568 | – |
| FY 2022 | 11,000 | 11,000 | 17,700 | – |
| FY 2023 | 17,000 | 17,000 | 24,700 | – |
| FY 2024 | 15,000 | 15,000 | 14,000 | – |
| Outyears | 9,400 | 9,400 | 11,432 | – |
| **Total, Design (TEC)** | **80,400** | **80,400** | **80,400** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 100,657 | 100,657 | 65,387 | – |
| FY 2022 | 39,000 | 39,000 | 34,085 | – |
| FY 2022 - IRA Supp. | 90,000 | 90,000 | – | – |
| FY 2023 | 73,000 | 73,000 | 15,000 | 70,000 |
| FY 2024 | 105,000 | 105,000 | 80,000 | 20,000 |
| Outyears | 189,943 | 189,943 | 313,128 | – |
| **Total, Construction (TEC)** | **597,600** | **597,600** | **507,600** | **90,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 128,657 | 128,657 | 77,955 | – |
| FY 2022 | 50,000 | 50,000 | 51,785 | – |
| FY 2022 - IRA Supp. | 90,000 | 90,000 | – | – |
| FY 2023 | 90,000 | 90,000 | 39,700 | 70,000 |
| FY 2024 | 120,000 | 120,000 | 94,000 | 20,000 |
| Outyears | 199,343 | 199,343 | 324,560 | – |
| **Total, TEC** | **678,000** | **678,000** | **588,000** | **90,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 14,000 | 14,000 | 8,820 | – |
| FY 2022 | 3,000 | 3,000 | 3,126 | – |
| FY 2022 - IRA Supp. | 6,000 | 6,000 | – | – |
| FY 2023 | 4,000 | 4,000 | – | 3,800 |
| FY 2024 | – | – | – | 2,200 |
| Outyears | 5,000 | 5,000 | 14,054 | – |
| **Total, OPC** | **32,000** | **32,000** | **26,000** | **6,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 142,657 | 142,657 | 86,775 | – |
| FY 2022 | 53,000 | 53,000 | 54,911 | – |
| FY 2022 - IRA Supp. | 96,000 | 96,000 | – | – |
| FY 2023 | 94,000 | 94,000 | 39,700 | 73,800 |
| FY 2024 | 120,000 | 120,000 | 94,000 | 22,200 |
| Outyears | 204,343 | 204,343 | 338,614 | – |
| **Total, TPC** | **710,000** | **710,000** | **614,000** | **96,000** |

*Note:*

– *In FY 2021, the Office of Science reprogrammed $19,343,211.24 of prior year funds from this project to support the LCLS-II project at SLAC. The Prior Year Budget Authority in the table above reflects this reprogramming. Also in FY 2021, a total of $10,000,000 in current year and prior year funding was reprogrammed to the LCLS-II-HE project and additional funds are included in the outyears to maintain the project profile.*

4. **Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 73,400 | 35,000 | **N/A** |
| Design - Contingency | 7,000 | 4,000 | **N/A** |
| **Total, Design (TEC)** | **80,400** | **39,000** | **N/A** |
| Construction | 240,400 | 33,000 | **N/A** |
| Site Preparation | 2,000 | 9,000 | **N/A** |
| Equipment | 220,000 | 468,000 | **N/A** |
| Construction - Contingency | 135,200 | 79,000 | **N/A** |
| **Total, Construction (TEC)** | **597,600** | **589,000** | **N/A** |
| **Total, TEC** | **678,000** | **628,000** | **N/A** |
| *Contingency, TEC* | *142,200* | *83,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | 9,000 | 15,000 | **N/A** |
| Conceptual Planning | 1,000 | 2,000 | **N/A** |
| Conceptual Design | 8,000 | 2,000 | **N/A** |
| Start-up | 6,700 | 8,000 | **N/A** |
| OPC - Contingency | 7,300 | 5,000 | **N/A** |
| **Total, Except D&D (OPC)** | **32,000** | **32,000** | **N/A** |
| **Total, OPC** | **32,000** | **32,000** | **N/A** |
| *Contingency, OPC* | *7,300* | *5,000* | ***N/A*** |
| **Total, TPC** | **710,000** | **660,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***149,500*** | ***88,000*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 128,657 | 50,000 | — | 90,000 | — | 359,343 | 628,000 |
| | OPC | 14,000 | 3,000 | — | 4,000 | — | 11,000 | 32,000 |
| | TPC | 142,657 | 53,000 | — | 94,000 | — | 370,343 | 660,000 |
| FY 2024 | TEC | 128,657 | 50,000 | 90,000 | 90,000 | 120,000 | 199,343 | 678,000 |
| | OPC | 14,000 | 3,000 | 6,000 | 4,000 | — | 5,000 | 32,000 |
| | TPC | 142,657 | 53,000 | 96,000 | 94,000 | 120,000 | 204,343 | 710,000 |

*Note:*

– *In FY 2021, the Office of Science reprogrammed $19,343,211.24 of prior year funds from this project to support the LCLS-II project at SLAC. The Prior Year Budget Authority in the table above reflects this reprogramming. Also in FY 2021, a total of $10,000,000 in current year and prior year funding was reprogrammed to the LCLS-II-HE project and additional funds are included in the outyears to maintain the project profile.*

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2Q FY 2030 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 2Q FY 2055 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations, Maintenance and Repair | 21,500 | 21,500 | 537,500 | 537,500 |

The numbers presented are the incremental operations and maintenance costs above the LCLS-II facility without escalation. The estimate will be updated and additional details will be provided after CD-2, Approve Project Performance Baseline.

### 7. D&D Information

At this stage of project planning and development, SC anticipates that there will be no new area being constructed in the construction project.

### 8. Acquisition Approach

Based on the DOE determination at CD-1, SLAC is acquiring the LCLS-II-HE project under the existing DOE Management and Operations (M&O) contract.

SLAC has completed a Conceptual Design Report for the LCLS-II-HE project and is in the preliminary design phase, identifying requirements and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully operating and are maintained as a SLAC-wide resource.

SLAC is partnering with other laboratories for design and procurement of key technical subsystem components. Technical system designs require research and development activities. Preliminary cost estimates for these systems are based on actual costs from LCLS-II and other similar facilities, to the extent practicable. The M&O contractor is fully exploiting recent cost data in planning and budgeting for the project. SLAC or partner laboratory staff will complete the design of the technical systems. SLAC or subcontracted vendors with the necessary capabilities will fabricate the technical equipment. All subcontracts will be competitively bid and awarded based on best value to the government. The M&O contractor's performance will be evaluated through the annual laboratory performance appraisal process.

Lessons learned from the LCLS-II project and other similar facilities are exploited fully in planning and executing LCLS-II-HE.

## 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 the environment from local to global scales, including a focus on climate change experimental research and predictive 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]), experimental, and modeling 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 feedbacks 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 local 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 the scientific community and engagement with the federally chartered BER Advisory Committee.

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 science. 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 genomics-based tools of plant and microbial systems biology to pursue the early-stage research that will lead to the development of transformative bio-based products and clean energy technologies to underpin a 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. BER research contributes to reducing the greatest uncertainties in model predictions, e.g., involving clouds and aerosols, and is incorporating new observations and information from initiatives such as the Urban Integrated Field Laboratories (IFLs). DOE research has made considerable advances in increasing the reliability and predictive capabilities of these models using AI/ML, access to DOE's fastest computers, and systematic comparisons with observational data to improve confidence in model predictions.

BER-supported research continues to produce the software and algorithms that enable the productive application of models that span genomics, systems biology, environmental and climate sciences. 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 as a basis for addressing of future bioenergy and environmental challenges. BER's 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. Cloud-aerosol data provided by the Atmospheric Radiation Measurement (ARM) are necessary in developing, testing, and validating increasingly sophisticated system models.

**Highlights of the FY 2024 Request**

The FY 2024 Request for BER is $931.7 million. BER will enhance its research on climate science by expansion of Urban Integrated Field Laboratories (Urban IFLs) and the network of climate centers, affiliated with Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs); continue investments in AI approaches for improving Earth and environmental system predictability; and expanded Earthshots that focus on science at the nexus of clean energy production and climate change. BER will enhance its biosystems research by: continuing the Energy Earthshot Research Centers (EERCs) and expanding Earthshot Research activities to bring together multi-disciplinary teams to more rapidly remove barriers hampering the translation of basic science into innovative technological solutions; speeding development of new innovations in biotechnology under the Accelerate and the Advanced Manufacturing initiatives to include development of sensor technologies to enable the translation of laboratory-scale results, such as in fabricated ecosystems, to broader-scale field ecosystems. BER will continue the Established Program to Stimulate Competitive Research (EPSCoR) and the Reaching a New Energy Sciences Workforce (RENEW) and Funding for Accelerated, Inclusive Research (FAIR) initiatives, BER will build stronger programs with underrepresented institutions and regions, including investing in a more diverse and inclusive workforce.

<u>Research</u>

- Within Genomic Sciences, the BRCs will provide new research both individually and through shared research themes, underpinning the production of clean energy and chemicals from sustainable biomass resources. The EERCs will continue efforts with a specific focus on translational research that lowers risks and speeds adoption of basic research results to industry for a broader bio-based economy. The Biopreparedness Research Virtual Environment (BRaVE) will add additional functionality to its collaborative cyber infrastructure allowing distributed networks of scientists to work on multidisciplinary research priorities and/or national emergency challenges and include low dose radiation research. Efforts to accelerate emerging technologies and advanced manufacturing techniques will be enhanced. 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 multi-modal and QIS-enabled techniques to understand biological processes.
- BER will continue FAIR to provide focused investment on enhancing biological and environmental research and capacity building involving clean energy and climate research at HBCUs and MSIs.
- Earth and Environmental Systems Sciences research will focus on improving the representation of physical, biogeochemical, and human processes to enhance the predictability of climate, Earth, and environmental systems. 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. Modeling research, in particular the DOE Exascale Energy Earth System Model (E3SM), will expand and continue activities to utilize advanced software and AI/ML for running on future DOE computer architectures, exascale research activities will transition from the Exascale Computing Project (ECP) to a broader focus on software for advanced computing and sustainability across current and future computing platforms. The Data Management effort will enhance data archiving and management capabilities, including use of AI research for watershed systems.
- RENEW expands targeted efforts including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research. RENEW encompasses all BER activities.

<u>Facility Operations</u>

- The JGI will continue providing genome sequence data and analysis techniques for a wide variety of plants and microbial communities. ARM will continue new observations to advance Earth System models. The site in Alabama will be fully operational. EMSL will provide analytical and imaging capabilities in support of BER's biological, environmental, and climate science priorities; and will embark on development of a capability for microbial molecular phenotyping.

<u>Projects</u>

- The BER FY 2024 Request includes $10.0 million to initiate the Microbial Molecular Phenotyping Capability (M2PC) project at the Pacific Northwest National Laboratory.
- General Plant Projects (GPP) funding provides for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems to maintain the productivity and usefulness of DOE-owned facilities and to meet requirements for safe and reliable operation.

## Biological and Environmental Research
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Biological and Environmental Research** | | | | |
| Genomic Science | 275,500 | 328,685 | 338,750 | +10,065 |
| Biomolecular Characterization and Imaging Science | 45,000 | 45,000 | 45,750 | +750 |
| Biological Systems Facilities & Infrastructure | 84,500 | 90,000 | 92,000 | +2,000 |
| **Total, Biological Systems Science** | **405,000** | **463,685** | **476,500** | **+12,815** |
| Atmospheric System Research | 36,000 | 36,000 | 40,000 | +4,000 |
| Environmental System Sciences | 114,000 | 120,800 | 137,000 | +16,200 |
| Earth and Environmental Systems Modeling | 105,000 | 115,500 | 120,500 | +5,000 |
| Earth and Environmental Systems Sciences Facilities and Infrastructure | 155,000 | 172,700 | 147,700 | -25,000 |
| **Total, Earth and Environmental Systems Sciences** | **410,000** | **445,000** | **445,200** | **+200** |
| **Subtotal, Biological and Environmental Research** | **815,000** | **908,685** | **921,700** | **+13,015** |
| **Construction** | | | | |
| 24-SC-31 Microbial Molecular Phenotyping Capability (M2PC), PNNL | – | – | 10,000 | +10,000 |
| **Subtotal, Construction** | **–** | **–** | **10,000** | **+10,000** |
| **Total, Biological and Environmental Research** | **815,000** | **908,685** | **931,700** | **+23,015** |

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $25,184,000 and STTR $3,545,000
- FY 2023 Enacted: SBIR $21,327,000 and STTR $2,999,000
- FY 2024 Request: SBIR $22,278,000 and STTR $3,137,000

## Biological and Environmental Research
## Explanation of Major Changes

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Biological Systems Science** | **+$12,815** |
| Activities will continue early-stage core research to understand the complex mechanisms controlling the interplay of microbes and plants within broader organized biological systems. The enhanced BRCs will provide new research underpinning the production of clean energy and chemicals from sustainable biomass resources through individual efforts and inter-BRC shared-theme research. BER will continue the EERCs and enhance the Earthshot Research 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. Efforts in secure biosystems design research will decrease as projects are completed. FAIR is enhanced, including clean energy and climate research at HBCUs and MSIs. New emerging technologies will develop capabilities that scale from laboratory fabricated ecosystems to field ecosystems using integrated automated sensor networks, complementing new efforts to understand molecular processes governing soil-microbe-plant interactions with the environment that control carbon turnover. Biotechnology innovations will continue to be pursued to assist development of advanced manufacturing techniques. BRaVE is expanded to include low dose radiation research. Development of new bioimaging, measurement and characterization approaches will include expanded integrative imaging and analysis platforms, including using QIS materials. JGI will initiate plant transformation research to accelerate the understanding and design new beneficial functions into plants. EPSCoR continues to support research activities related to BER. | |
| **Earth and Environmental Systems Sciences** | **+$200** |
| Activities will continue to support the development of high-resolution Earth system predictive modeling, analysis, and intercomparison capabilities focused on DOE mission needs for evidence-based energy and infrastructure resilience and security. The Integrative Artificial Intelligence for Earth System Predictability (AI4ESP) effort will motivate the radical acceleration of high-resolution predictive capabilities across the DOE climate model-data-experiment enterprise, taking advantage of AI/ML techniques for climate science. The ECP activities transition to core research efforts as the ECP concludes. Environmental System Science will increase support of the Urban IFLs providing new place-based data for informing climate and Earth system models. The support for the Energy Earthshot Research activities will be enhanced. An enhanced RENEW will increase research and capacity building at under-represented institutions and HBCUs and MSIs across all BER activities, including through a RENEW graduate fellowship. The network of climate resilience centers is expanded. 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. ARM will initiate full operations with community engagement at its Alabama observatory, and a cloud chamber research effort will be initiated to complement ARM’s field observations of cloud-aerosol interactions. 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 environmental field data. | |
| **Construction** | **+$10,000** |
| Design activities will be initiated for the Microbial Molecular Phenotyping Capability (M2PC) at the Pacific Northwest National Laboratory. | |
| **Total, Biological and Environmental Research** | **+$23,015** |

**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) and other committees of the Office of Science and Technology Policy (OSTP). This includes all biological, Earth and environmental systems investments in theoretical, experimental, and predictive modeling research, 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 and enables climate risk analysis with more accurate capabilities to design, finance, and deploy clean energy solutions. 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. Coordination with OSTP and other federal agencies on short-term weather, seasonal, and short-term climate forecasts is conducted under the Interagency Council for Advancing Meteorological Services (ICAMS), chartered by OSTP in 2020 as part of the U.S. Weather Act of 2017. Furthermore, 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 is a member of the advisory committee for DoD's BioMADE project researching synthetic biology applications.

All climate systems research activities within BER are coordinated through the interagency U.S. Global Change Research Program (USGCRP) and other NSTC subcommittees. Through this engagement, the DOE E3SM has evolved to become the world's highest resolution Earth system model able to run on exascale computers, facilitating the scientific community in developing and testing system-level scientific concepts on the smallest scales. Other agencies, e.g., NOAA, NASA, the Navy, and NSF, are following developments in E3SM via both USGCRP and ICAMS. 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.*
Several improvements towards a better understanding of the capture, cycling and conversion of carbon in the environment and within industrial processes were made across the biological systems science programs. Molecular scale understanding of enzymatic $CO_2$ capture and fixation, using instruments at the SLAC National Accelerator Laboratory are leading to new ways to design and optimize biomolecules for $CO_2$ capture. Research on carbon cycling processes at the Universities of California-Berkeley and Wisconsin-Madison, for example, led to the discovery of the importance of fungal organisms in the restoration of soil microbial ecology after a fire. Another research project, funded by BER, DOE Bioenergy Technologies Office, and Lanzatech, engineered a bacterial species capable of utilizing gaseous $CO_2$ in an industrial waste stream and convert it to acetone and isopropanol, valuable chemical products. The work highlights an efficient approach to engineering organisms for industrial-scale purposes.

*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 from the Bioenergy Research Centers include:
- Improved pathway engineering in microbes to convert cellulosic sugars to biofuels. The Joint BioEnergy Institute optimized an alternate metabolic pathway in E. coli to increase production efficiency of isoprenols as biofuel substitutes.

- Improved ethanol production through modification of transcription factor expression in Poplar (trees). Researchers at the Center for Bioenergy Innovation, aided by previous studies of the Poplar genome, identified and altered the expression of a key transcription factor impacting the lignin composition within the cell wall.
- Key data informing the agronomics of perennial bioenergy crops for bioenergy and bioproduct production. Researchers at the Center for Advanced Bioenergy and Bioproducts Innovation used a meta-regression model to analyze 4,214 yield observations and found that yields peaked between 6 and 7 years, increased nitrogen resulted in small yield increases but at declining rates with crop age, and that growth of these crops on low-productivity lands can equal that on high-productivity lands.
- Recovery of valuable components from lignin. The Great Lakes Bioenergy Research Center is exploring an oxidative alkaline depolymerization process to break down lignin and separate it into components for later conversion to products of higher value.

*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.*

The DOE E3SM developed and incorporated a new cryosphere configuration that better simulates Antarctic iceshelf melting commensurate with present day observations. This is an important improvement that reduces uncertainties in the projections of the Antarctic response to climate change and Antarctica's contribution to global sea-level rise. Future changes in hydrology caused by shifts in the jet stream were also analyzed for the midwestern U.S. Findings indicate that the North American westerly jet stream is projected to shift northward under global warming scenarios, causing more intense late-spring rainfalls, and a higher chance of late-summer droughts. In another project led by Lawrence Berkeley National Laboratory, ground-breaking analyses focused on the interdependence of forest change, surface climate, and evapotranspiration, and the processes governing observed changes between 1980 and 2016. Observations show a slowing of the hydrologic cycle associated with Amazonian deforestation, including a reduction in evapotranspiration causing a drying of the atmosphere. Finally, a new focus on urban climate science and the representation of local scale, physical, biogeochemical, ecological, and human processes for diverse urban communities has been incorporated into Earth system models. Results show that novel building designs can measurably mitigate the impacts of urban climate change.

*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 JGI developed two new streamlined approaches for studying transcription factors involved in gene expression. The two new complementary methods, called Biotin DAP-seq and MultiDAP allow for quick protein purification, reducing workflows from months to days, and comparative analyses across genomes of multiple species in a single experiment leading to new comprehensive insights into gene regulatory processes within cells.
- The EMSL studied chemical processes inside roots from three tropical rainforest plants using EMSL's metabolomic and imaging technologies to better predict how different plants react to rising temperature and drought. Each of the plant roots responded differently (e.g., building thicker roots or generating a biochemical defense), indicating that multiple strategies are needed to achieve drought resilience.
- The ARM used large eddy simulations at the Southern Great Plains (SGP) observatory in Oklahoma to make major improvements to convective parameterizations that are necessary to improve predictability of climate and Earth system models. A major advancement from this research is a more sophisticated three-dimensional mathematical characterization of updrafts in storms, leading to improved rainfall predictions.

**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, 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 BRCs, as well as the DOE JGI, a DOE scientific user facility.

<u>Genomic Science</u>

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 build on existing genomics-based research and develops broad-based, 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 wide variety of clean energy and biotechnology applications underpinning a more decarbonized bioeconomy. The climate related-science supports new approaches and systems for low carbon biomanufacturing, especially with respect to genome-enabled engineering and design of biomaterials, along with developing new technologies and integrated automated sensors that scale from laboratory-fabricated ecosystems to field ecosystems. These enhanced efforts support the development of emerging technologies under the Accelerate and the Advanced Manufacturing initiatives. BER's contribution towards understanding and anticipating the convergence of advanced genome science with other fields is critical for foresight into 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 and climate research at minority serving institutions, including attention to underserved and environmental justice communities. FAIR will expand and encompass all BER activities.

The EERC program, launched in FY 2023, will enhance multi-investigator, multi-disciplinary teams led by the DOE laboratories to perform energy-relevant research with a scope and complexity beyond what is possible in standard or small-group awards. The EERCs will continue to address key research challenges hampering the translation of basic research results to applied research and development activities. 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. The EERCs are complemented by expanded Energy Earthshot research conducted within academia and focused on cross-cutting basic research themes and interfaces among the Centers. BER funding will ensure that directed biological fundamental research and capabilities at SC user facilities address the most challenging barriers hampering the translation of basic research innovations to applied research and development activities.

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. The BRaVE effort will expand to include low dose radiation research.

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 HBCUs and MSIs, and within rural communities where new crop-based clean energy and bioproduct production could spark new industries and bioeconomic development.

This activity provides support for the DOE EPSCoR that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single PI and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards.

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. In FY 2024, the JGI will explore new plant transformation capabilities to accelerate the ability to modify and/or design new beneficial functions into plants. The lack of effective techniques for plant transformation across species severely limits plant science and this new activity addresses this crucial need within the bioenergy/bioproduct research community.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Biological Systems Science** | **$463,685** | **$476,500** | **+$12,815** |
| Genomic Science | $328,685 | $338,750 | +$10,065 |
| Foundational Genomics research supports new research on microorganisms with advantageous bioenergy and bioproduct traits. Biosystems design research accelerates the ability to design plants and microorganisms with specific beneficial low carbon clean energy, bioproduct and biomaterials production traits. New efforts provide emerging technologies to develop integrated automated sensors that scale from laboratory fabricated ecosystems to field ecosystems as part of the Accelerate initiative. | | 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 and Advanced Manufacturing initiatives. | Funding will support new research on microorganisms and plants with clean energy, carbon sequestration 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. To support the Accelerate and Advanced Manufacturing initiatives, new emerging technologies will integrate *in situ* sensors, imaging, 'omics analysis, and autonomous controls and continuous data acquisition and analysis. Completed efforts in Secure Biosystems Design will ramp down to fully fund efforts within the BRCs. |
| BER launches Energy Earthshot Research Centers to address key biological research challenges at the interface between currently supported basic research and applied research and development activities. | | BER will expand the Energy Earthshot Research and continue Centers initiated in FY 2023 to include additional key biological research challenges at the interface between currently supported basic research and applied research and development activities to help speed translation of basic discoveries to industry. | Funding will support additional research for the DOE Earthshot activities. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Environmental Genomics continues plant functional genomics research to understand genotype to phenotype translations leading to beneficial bioenergy or bioproduct traits in potential bioenergy crops. | 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. | No change |
| Environmental microbiome science continues efforts to understand the functions of environmentally relevant microbial communities in a variety of ecosystems. | Environmental microbiome science continues efforts to understand the functions of environmentally relevant microbial communities in a variety of ecosystems. | No change |
| BRaVE expands 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, including low dose radiation research. | BRaVE will continue to add functionality to its expanding computational platform and experimental workflows. BRaVE continues to build a distributed network of data and experimental capabilities that can be accessed by multidisciplinary teams of scientists working together on urgent multiprogram priorities and/or emergency situations. BRaVE will expand current efforts addressing environmental biothreat scenarios to include low dose radiation research. | The BRaVE efforts will expand to include low dose radiation research. |
| The FAIR initiative strengthens clean energy genomic research at HBCUs and MSIs, building partnerships with the DOE national labs. | The FAIR initiative will strengthen clean energy and climate research at HBCUs and MSIs, building partnerships with the DOE national labs. | FAIR will expand and encompass all BER activities, supporting opportunities at HBCUs and MSIs. |
| Computational Bioscience supports research efforts within Genomic Science by providing bioinformatics, simulation and modeling capabilities through the KBase platform and within the NMDC. Both platforms continue integrative activities among each other within the Advanced Computing Initiative and with the JGI. | 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. | Increased funding will support research and linkages among KBase, NMDC and JGI. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| The four BRCs continue with 5-year renewal to support multidisciplinary clean energy research underpinning a broader bio-based economy. The BRCs 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. | The BRCs will 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 MSIs) and within rural communities where new crop-based clean energy and bioproduct production could spark new industries and bioeconomy development. | The four BRCs will expand their efforts on theme-based collaborative activities to accelerate genome engineering for plants and microbes advance 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 MSIs) and rural communities where this research could lead to new bioeconomy opportunities. |
| Funding supports early-stage R&D, including research that underpins DOE energy technology programs, the SC Energy Earthshots initiative, and innovations for climate science. Following the previous year's focus on State-National Laboratory Partnership awards, FY 2023 emphasizes Implementation Awards to larger multiple investigator teams that develop research capabilities in EPSCoR jurisdictions. Investment continues in early career research faculty from EPSCoR-designated jurisdictions and in co-investment with other programs for awards to eligible institutions. | Funding supports EPSCoR State-National Laboratory Partnership awards and early career awards. | Continued support for research in EPSCoR jurisdictions. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Biomolecular Characterization and Imaging Science $45,000 | $45,750 | +$750 |
| New multimodal bioimaging research supports 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. | 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. | Funding will support additional multimodal bioimaging research activities. |
| Biological Systems Facilities & Infrastructure $90,000 | $92,000 | +$2,000 |
| JGI provides users with high quality genome sequences and new analysis techniques for complex plant and microbiome samples. Integrative activities with KBase and the NMDC provides 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 continues at a reduced pace to support the integrative activities with KBase and the NMDC. | 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. A new plant transformation capability will be explored to provide needed techniques to transform a wider variety of plants for genome interrogation and design. | 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. Funding will also support a new plant transformation activity to provide the genomic tools to more broadly understand, modify, and design plants with beneficial traits for bioenergy and bioproducts. |

*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, excluding facility operations.*

## 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 climate system 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 goal of new science is to develop and enhance a predictive, systems-level understanding of the fundamental processes that addresses environmental and energy-related challenges associated with extreme phenomena. Investments 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 to push the envelope on predictive capacity. 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 ARM and EMSL facilities. 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 tool development and archival capabilities that combine observed and model-generated data that are produced by field experiments and modeling activities conducted by scientists supported by DOE and other relevant organizations. This activity also serves the international community by archiving information generated by all domestic and international climate modeling centers that participate in the U.S. National Climate Assessment and/or the Intergovernmental Panel on Climate Change (IPCC).

### 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, 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 and turbulence conditions; and targeted geographic regions that are climate-sensitive or are known to limit predictability in Earth system models. 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 phenomena that limit the predictability of atmospheric processes, properties, and dynamical evolution. Using integrated, scalable testbeds that incorporate process-level understanding, climate, Earth, and environmental system models ASR research seeks to assure greater confidence in system level understanding and dramatically improved predictions that span local to global scales.

Environmental System Sciences

Environmental System Science supports research to provide an integrated, robust, and scale-aware predictive understanding of environmental systems, including the roles of physical and hydro-biogeochemical processes and variable geomorphology, while extending from the subsurface to the top of the vegetative canopy. 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, terrestrial-aquatic interfaces that include coastal zones, and urban-rural transitions. Research spans 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 continue place-based Urban Integrated Field Laboratories (IFLs) with strengthened coordination 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.

The RENEW initiative expands across BER activities. RENEW will target efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research. The National Virtual Climate Laboratory (NVCL) will continue to provide greater access to information about DOE's climate science activities at the National Laboratories, with the intended audience to be, in particular, HBCUs, Tribal Colleges and Universities (TCUs), Hispanic Serving Institutions (HSIs), and other MSIs, as well as stakeholder communities. A network of climate resilience centers that are affiliated with HBCUs and MSIs will expand, with a focus on developing the science base to achieve climate resilience solutions that can be deployed to America's communities.

The activity also supports the management of 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. Management activities focus on data quality and organizational support to the network and directed 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 continuing 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/ML techniques, robust couplers, diagnostics, performance metrics, and advanced data analytics. AI4ESP 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. Furthermore, as the ECP concludes, the exascale research activities will transition from the ECP to a broader focus on software for advanced computing and sustainability across current and future computing platforms. Priority Earth system model components include the ocean, sea-ice, land-ice, atmosphere, terrestrial ecosystems, urban systems, 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), i.e., a computationally efficient model that runs on DOE's Leadership Computing Facility exascale architectures, that will be extended 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 contribute to the current and future Earthshot topics by providing supporting climate information needed to enhance future designs and deployment strategies. For example, the current activities support offshore wind energy production as well as evaluating the impacts of a future hydrogen economy on climate change predictions.

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 cutting edge 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 2024, ARM will continue operations at the three fixed sites. One mobile facility will continue its deployment to San Diego for the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE) with the goal to characterize the microphysics and dynamics of marine stratocumulus clouds across all four seasons at a coastal location, such as the Scripps Pier and the Scripps Mt. Soledad sites in La Jolla. An important enhancement as part of this study is the collection of simultaneous in-cloud aerosol and droplet measurements to investigate the differences in these cloud properties during regional polluted and clean marine conditions. The second mobile unit, after having completed its deployment in central Colorado, will be deployed to Tasmania, Australia, to study cloud-aerosol interactions in the Southern Ocean. The third mobile unit will continue its long-term deployment in Alabama to observe cloud-aerosol interactions in a midlatitude forested ecosystem. ARM will continue to incorporate very high-resolution Large Eddy Simulations during specific campaigns as 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 different types of atmospheric sciences research, e.g., calibration and validation of space-borne sensors, and improvements in weather models. A cloud chamber research effort will be initiated to complement ARM's field observations of cloud-aerosol interactions.

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 utilize its aerial capabilities, including the Arctic Shark as an uncrewed aerial system (UAS) and the crewed Bombardier Challenger aircraft, Air-ARM. Acceptance testing and evaluation on the crewed aircraft will be completed, meeting Federal Aviation Administration (FAA) requirements, 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 be delayed until FY 2024.

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 both interfacial and surface materials (including aerosols), that are 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 contributes to an improved understanding of the biogeochemical controls on thawing permafrost that in turn affect Arctic infrastructure vulnerability. 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 sciences.

GPP funding will provide for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems to maintain the productivity and usefulness of DOE-owned facilities and to meet requirements for safe and reliable operation.

Data sets generated by ARM, EMSL, other DOE, and other federally supported experimental and modeling research activities are enormous. The trend towards more sophisticated science, derived from the integration of observations and models that can lead to increased complexity and improved predictability, requires the use of training data associated with AI/ML. While these capabilities will propel American science to the next generation, these new capabilities are also needed to more efficiently extend scientific discovery in support of evolving technological and innovation challenges, e.g., to inform the design of more robust resilient infrastructures, conduct more robust analyses of mitigation options to avert the impacts of natural disasters, enhance management choices to secure supply chains, and create novel opportunities for environmental stewardship. Accessibility and usage of these complex and interconnected data sets are fundamental for scientific discovery, technological innovation, decision-making, and national security.

The BER Data Management activity will focus efforts on archiving scientifically useful data from the Earth System Grid Federation, Ameriflux, NGEE field experiments, SPRUCE site observations, and experimental programs involving watersheds and coastal systems.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Earth and Environmental Systems Sciences** | **$445,000** | **$445,200** | **+$200** |
| Atmospheric System Research | $36,000 | $40,000 | +$4,000 |
| Funding for 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 and data from the TRACER and SAIL campaigns. ASR continues to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site. | | ASR will continue research on clouds, aerosols, and thermodynamic processes, with a focus on data from the ARM fixed sites as well as data from the TRACER and SAIL campaigns. ASR will continue to make use of data generated by Large Eddy Simulations as part of ARM facility deployments. Scope will be expanded to include urban areas. | Funding will support an expanded scope to include urban areas. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Environmental System Sciences $120,800 | $137,000 | +$16,200 |
| Funding for ESS focuses research on permafrost and maintains 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 Urban IFLs expand to support climate science. The NVCL is fully implemented and continues to provide access to the single portal to DOE lab climate capabilities. Funding initiates the network of climate centers focused on resilience. RENEW expands to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. | ESS will continue 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 IFLs will be enhanced to support climate science yet with more coordination. The NVCL will continue to provide access as the single portal to DOE lab climate science capabilities with key stakeholders from underrepresented and impacted communities through training and outreach for equitable climate resilience solutions. The network of climate resilience centers focused on resilience will increase. The RENEW initiative expands targeted efforts, including a RENEW graduate fellowship, to increase participation and retention of individuals from underrepresented groups in SC research activities and encompasses all BER activities. | Funding will continue investments for coastal watershed research in the mid-Atlantic, Great Lakes, and Puget Sound with new observations, enhanced modeling, and data-model synthesis. The Urban IFLs will expand coordination and collaboration, with more integrated field data with a next generation Earth System Modeling framework, and create a science capability to advance climate and energy research as a unified co-dependent system. The increase broadens RENEW activities across BER. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Earth and Environmental Systems Modeling $115,500 | $120,500 | +$5,000 |
| Funding for Earth and Environmental Systems Modeling focuses 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 incorporates AI and unsupervised learning capabilities and enables more sophisticated research based on higher model resolution, through the Integrative AI4ESP. The new version adds advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability on Antarctic ice shelf melting, continental ice sheet evolution and sea level rise, and the effects of changing water cycles on watershed and coastal hydrological systems. Funding also initiates foundational modeling for the offshore wind and hydrogen Energy Earthshots. | 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 will continue AI/ML capabilities and enable more sophisticated science that demands higher model resolution and greater accuracy, through the Artificial Intelligence Framework for AI4ESP. As the ECP concludes, the exascale research activities will transition from the ECP to a broader focus on software for advanced computing and sustainability across current and future computing platforms. The new E3SM 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, the effects of changing water cycles on watershed and coastal hydrological systems, and new challenges involving urban systems. The Request will also support foundational modeling in support of Energy Earthshot topics that focus on robust projections that link details of climate change with the design and deployment of clean energy initiatives. | 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 ECP research activities will transition ECP researchers, software, and technologies into core research efforts. New investments enhance support for Earthshot topics, that focus on efficient design, deployment, and effectiveness of renewable and clean energy infrastructures to combat climate change. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Funding focuses 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 (including the Great Lakes and Puget Sound), mid-latitude-Arctic interactions, and high-resolution studies of urban and urban-rural transition regions. | 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, in particular, to coastal zones (including the Great Lakes and Puget Sound), and high-resolution studies of urban and urban-rural transition regions. | Funding will continue to support research with a shift in emphasis from large scale dynamics 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. |
| Earth and Environmental Systems Sciences Facilities and Infrastructure $172,700 | $147,700 | -$25,000 |
| Funding for ARM continues to provide new observations through long term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic site. An ARM mobile unit completes installation and begin operations in Alabama. The funding prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM continues and completes deployment of its second mobile facility to Colorado; and it prepares and deploys its first mobile facility to San Diego. Scientists are using 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. After rebaselining to meet FAA requirements, acceptance testing and evaluation are completed on the Air-ARM 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 continues as well as continuing a multi-year instrumentation refresh. | ARM will continue to provide new observations through long term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic site. The ARM mobile unit in Alabama will be fully operational. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will continue deployment to the EPCAPE campaign in 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. A third ARM unit will be deployed to Tasmania to study cloud-aerosol interactions. Acceptance testing and evaluation will be completed on the Air-ARM aircraft, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. Air-ARM flight operations are anticipated in late FY 2024 pending FAA final reviews and approvals. | Funding will support ARM site operations, and mobile facilities operations. A mobile facility will continue deployment to the EPCAPE campaign, in San Diego; and another facility will be deployed to Australia. After major investments in FY 2022 to install the third ARM unit to Alabama, this capability will routinely collect data in support of community science. Air-ARM flight operations are anticipated in late FY 2024 pending FAA reviews and approvals. A cloud chamber research effort will be initiated to complement ARM's field observations of cloud-aerosol interactions. Reductions are due to the completion of the installation of the Alabama site. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| | The ARM support for the Urban IFL for climate science will continue as well as continue a multi-year instrumentation refresh. A cloud chamber research effort will be initiated to complement ARM's field observations of cloud-aerosol interactions. | |
| Funding for EMSL emphasizes 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. A multi-year instrumentation refresh continues. Other Project Cost support the microbial molecular phenotyping capability planned project. | 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 the initial construction of microbial molecular phenotyping capability. | Funding will promote multi-disciplinary science using various combinations of EMSL's most sophisticated instrumentation. Reallocations within EMSL rebalances operations and research. |
| GPP funding provides for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems to maintain the productivity and usefulness of DOE-owned facilities and to meet requirements for safe and reliable operation. In FY 2023 GPP supports improved cooling for High Performance Computing infrastructure at EMSL and remodeling EMSL laboratories to create lab spaces to co-locate capabilities that cross-cut EMSL's integrated research platforms | GPP funding will provide for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems to maintain the productivity and usefulness of DOE-owned facilities and to meet requirements for safe and reliable operation. The Request provides for EMSL laboratories remodel to unpack and relocate prioritized core capabilities. This includes refurbishing electrical, HVAC, and other safety-related systems in several core analytical and microscopy instrument labs and moving instruments to relieve overcrowding. | Funding will support the remodeling efforts at EMSL to unpack and relocate prioritized core capabilities. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Funding for the Earth and Environmental Sciences Data Management activity enhances 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 are maintained. Advanced analytical methodologies such as Machine Learning is used to improve the predictability of extreme events more rapidly using the combination of field observations with Earth system models. | The Earth and Environmental Sciences Data Management activity will continue 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 will be used to improve the predictability of extreme events more rapidly using the combination of field observations with Earth system models. | No Change. |

*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, excluding facility operations.*

**Description**

This subprogram supports line-item construction for the BER program. All Total Estimated Costs (TEC) are funded in this subprogram, including engineering, design, and construction. The FY 2024 Request of $10,000,000 initiates the Microbial Molecular Phenotyping Capability project.

<u>24-SC-31, Microbial Molecular Phenotyping Capability (M2PC), PNNL</u>

The M2PC project will design and construct a new capability that will provide approximately 36,000 gross square feet of wet chemistry and instrumentation space conducive for highly autonomous operations. In addition, the M2PC design will include acquisition of analytical instrumentation and microbial culturing and characterization capabilities that will be modular and expandable, self-contained, and operate in an automated pod configuration. Capabilities will include a suite of 5 to 10 microbial culturing pods, 3 to 5 biological and functional assay pods, and 4 to 5 analytical phenotyping workflow pods with workstations for 10 to 15 research and support staff. This new capability will position the BER program to take a global lead in answering the most pressing challenge in biology—generating molecular phenotypic data at a pace that matches the rapid developments in high throughput genome sequencing and synthesis. Applicability of this capability to BER interests in biofuels production, lignocellulose breakdown, and carbon/nutrient/elemental cycling, will create a knowledge ecosystem that will provide data to amplify BER's genome engineering and biosystems design efforts, as well as mechanistic hydro-biogeochemistry modeling capabilities.

## Biological and Environmental Research
## Construction

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Construction** | **$ —** | **$10,000** | **+$10,000** |
| 24-SC-31, Microbial Molecular Phenotyping Capability (M2PC), PNNL | $ — | $10,000 | +$10,000 |
| No funding was requested in FY 2023. | | Funding will support the new M2PC project at PNNL. | Funding will initiate the new M2PC project at PNNL. |

**Biological and Environmental Research**
**Capital Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 25,000 | 34,950 | 25,500 | -9,450 |
| Minor Construction Activities | | | | | | |
| General Plant Projects | N/A | N/A | – | 10,000 | 5,000 | -5,000 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **25,000** | **44,950** | **30,500** | **-14,450** |

**Capital Equipment**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Major Items of Equipment | | | | | | |
| Earth and Environmental Systems Sciences | | | | | | |
| Atmospheric Radiation Measurement (ARM) Aerial Observation Capability (Air-ARM) | 27,186 | 17,486 | – | 9,700 | – | -9,700 |
| Total, MIEs | N/A | N/A | – | 9,700 | – | -9,700 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 25,000 | 25,250 | 25,500 | +250 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **25,000** | **34,950** | **25,500** | **-9,450** |

*Note:*
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*

**Minor Construction Activities**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| GPPs (greater than or equal to $5M and less than $30M) | | | | | | |
| HPC Infrastructure Upgrades (GPP HPC Upgrades [Refresh] ), PNNL | 5,000 | – | – | 5,000 | – | -5,000 |
| Project 2 - Crosscutting Capabilities (3020EMSL Remodel to Cross-Cut IRPs), PNNL | 5,000 | – | – | 5,000 | – | -5,000 |
| Project 3 - Relocations (3020EMSL Remodel to Unpack and Relocate), PNNL | 5,000 | – | – | – | 5,000 | +5,000 |
| Total GPPs (greater than or equal to $5M and less than $30M) | N/A | N/A | – | 10,000 | 5,000 | -5,000 |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **–** | **10,000** | **5,000** | **-5,000** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **–** | **10,000** | **5,000** | **-5,000** |

**Biological and Environmental Research**
**Major Items of Equipment Description(s)**

Earth and Environmental Systems Sciences Facilities and Infrastructure:

*Atmospheric Radiation Measurement Research Facility (ARM) – Air-ARM*

The Air-ARM project received CD-2/3 approval on November 12, 2018, with an original total project cost of $17,700,000. BER-supported scientists require high-quality and well-characterized *in situ* aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the ARM user facility has been using a dedicated large twin-turboprop Gulfstream-1 (G-1) aircraft to conduct weeks- to months-long intensive observational campaigns over a range of meteorological conditions and locations around the world. The G-1 aircraft used by ARM was built in 1961, was one of only 10 G-1's that remain in service worldwide, and is at the end of its service life. BER retired and replaced the aircraft in FY 2019. The FY 2019 Enacted Budget included funding to replace the Battelle-owned G-1 aircraft that supported airborne data collection as part of ARM field campaigns. Since FY 2020, the newly acquired aircraft has undergone testing and evaluation, including modifications to the air frame to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. Also, the aircraft has undergone ground-based and airborne testing, in order to prepare it for scientific studies. In order to meet FAA requirements the total project cost has increased (+$9.7M), and planned research flight operations will be delayed until FY 2024.

**Biological and Environmental Research**
**Minor Construction Description(s)**

**General Plant Projects $5 Million to less than $30 Million**

**Outfitting of Research and Collaborations Spaces**
**General Plant Project Details**

| | |
|---|---|
| **Project Name:** | Project 3 – Relocations (3020EMSL Remodel to Unpack and Relocate), PNNL |
| **Location/Site:** | Pacific Northwest National Laboratory |
| **Type:** | GPP |
| **Total Estimated Cost:** | $5,000,000 |
| **Construction Design:** | $0 |
| **Project Description:** | EMSL has been developing plans for backfill of space vacated in EMSL once the capability relocations into the Energy Sciences Center have been completed. Approximately 13,000 square feet equivalent of lab modules have been relocated and EMSL has identified four strategic priorities for backfilling the space. This project will renovate and backfill laboratory spaces in support of EMSL capabilities and strategic plan with a focus on unpacking crowded laboratories that support EMSL's prioritized core capabilities. Conceptual design is planned for completion in FY 2023 in anticipation of FY 2024 funding. |

**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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Scientific User Facilities - Type B** | | | | | |
| **Environmental Molecular Sciences Laboratory** | **56,000** | **54,231** | **64,750** | **50,250** | **-14,500** |
| Number of Users | 850 | 744 | 750 | 750 | – |
| **Joint Genome Institute** | **84,500** | **81,580** | **90,000** | **92,000** | **+2,000** |
| Number of Users | 2,200 | 2,243 | 2,300 | 2,350 | +50 |
| **Atmospheric Radiation Measurement Research Facility** | **90,000** | **87,003** | **87,000** | **85,500** | **-1,500** |
| Number of Users | 980 | 1,113 | 1,200 | 1,200 | – |
| **Total, Facilities** | **230,500** | **222,814** | **241,750** | **227,750** | **-14,000** |
| Number of Users | 4,030 | 4,100 | 4,250 | 4,300 | +50 |

**Biological and Environmental Research**
**Scientific Employment**

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 1,600 | 1,750 | 1,805 | +55 |
| Number of Postdoctoral Associates (FTEs) | 410 | 460 | 480 | +20 |
| Number of Graduate Students (FTEs) | 580 | 640 | 685 | +45 |
| Number of Other Scientific Employment (FTEs) | 395 | 430 | 435 | +5 |
| **Total Scientific Employment (FTEs)** | **2,985** | **3,280** | **3,405** | **+125** |

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

**24-SC-31, Microbial Molecular Phenotyping Capability (M2PC), PNNL**
**Pacific Northwest National Laboratory, PNNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Microbial Molecular Phenotyping Capability is $10,000,000 of Total Estimated Cost (TEC) funding and $950,000 of Other Project Cost (OPC) funding. This is the initial Construction Project Data Sheet (CPDS) for the project. The project proposes to design and construct a new research capability for the M2PC that will be broadly available to the scientific community as part of an Office of Science User Facility. The preliminary Total Project Cost (TPC) range is $80,000,000 to $120,000,000.

**Significant Changes**

This project is a new start in FY 2024. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-0, which was approved on April 28, 2021, with a preliminary TPC cost range of $80,000,000 to $120,000,000 and CD-4 range of FY 2026 to FY 2029. Through the development of the draft CD-1 materials, the project scope and schedule have been conceptually defined and are reflected in the tables below. The project is pursuing a tailoring strategy to combine CD-2 and CD-3A.

In FY 2024, the TEC funding of $10,000,000 will be used to obtain designs for both the facility as well as for the instrumentation, and the $950,000 in OPC will be used to prepare for CD-2/3A.

A Federal Project Director has been assigned to the project. The Federal Project Director is level I certified with a level II certification pending approval.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 4/28/21 | 3Q FY 2023 | 4Q FY 2023 | 1Q FY 2025 | 4Q FY 2024 | 4Q FY 2025 | 4Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | CD-3A |
|---|---|
| FY 2024 | 1Q FY 2025 |

**CD-3A** – Approve Long-Lead Procurements and instrument configurations, including design and assembly of custom automation carts/enclosures and associated robotics, and procurement of an 800 MHz NMR (nuclear magnetic resonance) spectrometer and a cryo-EM (electron microscope) system.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 11,000 | 104,000 | 115,000 | 5,000 | 5,000 | 120,000 |

## 2. Project Scope and Justification

**Scope**

The M2PC project will design and construct a new capability that will provide approximately 36,000 gross square feet of wet chemistry and instrumentation space conducive for highly autonomous operations. In addition, the M2PC design will include acquisition of analytical instrumentation and microbial culturing and characterization capabilities that will be modular and expandable, self-contained, and operate in an automated pod configuration. Capabilities will include a suite of 5 to 10 microbial culturing pods, 3 to 5 biological and functional assay pods, and 4 to 5 analytical phenotyping workflow pods with workstations for 10 to 15 research and support staff.

**Justification**

Within the Biological and Environmental Research (BER) program, basic research to gain a predictive understanding of biological systems provides the foundation for harnessing and integrating the latest biosystems design techniques with data science and multi-scale modeling approaches. This effort will advance a burgeoning bioeconomy, as well as enable prediction of the future state of the Earth system. Toward systems-level understanding, BER-supported research has increasingly embraced the integration of multi-omics analyses together with phenotypic characterization of microbial isolates and communities to determine the function of expressed genes and pathways.

While the number of microbial isolates and chassis microbes interrogated is expanding rapidly along with advances in next generation genome sequencing and synthesis, incomplete and constrained genome annotation limits the ability to understand and model the range of activities and functions of individual microbes, engineered microbial consortia with bio-industrial potential or ecological relevance, and microbial communities from natural soil environments. Specifically, there is a significant gap in the ability of the scientific community to identify proteins and biochemical pathways of unknown function in microbes at the single-cell to microbial-community scales, in part because the phenotypes of microbes change rapidly due to environmental factors and perturbations. To address this gap, BER proposes a research capability for a Microbial Molecular Phenotyping Capability that would be broadly available to the scientific community as part of a DOE Office of Science User Facility.

An emphasis on coupled high-throughput autonomous experimental and multimodal analytical capabilities would be the primary components of the instrumentation part of the M2PC. These capabilities would be integrated with, and amplify, existing BER data platforms within the DOE JGI, the NMDC, and the KBase to speed the discovery of new protein functions and metabolic pathways in microbial systems, including fungi, algae, bacteria, protists, archaea, and viruses.

This new capability will position BER to take a global lead in answering the most pressing challenge in biology—generating molecular phenotypic data at a pace that matches the rapid developments in high throughput genome sequencing and synthesis. Applicability of this capability to BER interests in biofuels production, lignocellulose breakdown, and carbon/nutrient/elemental cycling, would create a knowledge ecosystem that would provide data to amplify BER's genome engineering and biosystems design efforts, as well as mechanistic hydro-biogeochemistry modeling capabilities.

While the Office of Science is exempt from DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets, the M2PC project intends to deploy a certifiable earned value management system and be conducted in accordance with the project management principles of DOE O 413.3B[a].

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance.

[a] Memorandum For Office of Science Associate Directors, From W.F. Brinkman, Director, Office of Science, "Office of Science is Exempt from DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets," dated February 2, 2011.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Demonstrate high-throughput (HTP) Strain Culturing | Capacity to operate with 500 Design, Build, Test, Learn (DBTL) Strain Starts/Week | Capacity to operate with 2,000 DBTL Strain Starts/Week |
| Demonstrate HTP Microbiome Culturing | Capacity to operate with 100 Microbiome Starts/Week | Capacity to operate with 500 Microbiome Starts/Week |
| Demonstrate HTP Assaying and Phenotyping | Capacity to obtain 1,000,000 Data Points/Month | Capacity to obtain 3,000,000 Data Points/Month |
| Remote Capability to Access Operations | Demonstrate that remote users can run pre-defined EMSL protocols to be executed autonomously within M2PC across culturing, assaying, and analyses | Demonstrate remote users can perform dynamic experimental intervention with help from EMSL staff |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| FY 2024 | 10,000 | 10,000 | 10,000 |
| Outyears | 1,000 | 1,000 | 1,000 |
| **Total, Design (TEC)** | **11,000** | **11,000** | **11,000** |
| Construction (TEC) | | | |
| Outyears | 104,000 | 104,000 | 104,000 |
| **Total, Construction (TEC)** | **104,000** | **104,000** | **104,000** |
| Total Estimated Cost (TEC) | | | |
| FY 2024 | 10,000 | 10,000 | 10,000 |
| Outyears | 105,000 | 105,000 | 105,000 |
| **Total, TEC** | **115,000** | **115,000** | **115,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2023 | 250 | 250 | 250 |
| FY 2024 | 950 | 950 | 950 |
| Outyears | 3,800 | 3,800 | 3,800 |
| **Total, OPC** | **5,000** | **5,000** | **5,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2023 | 250 | 250 | 250 |
| FY 2024 | 10,950 | 10,950 | 10,950 |
| Outyears | 108,800 | 108,800 | 108,800 |
| **Total, TPC** | **120,000** | **120,000** | **120,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 7,700 | N/A | **N/A** |
| Design - Contingency | 3,300 | N/A | **N/A** |
| **Total, Design (TEC)** | **11,000** | **N/A** | **N/A** |
| Construction | 72,700 | N/A | **N/A** |
| Construction - Contingency | 31,300 | N/A | **N/A** |
| **Total, Construction (TEC)** | **104,000** | **N/A** | **N/A** |
| **Total, TEC** | **115,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *34,600* | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| OPC, Except D&D | 4,000 | N/A | **N/A** |
| Conceptual Design | 1,000 | N/A | **N/A** |
| **Total, Except D&D (OPC)** | **5,000** | **N/A** | **N/A** |
| **Total, OPC** | **5,000** | **N/A** | **N/A** |
| *Contingency, OPC* | ***N/A*** | *N/A* | ***N/A*** |
| **Total, TPC** | **120,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***34,600*** | ***N/A*** | ***N/A*** |

5. **Schedule of Appropriations Requests**

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | — | — | — | 10,000 | 105,000 | 115,000 |
| | OPC | — | — | 250 | 950 | 3,800 | 5,000 |
| | TPC | — | — | 250 | 10,950 | 108,800 | 120,000 |

6. **Related Operations and Maintenance Funding Requirements**

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2079 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

7. **D&D Information**

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at PNNL | 36,000 |
| Area of D&D in this project at PNNL | — |
| Area at PNNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | — |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | 36,000 |
| Total area eliminated | — |

8. **Acquisition Approach**

The Acquisition Strategy for the M2PC project is under development and will be reviewed as part of the CD-1 process.

# Fusion Energy Sciences

## Overview

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. In addition, the FES mission includes the development of a competitive fusion power industry in the U.S.

High-temperature fusion plasmas at hundreds of millions of degrees are being exploited to become the basis for a future carbon-free energy source. Once developed, fusion will provide an energy source well-suited for on-demand electrical production and other non-electric applications, supplementing intermittent renewables and fission. Energy from fusion has the potential to be carbon-free, inherently safe, and without the production of long-lived radioactive waste.

The frontier area of high-power, long-pulse fusion burning plasmas, to be enabled by the ITER experimental facility, will allow the discovery and study of new scientific phenomena relevant to fusion as a future carbon-free energy source. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U) are world-leading Office of Science (SC) user facilities for experimental research, used by scientists from national laboratories, universities, and industry research groups, to optimize magnetic confinement regimes. Partnerships with the growing fusion private sector could potentially shorten the time for developing fusion energy by combining efforts to resolve common scientific and technological challenges; along with the Innovation Network for Fusion Energy (INFUSE) voucher program, FES will be establishing a Fusion Development Milestone Program in support of the Administration's Bold Decadal Vision (BDV) for commercializing fusion energy.

Complementing these experimental activities is a significant effort in fusion theory and simulation to predict and interpret the complex behavior of plasmas as self-organized systems. FES supports a Scientific Discovery through Advanced Computing (SciDAC) portfolio, in partnership with the Advanced Scientific Computing Research (ASCR) program. FES will prioritize transitioning Exascale Computing Project (ECP) researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes. U.S. scientists use international partnerships to conduct research on overseas tokamaks and stellarators with unique capabilities. The development of novel materials that can withstand enormous heat and neutron exposure is important for fusion and the design basis for a fusion pilot plant (FPP).

The FES program also supports discovery plasma science in research areas such as plasma astrophysics, high-energy-density laboratory plasmas (HEDLP), and low-temperature plasmas. Practical applications of plasmas are found in microelectronics fabrication, nanomaterial synthesis, and space weather forecasting. Some of this research is carried out through partnerships with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA).

The FES program invests in several SC cross-cutting initiatives such as artificial intelligence and machine learning (AI/ML), quantum information science (QIS), microelectronics, advanced manufacturing, advanced computing, and Accelerate Innovations in Emerging Technologies (Accelerate). In addition, continued funding for the Established Program to Stimulate Competitive Research (EPSCoR), the Reaching a New Energy Sciences Workforce (RENEW), and the Funding for Accelerated, Inclusive Research (FAIR) initiatives, FES will build stronger programs with underrepresented institutions and regions, including emerging research institutions (ERIs), minority serving institutions (MSIs) and historically black colleges and universities (HBCUs), for a more diverse and inclusive workforce.

FES program directions and activities are informed by the 2020 long-range plan (LRP) "Powering the Future: Fusion and Plasmas"[a] from the Fusion Energy Sciences Advisory Committee (FESAC), as well as reports from the National Academies of Sciences, Engineering, and Medicine (NASEM) and community workshops. Fusion energy is a critical clean energy and climate technology and infrastructure innovation R&D investment mentioned in the annual joint memorandum on "Multi-Agency research and Development Priorities for the FY 2024 Budget" from the Office of Management and Budget and the Office of Science and Technology Policy.[b]

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[a] https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf

[b] https://www.whitehouse.gov/wp-content/uploads/2022/07/M-22-15.pdf

**Highlights of the FY 2024 Request**

The FY 2024 Request is $1,010.5 million with key elements listed below. The Request is aligned with recommendations in the recent FESAC LRP and the Administration's BDV; in bold font below are some specific examples of FES implementation of both. The FY 2024 Request includes:

Research

- DIII-D research: **Increase access for all users including those from universities pursuing research and development (R&D) at the frontiers of plasma science, and those from private industry by revising the facility user agreements.**
- NSTX-U research: Support initial machine commissioning, along with collaborative research at other facilities for addressing program priorities **including aspect ratio studies for an FPP.**
- Partnerships with private fusion efforts: **Support public-private partnerships with the Fusion Development Milestone and INFUSE programs.**
- Inertial Fusion Energy (IFE) and ITER Research: **Implement priority research opportunities that came out of the Basic Research Needs Workshops in these two scientific areas.**
- Fusion R&D Centers: **Initiate four multi-institutional, multi-disciplinary centers for Blanket/Fuel Cycle, Advanced Simulations, Structural/Plasma Facing Materials, and Enabling Technologies supporting public & private FPP efforts.**
- SciDAC: Continue development of an integrated simulation capability, expanding it from whole-device to whole-facility modeling, in partnership with ASCR.
- Long Pulse—Tokamak: **Support multi-disciplinary, multi-institutional teams working on international facilities, including validation of burning plasma models and FPP design tools.**
- Discovery plasma science: Continue support for basic plasma science collaborative facilities, HEDLP research/facilities, measurement innovation, QIS, and microelectronics research through new Microelectronics Science Research Centers.
- AI/ML: Support multi-institutional teams working to develop AI/ML tools in high-priority areas.
- Future Facilities Studies: **Support studies and research for a future fusion neutron source facility that is critical to the development of materials for fusion energy and was identified as the highest priority new facility in the FESAC LRP.**
- RENEW: **Expand targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research.**
- FAIR: Provide focused investment for enhancing research on clean energy, climate, and related topics at ERIs, HBCUs, and MSIs.
- Accelerate: Support scientific research to accelerate the transition of scientific advances to energy technologies.
- EPSCoR: Support FES research in states and territories with historically lower Federal academic research funding.

Facility Operations

- DIII-D operations: Support 14 weeks of facility operations, representing 90 percent of optimal funding, and complete ongoing machine and infrastructure improvements.
- NSTX-U recovery and operations: Continue the recovery and repair activities. NSTX-U Operations will support machine assembly and hardware commissioning.

Projects

- U.S. hardware development and delivery to ITER: Support the continued design, fabrication, and delivery of U.S. in-kind hardware systems, including the continued fabrication, testing, and delivery of the Central Solenoid magnet modules, tokamak cooling water, tokamak exhaust processing, electron and ion heating transmission lines, diagnostics, tokamak fueling, disruption mitigation, vacuum auxiliary, and roughing pumps.
- Petawatt laser facility upgrade for HEDLP science: Support design activities for a world-leading upgrade to the Matter in Extreme Conditions (MEC) instrument on the Linac Coherent Light Source-II (LCLS-II) facility at SLAC National Accelerator Laboratory (SLAC).
- Major Item of Equipment (MIE) project for plasma-material interaction research: Continue to support the Material Plasma Exposure eXperiment (MPEX) MIE project, which includes the design, fabrication, installation, and commissioning of the MPEX linear plasma device, and associated facility modification and reconfiguration.

Other

- General Plant Projects/General Purpose Equipment (GPP/GPE): Support infrastructure improvements and repairs at the Princeton Plasma Physics Laboratory (PPPL) and other DOE laboratories.

**Fusion Energy Sciences**
**Funding**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Fusion Energy Sciences** | | | | |
| Advanced Tokamak | 123,390 | 134,122 | 157,722 | +23,600 |
| Spherical Tokamak | 99,000 | 107,000 | 92,350 | -14,650 |
| Theory & Simulation | 43,000 | 50,500 | 70,000 | +19,500 |
| GPP/GPE Infrastructure | 1,500 | 1,500 | 1,000 | -500 |
| Public-Private Partnerships | 31,000 | 31,000 | 135,000 | +104,000 |
| Artificial Intelligence and Machine Learning | 7,000 | 11,000 | 11,000 | – |
| Strategic Accelerator Technology | 3,073 | – | – | – |
| Inertial Fusion Energy (IFE) | – | 10,000 | 15,000 | +5,000 |
| **Total, Burning Plasma Science: Foundations** | **307,963** | **345,122** | **482,072** | **+136,950** |
| Long Pulse: Tokamak | 15,000 | 15,000 | 15,000 | – |
| Long Pulse: Stellarators | 8,500 | 7,500 | 7,500 | – |
| Materials & Fusion Nuclear Science | 59,500 | 56,500 | 147,500 | +91,000 |
| Future Facilities Studies | 3,000 | 2,000 | 14,674 | +12,674 |
| **Total, Burning Plasma Science: Long Pulse** | **86,000** | **81,000** | **184,674** | **+103,674** |
| ITER Research | 2,000 | 2,000 | 2,000 | – |
| **Total, Burning Plasma Science: High Power** | **2,000** | **2,000** | **2,000** | **–** |
| Plasma Science and Technology | 39,000 | 46,000 | 39,000 | -7,000 |
| Measurement Innovation | 3,000 | 2,915 | 2,000 | -915 |
| Quantum Information Science (QIS) | 10,000 | 10,000 | 10,000 | – |
| Advanced Microelectronics | 5,000 | 5,000 | 15,000 | +10,000 |
| Other FES Research | 4,037 | 4,185 | 2,500 | -1,685 |
| Reaching a New Energy Sciences Workforce | 3,000 | 6,000 | 11,250 | +5,250 |
| FES-Funding for Accelerated, Inclusive Research (FAIR) | – | 2,000 | 4,000 | +2,000 |
| FES-Accelerate Innovations in Emerging Technologies | – | 4,000 | 6,000 | +2,000 |

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| FES-Established Program to Stimulate Competitive Research (EPSCoR) | – | 2,000 | 2,000 | – |
| **Total, Discovery Plasma Science** | **64,037** | **82,100** | **91,750** | **+9,650** |
| **Subtotal, Fusion Energy Sciences** | **460,000** | **510,222** | **760,496** | **+250,274** |
| **Construction** | | | | |
| 20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC | 11,000 | 11,000 | 10,000 | -1,000 |
| 14-SC-60 U.S. Contributions to ITER | 242,000 | 242,000 | 240,000 | -2,000 |
| **Subtotal, Construction** | **253,000** | **253,000** | **250,000** | **-3,000** |
| **Total, Fusion Energy Sciences** | **713,000** | **763,222** | **1,010,496** | **+247,274** |

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $13,457,000 and STTR $1,899,000
- FY 2023 Enacted: SBIR $10,921,000 and STTR $1,536,000
- FY 2024 Request: SBIR $18,765,000 and STTR $2,642,000

**Fusion Energy Sciences**
**Explanation of Major Changes**

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Burning Plasma Science: Foundations** | **+136,950** |
| The Request for DIII-D will support 14 weeks of research operations as well as completion of facility enhancements. Funding for the NSTX-U program will support the recovery activities and maintain collaborative research at other facilities to support NSTX-U research program priorities. The Request will expand support for the Fusion Development Milestone Program with private fusion industry. Support will continue for IFE science and technology. SciDAC will maintain emphasis on whole-facility modeling and will support a new integrated center on advanced simulations. Enabling R&D will focus attention on high-temperature superconductor development and will support a new R&D center on enabling technologies for fusion. Funding is provided for GPP/GPE to support critical infrastructure improvements and repairs. | |
| **Burning Plasma Science: Long Pulse** | **+103,674** |
| The Request will support high-priority international collaboration activities, for both tokamaks and stellarators. The Request will enhance funding for materials and fusion nuclear science research programs with the establishment of two new centers. The Request will support activities within the approved Critical Decision-2/3 (CD-2/3) baseline/start of construction for the MPEX MIE project. The Request continues support for a Future Facilities Studies program that will focus its efforts on conducting preliminary studies and research of a future fusion neutron source facility that can meet the performance requirements identified in recent community workshops. | |
| **Burning Plasma Science: High Power** | **$ —** |
| The Request will continue to support an ITER Research program to prepare the U.S. fusion community to take full advantage of ITER. | |
| **Discovery Plasma Science** | **+9,650** |
| For General Plasma Science (GPS), the Request will emphasize user research on collaborative research facilities at universities and national laboratories as well as interagency coordination and collaboration with the NSF on single investigator projects. For HEDLP, the Request will support research utilizing the MEC instrument of the LCLS user facility at SLAC and supporting research on the ten LaserNetUS network facilities. For QIS, the Request continues support for the National QIS Research Centers and the core research portfolio stewarded by FES. New Microelectronics Science Research Centers begin as authorized under the Micro Act. The RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups. Support will continue for FAIR, Accelerate, and the EPSCoR program. | |
| **Construction** | **-3,000** |
| FES will continue to support design activities for a world-leading upgrade to the MEC experimental hall facility. The U.S. Contributions to ITER project will continue design, fabrication, and delivery of First Plasma hardware, including continued fabrication and delivery of the central solenoid superconducting magnet modules. The Request supports funding for construction financial contributions to the ITER Organization (IO). | |
| **Total, Fusion Energy Sciences** | **+247,274** |

**Basic and Applied R&D Coordination**

FES participates in coordinated intra- and inter-agency initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the MEC instrument at the SLAC LCLS user facility operated by the Basic Energy Sciences (BES) program, supports high-performance computing research with ASCR, uses the BES-supported High Flux Isotope Reactor (HFIR) facility at Oak Ridge National Laboratory (ORNL) for fusion materials irradiation research, and supports the construction of a high field magnet vertical test facility at the Fermi National Accelerator Laboratory with the High Energy Physics (HEP) program. Within DOE, FES manages a joint program with NNSA in HEDLP science and continues to support awards jointly funded with the Advanced Research Projects Agency-Energy (ARPA-E). FES also supports the fusion crosscutting team focusing on the BDV. Outside DOE, FES carries out a discovery-driven plasma science research program in partnership with NSF. The joint programs with NNSA and NSF involve coordination of solicitations, peer reviews, and workshops.

**Program Accomplishments**

*DIII-D researchers develop optimized plasma performance scenarios.*

U.S. researchers at the DIII-D National Fusion Facility simulated a unique approach to a compact fusion power plant concept, using physics-based simulations to optimize plasma performance. Optimal solutions were identified with high plasma density and self-driven plasma currents. The plasma current was driven in part from neutral particle beams and ultra-high harmonic (helicon) fast waves, a new technology being tested on the DIII-D facility.

*Research on fusion facilities can improve spacecraft technology.*

The DIII-D tokamak was used to study carbon ablation under re-entry heat fluxes, demonstrating that the hot plasma created in DIII-D offers a novel and potentially improved way of advancing spacecraft technology. Past heat shield testing approaches suffered from the problem that no single method could simulate the exact heating conditions present during a high-speed atmospheric entry. In the DIII-D experiments, the team was able to gather a range of valuable data, allowing them to improve theoretical models and numerical simulations.

*U.S. researchers contribute to fusion energy record at the Joint European Torus (JET) facility.*

In JET, a record 59 megajoules (MJ) of fusion energy was generated over a five-second pulse flattop in 2022, more than doubling the 22 MJ record set at JET in 1997. Several U.S. collaborations on JET supported this deuterium-tritium campaign. Their contributions included predictive modeling and simulations of burning plasma scenarios, the use of an external antenna to drive magnetic fluctuations and measure plasma stability, and the provision and operation of a diagnostic to measure the loss of energetic ions that provide heat to the plasma.

*Machine learning improves equilibrium reconstruction in fusion experiments.*

A team has significantly revised the U.S.-developed plasma Equilibrium reconstruction and FITting (EFIT) code to facilitate application of ML and AI algorithms for fusion data analysis applications. A single device-independent core equilibrium solver called EFIT-AI has been created that can reconstruct equilibria for many tokamaks around the world and is portable to U.S. high-performance computing facilities, including Cori and Perlmutter at the National Energy Research Scientific Computing (NERSC) center. Surrogate artificial neural networks have been trained and used to achieve a 600-fold speedup of reconstructions based on data from magnet field sensors.

*INFUSE: Extending partnerships with the fusion private sector.*

The INFUSE program was launched in FY 2019. In FY 2022, a major modification was made that enables companies to partner directly with U.S. universities, a first for a DOE voucher-style program. To date, 72 awards totaling $14.7 million have been made to 20 unique private companies partnering with 10 DOE labs and 8 U.S. universities.

*All the strength, none of the struggle: An alternative manufacturing path toward advanced steels.*

Oxide dispersion-strengthened steels (ODS) are promising structural materials for future fusion reactors but have traditionally struggled due to the need for a complex and unreliable processing route. Recent research under a joint FES/ARPA-E program has demonstrated that powders produced by gas atomization reaction synthesis offer the potential for circumventing the most difficult step of the traditional manufacturing process while enabling a similar level of strength in the end material. This opens the way for new solid-state and additive processing approaches and promises an alternative, scalable route for manufacturing these advanced alloys for future fusion energy systems.

*MPEX MIE project receives approval of project baseline and start of construction.*
The scientific demonstration of magnetic fusion energy as an environmentally sustainable and economically competitive energy source will require mastery of materials science issues associated with the plasma-material interface. The MPEX MIE project will deliver a world-leading capability for the testing of plasma-facing materials and components under reactor-relevant plasma loading conditions. The MPEX MIE project received formal Approval of Performance Baseline and Start of Construction (CD-2/3) on August 19, 2022, a major milestone for the project.

*Spherical tokamak mode discovered after a 13-year hunt.*
Researchers at PPPL had found that no matter how much heat they poured into the NSTX plasma, the maximum temperature remained the same. Although the experimental result was clear and repeatable, the physical mechanism causing this trend remained a mystery until this year. Now, scientists have simulated a plasma instability, triggered when the pressure of the plasma reaches a threshold value, that may explain the observed phenomenon. The discovery of this instability is expected to improve designs of future fusion pilot plants.

*Precise stellarator quasi-symmetry can be achieved with electromagnetic coils.*
Magnetic fields with quasi-symmetry are known to provide good confinement of charged particles and plasmas, but the extent to which quasi-symmetry can be achieved in practice has remained an open question. Recently, toroidal magnetic fields that are quasi-symmetric to orders of magnitude higher precision than previously known fields were discovered for the first time. These fields can be accurately produced with the use of electromagnetic coils of only moderate engineering complexity. When scaled to a reactor, the best-found configuration loses only 0.04 percent of energetic particles.

*High energy density research has the potential to advance cancer treatments.*
More than 50 percent of all cancer patients are treated with radiation as the current standard of care. Of critical importance in radiotherapy is targeting tumors while sparing the healthy tissues. Supported by the LaserNetUS initiative, scientists developed a new platform for ultra-high dose rate radiobiology using a high-intensity laser. Cell survival measurements of human normal and tumor cells exposed to laser-driven protons showed promising results. These findings and the new platform have the potential to advance cancer radiotherapy with compact high-intensity lasers.

*Low-temperature plasma for removing micropollutants from fresh water.*
Microcontaminants such as per- and poly-fluoroalkyl substances in fresh water are challenging since they do not degrade and are not easily removed from water by conventional means. One of the most effective ways to degrade these harmful chemicals is using a nonthermal plasma in contact with water. A plasma-liquid interface has been shown to contain a variety of reactive species capable of initiating reduction-oxidation reactions, important for degrading these harmful chemicals. Researchers from the University of Washington at St. Louis and Princeton Collaborative Research Facility at PPPL have carried out controlled redox reactions to infer the reduction potential at the plasma-liquid interface from measured plasma parameters such as electron number density and temperature and obtained promising results.

*Further progress in U.S. Contributions to ITER project*
The U.S. Contributions to ITER project successfully completed thermal-cycle testing of Central Solenoid Magnet Module 4, awarded subcontracts for Tritium Exhaust Processing system prototypes, and further advanced the Vacuum Auxiliary system design.

## Fusion Energy Sciences
## Burning Plasma Science: Foundations

**Description**

Burning Plasma Science: Foundations subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials and supports the development of a competitive fusion power industry in the U.S. through partnerships with the private sector.

Among the activities supported by this subprogram are:

- Research at major experimental user facilities aimed at resolving fundamental advanced tokamak and spherical tokamak science issues.
- Support for public-private partnerships with the Fusion Development Milestone Program and through INFUSE.
- Research on IFE science and technology.
- Research on small-scale magnetic confinement experiments.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Research on technologies needed to support continued improvement and capabilities of current and future facilities.
- Infrastructure improvements at PPPL and other DOE laboratories where fusion research is ongoing.
- Research on AI/ML relevant to fusion and plasma science.

Research in the Burning Plasma Science: Foundations area in FY 2024 will focus on high-priority scientific issues in alignment with the recommendations in the recent FESAC LRP and in support of the BDV for commercial fusion energy.

Advanced Tokamak

The Advanced Tokamak (AT) element supports a broad range of activities focused on closing gaps in the scientific and technical basis for the tokamak approach to fusion energy. The advanced tokamak is an integrated fusion energy system that simultaneously achieves a stationary plasma state characterized by high plasma pressure, high fractions of self-generated plasma current, adequate heat and particle confinement, and levels of heat and particle exhaust compatible with plasma-facing surfaces. The AT activity comprises several research lines to support the accompanying R&D in these areas, including the DIII-D National Fusion Facility, small-scale AT research, and Enabling R&D.

The DIII-D user facility at General Atomics is the largest magnetic fusion research experiment in the U.S. It can sustain plasmas at temperatures relevant to burning plasma conditions. Its extensive set of advanced diagnostic systems and extraordinary flexibility to explore various operating regimes make it a world-leading tokamak research facility. The current DIII-D five-year plan aims to deliver three major goals: (1) enable a successful ITER research program for both pulsed and steady-state operational scenarios; (2) develop the physics basis for and validation of the AT path to an FPP; and (3) advance the physics understanding of fusion science and technology across a broad front, developing validated predictive capabilities to project solutions to future devices. Small-scale AT research is complementary to the efforts at the major user facilities, providing rapid and cost-effective development of new techniques and exploration of new concepts.

Enabling R&D is aimed at advancing magnet, heating, and fueling technologies that support the confinement and operation of fusion plasmas in both current and future facilities. The Fusion Energy R&D Center for Enabling Technologies will integrate cross-cutting research to enable the next generation of fusion technologies that address both public and private FPP efforts.

Spherical Tokamak

The NSTX-U user facility at PPPL is designed to explore the physics of plasmas confined in a spherical tokamak (ST) configuration, characterized by a compact (apple-like) shape. If the predicted ST energy confinement improvements are experimentally realized in NSTX-U, then the ST might provide a more compact FPP than other plasma confinement geometries. NSTX-U recovery efforts will ensure reliable plasma operations of the facility for the future.

Small-scale ST plasma research involves high-risk, high-reward experimental efforts to provide data for this confinement concept. These efforts can help confirm theoretical models and simulation codes that support the development of an experimentally validated predictive capability for fusion plasmas.

Theory & Simulation

The Theory and Simulation activity is a key component of the FES program's strategy to develop the predictive capability needed for a sustainable fusion energy source. An experimentally validated predictive capability can minimize risk in future development steps and shorten the path toward the development of fusion energy, including the design of FPP concepts. This activity includes three interrelated but distinct elements: Theory, SciDAC, and Advanced Computing.

The Theory element is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of fusion plasmas. The research ranges from foundational analytic theory to mid- and large-scale computational work with the use of high-performance computing resources.

The FES SciDAC element, part of the SC-wide SciDAC program, is aimed at accelerating scientific discovery in fusion plasma science by capitalizing on SC investments in leadership-class computing systems and associated advances in computational science in partnership with ASCR. The portfolio selected in FY 2023 expands the scope of the program from whole-device modeling to whole-facility modeling, addressing recommendations in the FESAC LRP and provides a consistent set of high-fidelity tools for design and performance assessment of FPP concepts. In addition, a new integrated Fusion Energy R&D Center for Advanced Simulations will be established leveraging research performed by the SciDAC partnerships, to develop and apply predictive simulation tools that address both public and private FPP efforts.

The Advanced Computing element supports efforts that address the growing data needs of fusion research, resulting from both experimental and large-scale simulation efforts, by investing in enhanced data infrastructure capabilities. FES will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes.

GPP-GPE Infrastructure

This activity supports critical general infrastructure (e.g., utilities, roofs, roads, facilities, environmental monitoring, and equipment) at the PPPL site and other DOE laboratories where fusion research is ongoing.

Public-Private Partnerships

INFUSE provides private-sector fusion companies with access to world-class expertise and capabilities available at DOE's national laboratories and U.S. universities to overcome critical scientific and technological hurdles in fusion energy development. Topical areas supported by INFUSE include enabling technologies, materials science, diagnostics, modeling and simulation, and access to unique fusion experimental capabilities.

The Fusion Development Milestone Program aims to accelerate progress toward the development of commercial fusion energy by establishing partnerships with the private sector. It represents a first step toward the implementation of the Administration's BDV for commercial fusion energy. Key goals of this program in the near term include the achievement of preliminary designs and technology roadmaps for an FPP and enabling significant performance improvements of FPP concepts.

Artificial Intelligence and Machine Learning

This program supports the application of AI/ML techniques in partnership with data and computational scientists through the establishment of multi-institutional, interdisciplinary collaborations. Supported activities encompass multiple FES areas, including magnetic fusion, materials science, and discovery plasma science, and contribute to the development of FPP design tools. Activities include the development of fusion data resources and integrated data analysis and modeling tools.

Strategic Accelerator Technology

The objective is to leverage expertise across SC to maximize R&D progress in high-temperature superconducting (HTS) magnets for future facilities. A key aspect is the support of the High Field Vertical Magnet Test Stand at Fermi National Accelerator Laboratory, jointly funded with the SC High Energy Physics program, which will have world-leading capability for testing conductors. The Test Stand should be completed in FY 2024. Funding was not requested in FY 2023 or FY 2024 for this activity.

Inertial Fusion Energy (IFE)

This activity supports the development of the scientific foundations and technologies for IFE. These include advancing theory and modeling of laser-plasma instabilities, evaluating and improving target design and fabrication and robustness with respect to ignition and gain, investigating alternate concepts and advanced fuels, reducing the cost of IFE drivers and increasing the damage threshold optics and crystals, developing IFE target injectors capable of reaching reactor-relevant velocities without damaging the target or its fuel layer, and increasing the number of experiments at existing large-scale facilities.

## Fusion Energy Sciences
## Burning Plasma Science: Foundations

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Burning Plasma Science: Foundations** | **$345,122** | **$482,072** | **+$136,950** |
| Advanced Tokamak | $134,122 | $157,722 | +$23,600 |
| Funding supports 20 weeks of operations at the DIII-D facility, which is 90 percent of optimal. Research continues to exploit innovative current drive systems to assess their potential as actuators for a fusion pilot plant and to optimize plasma performance. Upgrades include increasing electron cyclotron power, completing the installation of the high-field-side lower hybrid current drive system and commencing experiments, and increasing the power of the neutral beam injection system.<br><br>Funding continues to support research in high-temperature superconducting magnet technology, plasma heating and current drive, plasma fueling, and other enabling technologies for fusion.<br><br>Funding continues support for small-scale AT experiments. | | The Request will support 14 weeks of operations in FY 2024 at the DIII-D facility as part of a two-year campaign that will deliver a total of 36 weeks of operations. The program will support a broader user base, completion of facility enhancements, refurbishment of essential equipment, research needed for ITER and a future FPP, and training opportunities for the next generation of fusion scientists. The Request will support the Fusion Energy R&D Center for Enabling Technologies and continued support for magnets, plasma heating and fueling. The Request will continue support for small-scale AT experiments at universities. | The increase will support DIII-D operations, research aligned with the FESAC LRP, major upgrades, training activities, and the Fusion Energy R&D Center for Enabling Technologies. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Spherical Tokamak | $107,000 | $92,350 | -$14,650 |
| Funding for operations supports the remaining NSTX-U Recovery fabrication and machine reassembly activities and begins supporting the commissioning of auxiliary heating systems in preparation for plasma operations. Research efforts focus on studies utilizing a variety of domestic and international spherical tokamak facilities; these studies are aligned with the mission of the NSTX-U program, which contributes to the development of the design basis for a next-step FPP.<br><br>Funding continues supporting small-scale ST studies dedicated to simplifying and reducing the capital cost of future fusion facilities. | | The Request for operations funding will support the remaining NSTX-U Recovery fabrication and machine reassembly activities and continue to support the commissioning of auxiliary heating systems in preparation for plasma operations. Research efforts will focus on studies utilizing a variety of domestic and international spherical tokamak facilities; these studies are aligned with the mission of the NSTX-U program, which contributes to the development of the design basis for a next-step FPP. The Request will continue to support small-scale ST studies dedicated to simplifying and reducing the capital cost of future fusion facilities. | Operations funding will support the continuation of the NSTX-U Recovery activities. Research funding will focus on the highest-priority scientific objectives, which are aligned with the FESAC LRP. |
| Theory & Simulation | $50,500 | $70,000 | +$19,500 |
| Funding supports efforts at universities, national laboratories, and private industry focused on the fundamental theory of magnetically confined plasmas and the development of a predictive capability for magnetic fusion.<br><br>Funding supports the SciDAC portfolio with emphasis on whole-facility modeling, in alignment with the LRP recommendations. It also provides a consistent set of high-fidelity tools for design and performance assessment of FPP concepts.<br><br>Funding also supports Advanced Computing, including investments in enhanced data infrastructure capabilities to address the growing data needs of fusion research. | | The Request will continue to support efforts at universities, national laboratories, and private industry focused on the fundamental theory of magnetically confined plasmas.<br><br>The Request will continue to support the SciDAC portfolio selected in FY 2023 and the development of a consistent set of high-fidelity simulation tools for design and performance assessment of FPP concepts. A new integrated Fusion Energy R&D Center for Advanced Simulations will also be established to develop and apply predictive simulation tools that address both public and private FPP efforts.<br><br>The Request will continue to support Advanced Computing, including investments in enhanced data infrastructure capabilities. | Research efforts will focus on the highest-priority activities, including continuing support of the SciDAC portfolio and the establishment of the Fusion Energy R&D Center for Advanced Simulations.<br><br>FES will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| GPP-GPE Infrastructure | $1,500 | $1,000 | -$500 |
| Funding supports infrastructure improvements, repair, maintenance, and environmental monitoring at PPPL and other DOE laboratories. | | The Request will continue to support infrastructure improvements, repair, maintenance, and environmental monitoring at PPPL and other DOE laboratories. | This activity will focus on the highest-priority infrastructure improvements. |
| Public-Private Partnerships | $31,000 | $135,000 | +$104,000 |
| Funding continues to support the INFUSE program, providing the private sector with access to DOE developed capabilities at both national laboratories and universities. Funding also continues support for a milestone-based fusion development program through partnerships with the private sector. | | The Request will continue to support public-private partnerships through the Fusion Development Milestone Program and the INFUSE program which connects the private sector to DOE developed capabilities at national laboratories and universities. | The increased funding will expand the Fusion Development Milestone Program which supports FPP preliminary designs and technology roadmaps to accelerate progress toward an FPP, by making additional awards and/or enhancing existing efforts. |
| Artificial Intelligence and Machine Learning | $11,000 | $11,000 | $ — |
| Funding supports a competitive solicitation to identify multi-institutional collaborations focused on deploying AI/ML applications across FES program elements. | | The Request will continue support for research awards made in FY 2023. The program will include deployment of distributed fusion data capabilities that support the development of FPP design tools and efficient utilization of fusion facilities. | No change. |
| Inertial Fusion Energy (IFE) | $10,000 | $15,000 | +$5,000 |
| Funding supports the new IFE program focused on the priority research opportunities in scientific foundations and technologies that were identified in the FY 2022 Basic Research Needs Workshop for IFE. | | The Request will support the priority research opportunities identified in the FY 2022 Basic Research Needs Workshop for IFE. | Research efforts will focus on the highest priority activities. |

*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, excluding facility operations.*

## Fusion Energy Sciences
## Burning Plasma Science: Long Pulse

### Description

The Burning Plasma Science: Long Pulse subprogram explores new and unique scientific regimes that can be achieved primarily with long-duration superconducting international machines and addresses the development of the materials and technologies required to withstand and sustain a burning plasma. The key objectives of this area are to utilize these unique capabilities to accelerate our scientific understanding of how to control and operate a burning plasma and contribute to the design of a FPP. This subprogram includes long-pulse international tokamak and stellarator research, domestic stellarator research, fusion nuclear science, materials research, and future facilities studies.

<u>Long Pulse: Tokamak</u>

This activity supports interdisciplinary teams from multiple U.S. institutions for collaborative research aimed at advancing the scientific and technology basis for sustained long-pulse burning plasma operation in tokamaks. Collaborative research on international facilities with capabilities not available in the U.S. aims at building the science and technology required to control, sustain, and predict a burning plasma, as described in the FESAC LRP. Multidisciplinary teams work together to close key gaps in the design basis for an FPP, especially in the areas of plasma-material interactions, transients control, and current drive for steady-state operation. The team approach provides unique training experiences for the next generation of fusion scientists, as well as the opportunity to establish international collaborations in new areas.

<u>Long Pulse: Stellarators</u>

This activity supports research on stellarators, which offer the potential of steady-state confinement regimes without transient events such as disruptions. The participation of U.S. researchers on the Wendelstein 7-X (W7-X) in Germany provides an opportunity to develop and assess divertor configurations for long-pulse, high-performance stellarators, including the provision of a pellet fueling injector for quasi-steady-state plasma experiments. U.S. researchers will play key roles in developing the operational scenarios and hardware configuration for high-power, steady-state operation, an accomplishment that will advance the performance/pulse length frontier for fusion. The U.S. is participating fully in W7-X research and has full access to data. Domestic compact stellarator research is focused on improvement of the stellarator magnetic confinement concept through quasi-symmetric shaping of the toroidal magnetic field.

<u>Materials & Fusion Nuclear Science</u>

The Materials and Fusion Nuclear Science activities seek to address the significant scientific and technical gaps between current-generation fusion experiments and future fusion nuclear devices, such as an FPP and, later, a first-of-a-kind fusion power plant. These fusion nuclear devices will produce heat, particle, and neutron fluxes that significantly exceed those in present confinement facilities, and new approaches and materials need to be developed and engineered for the anticipated extreme reactor conditions. The goal of Materials research is to develop a scientific understanding of how the properties of materials evolve and degrade due to fusion neutron and plasma exposure, to safely predict the behavior of materials in fusion reactors. The goal of Fusion Nuclear Science research is to advance the neutronics, blanket and fuel cycle, and safety analysis that are required to harness fusion power. To help address these gaps, two new integrated Fusion Energy R&D Centers will be initiated. The SC initiative on Fundamental Science to Transform Advanced Manufacturing has implications for both Materials and Fusion Nuclear Science.

Developing solutions for this scientifically challenging area requires innovative types of research along with new experimental capabilities. In the near term, this includes the MPEX MIE project, which will enable solutions for new plasma-facing materials, and a fusion neutron source, which will provide unique material irradiation capabilities for understanding materials degradation in the fusion nuclear environment.

<u>Future Facilities Studies</u>

The Future Facilities Studies activity supports studies and research for required facilities that are critical to the development of fusion energy and address needs of both the public and private sectors.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Burning Plasma Science: Long Pulse** | **$81,000** | **$184,674** | **+$103,674** |
| Long Pulse: Tokamak | $15,000 | $15,000 | $ — |
| Funding supports the second budget period for U.S. teams conducting research on international facilities, which helps close key gaps in the design basis for an FPP. | | The Request will support the final budget period for U.S. teams conducting research on international facilities. Activities will focus on exploitation of tokamak systems installed and commissioned in prior years. | No change. |
| Long Pulse: Stellarators | $7,500 | $7,500 | $ — |
| In the next W7-X experimental campaign, funding supports research on turbulent transport, stability and edge physics, and boundary and scrape-off-layer physics. Funding also supports experiments on domestic stellarators in regimes relevant to the mainline stellarator magnetic confinement efforts. | | The Request will support research on W7-X to control the plasma density in real time to minimize turbulence and to improve plasma confinement scenarios. The Request will also support continued research on compact domestic stellarators. | No change. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Materials & Fusion Nuclear Science | $56,500 | $147,500 | +$91,000 |
| Funding supports research activities in these areas, consistent with the recommendations of the FESAC Long-Range Plan. This includes continued development of critical technologies for an FPP, such as plasma-facing components, structural and functional materials, and breeding-blanket and tritium-handling systems. Funding also continues to support research into advanced manufacturing technologies consistent with the SC initiative in this area. Finally, funding supports the MPEX MIE project, with efforts focused on construction following the combined baselining and start of construction that was received on August 22, 2022. | | The Request will enable growth in the critical areas of materials and nuclear science research, which is vital for the deployment of an FPP. The focus of this program will be development of plasma-facing components, structural and functional materials, and breeding-blanket and tritium-handling systems. The Request will also continue to support research into advanced manufacturing technologies, consistent with the SC initiative in this area. Finally, the Request will continue to support the MPEX MIE project, consistent with the approved baseline for the project during the construction phase. | Funding will support the development of two new integrated Fusion Energy R&D Centers in the areas of structural/plasma facing materials and blanket/fuel cycle which will be key in facilitating both public and private FPP efforts. Support will continue for advanced manufacturing research. Funding for the MPEX project will increase to accommodate the project's new cost/schedule baseline. |
| Future Facilities Studies | $2,000 | $14,674 | +$12,674 |
| Funding supports the Future Facilities Studies activity to conduct design studies for an integrated fusion plant, e.g., an FPP, consistent with the FESAC Long-Range Plan recommendation. | | The Request will support conducting preliminary studies and research for a future fusion neutron source facility that is critical to the development and evaluation of materials for fusion energy and can meet the performance requirements identified in recent community workshops. | Funding will support R&D activities for a future fusion neutron source facility that was identified as the highest-priority new facility in the FESAC LRP. |

*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, excluding facility operations.*

## Fusion Energy Sciences
## Burning Plasma Science: High Power

### Description

The Burning Plasma Science: High Power subprogram supports research on experimental facilities that can produce large amounts of fusion power and maintain self-heated plasmas for hundreds of seconds, allowing scientists to study the burning plasma state. In a burning or self-heated plasma, at least half of the power needed to maintain the plasma at thermonuclear temperatures is provided by heating sources within the plasma. For the most common deuterium-tritium (D-T) fuel cycle, this internal heating source is provided by the energy of the helium nuclei (alpha particles) which are produced by the D-T reaction itself. A common figure of merit characterizing the proximity of a plasma to burning plasma conditions is the fusion gain or "Q", which is defined as the ratio of the fusion power produced by the plasma to the heating power injected into the plasma that is necessary to bring it, and keep it, at thermonuclear temperatures.

ITER will be the world's first burning plasma experiment that is expected to produce 500 MW of fusion power for pulses of 400 seconds, attaining a fusion gain of Q = 10. It is a seven-member international collaborative project to design, build, operate, and decommission a first-of-a-kind international fusion research facility in St. Paul-lez-Durance, France, aimed at demonstrating the scientific and technological feasibility of fusion energy. In addition to the U.S., the six other ITER members are China, the European Union, India, Japan, South Korea, and Russia. More information about the U.S. Contributions to the ITER project is provided in the FES Construction section.

<u>ITER Research</u>

To ensure that the U.S. fusion community takes full advantage of ITER research operations after First Plasma, it is necessary to organize a U.S. ITER research team to be ready on day one to benefit from the scientific and technological opportunities offered by ITER. Building such a team was also among the highest recommendations in the recent FESAC LRP. A Basic Research Needs workshop was held in FY 2022 to identify the highest-priority research and engagement opportunities for the U.S. to maximize the benefit of its participation in ITER. In addition, this activity supports the efficient dissemination of ITER data in support of FPP activities.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted | |
|---|---|---|---|---|
| **Burning Plasma Science: High Power** | **$2,000** | **$2,000** | | **$ —** |
| ITER Research | $2,000 | $2,000 | | $ — |
| Funding supports the highest-priority research and engagement opportunities identified in the Basic Research Needs workshop that was held in FY 2022. | | The Request will continue supporting the highest-priority research and engagement opportunities identified in the Basic Research Needs workshop that was held in FY 2022, as well as supporting the dissemination of ITER data in support of FPP activities. | No change. | |

*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, excluding facility operations.*

**Fusion Energy Sciences**
**Discovery Plasma Science**

**Description**

Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to understand the plasma universe and to learn how to control and manipulate plasmas for a broad range of applications. Plasma science is not only fundamental to understanding the nature of visible matter throughout the universe, but also to achieving the eventual production and control of fusion energy. Discoveries in plasma science are leading to an ever-increasing array of practical applications, some of them relevant to clean energy technologies, including synthesis of nanomaterials and artificial diamonds, efficient solar and fuel cells, fabrication of microelectronics and opto-electronic devices, energy-efficient lighting, low-heat chemical-free sterilization processes, tissue healing, combustion enhancement, satellite communication, laser-produced isotopes for positron emission tomography, and extreme ultraviolet lithography.

The Discovery Plasma Science subprogram is organized into the following activities:

<u>Plasma Science and Technology</u>

The Plasma Science and Technology (PS&T) activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These areas encompass extremes of the plasma state, ranging from the very small (several atom systems) to the extremely large (plasma structure spanning light years in length), from the very fast (attosecond processes) to the very slow (hours), from the diffuse (interstellar medium) to the extremely dense (diamond compressed to tens of gigabar pressures), and from the ultra-cold (tens of micro-kelvin degrees) to the extremely hot (stellar core). Advancing the science of these unexplored areas creates opportunities for new and unexpected discoveries with potential to be translated into practical applications. These activities are carried out on small- and mid-scale experimental collaborative research facilities.

The PS&T portfolio includes research activities in the following areas:

- General Plasma Science (GPS): Research at the frontiers of basic and low-temperature plasma science, including dynamical processes in laboratory, space, and astrophysical plasmas, such as magnetic reconnection, dynamo, shocks, turbulence cascade, structures, waves, flows and their interactions; behavior of dusty plasmas, non-neutral, single-component matter or antimatter plasmas, and ultra-cold neutral plasmas; plasma chemistry and processes in low-temperature plasma, interfacial plasma, synthesis of nanomaterials, and interaction of plasma with surfaces, materials or biomaterials.

- High Energy Density Laboratory Plasmas (HEDLP): Research directed at exploring the behavior of plasmas at extreme conditions of temperature, density, and pressure, including relativistic high energy density (HED) plasmas and intense beam physics, magnetized HED plasma physics, multiply ionized HED atomic physics, HED hydrodynamics, warm dense matter, nonlinear optics of plasmas and laser-plasma interactions, laboratory astrophysics, and diagnostics for HEDLP.

The PS&T activity stewards world-class plasma science experiments and collaborative research facilities at small and intermediate scales. These platforms not only facilitate addressing frontier plasma science questions, but also provide critical data for the verification and validation of plasma science simulation codes and comparisons with space observations. This effort maintains strong partnerships with NSF and NNSA.

<u>Measurement Innovation</u>

The Measurement Innovation activity supports the development of world-leading transformative and innovative diagnostic techniques and their application to new, unexplored, or unfamiliar plasma regimes or scenarios. The challenge is to develop diagnostics with the high spatial, spectral, and temporal resolution necessary to validate plasma physics models used to predict the behavior of fusion plasmas.

Quantum Information Science

The Quantum Information Science (QIS) activity supports basic research in QIS that can have a transformative impact on FES mission areas, including fusion and discovery plasma science, as well as research that takes advantage of unique FES-enabled capabilities to advance QIS development. The direction of the QIS efforts is informed by the findings of the 2018 Roundtable meeting[c] that was held to explore the unique role of FES in this rapidly developing high-priority crosscutting field and help FES build a community of next-generation researchers in this area. Among the areas supported by the QIS subprogram are quantum simulation capabilities for fusion and plasma science, quantum sensing for plasma diagnostics, HEDLP techniques to form novel quantum materials, and plasma science tools to simulate and control quantum systems. FES also participates in supporting the SC-wide crosscutting QIS research centers.

Advanced Microelectronics

The Advanced Microelectronics activity supports discovery plasma research in a multi-disciplinary, co-design framework to accelerate plasma-based microelectronics fabrication and advance the development of microelectronic technologies. The direction of the Advanced Microelectronics efforts is informed by the FESAC LRP, the NASEM Plasma 2020 decadal survey report, a FY 2022 workshop on plasma science for microelectronics nanofabrication, and the Creating Helpful Incentives to Produce Semiconductors for America (CHIPS and Science) Act of 2022. New Microelectronics Science Research Centers as authorized under the Micro Act will focus on a multi-disciplinary co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.

Other FES Research

This activity supports the Postdoctoral Research Program, which supports postdocs in the fusion and plasma science research areas for two years, and multiple fusion and plasma science outreach programs that work to increase fusion and plasma science literacy among the general public, K-12, undergraduate students, and graduate students. Other activities being supported include the U.S. Burning Plasma Organization (USBPO), peer-reviews for solicitations and project activities, FESAC, and other programmatic activities.

Reaching a New Energy Sciences Workforce (RENEW)

This activity supports the RENEW initiative to provide research and student training opportunities with academic institutions under-represented in the U.S. Science and Technology ecosystem and aligns with a recommendation in the FESAC LRP. In addition, this initiative expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research.

Funding for Accelerated, Inclusive Research (FAIR)

This activity supports the FAIR initiative, which will provide focused investment on enhancing research on clean energy, climate, and related topics at HBCUs, minority-serving institutions (MSIs) and emerging research institutions (ERIs).

Accelerate Innovations in Emerging Technologies (Accelerate)

This activity supports the Accelerate initiative, which will support cross-cutting scientific research to accelerate the transition of science advances to energy technologies.

Established Program to Stimulate Competitive Research (EPSCoR)

This activity provides support for the DOE EPSCoR program that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single principal investigator and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards.

[c] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf

## Fusion Energy Sciences
## Discovery Plasma Science

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Discovery Plasma Science** | **$82,100** | **$91,750** | **+$9,650** |
| Plasma Science and Technology | $46,000 | $39,000 | -$7,000 |
| *General Plasma Science* | *$19,000* | *$20,000* | *+$1,000* |
| Funding supports core research at the frontiers of basic and low temperature plasma science, as well as operations of and user-led experiments on collaborative research facilities. | | The Request will continue to support core research at the frontiers of basic and low-temperature plasma science, as well as external collaborations and operations of collaborative research facilities. | Funding will enhance core research in general plasma science. |
| *High Energy Density Laboratory Plasmas* | *$27,000* | *$19,000* | *-$8,000* |
| Funding supports basic and translational science, MEC and LaserNetUS operations and user support, and the SC-NNSA joint program. | | The Request will continue to support basic and translational science, MEC and LaserNetUS operations and user support, and the SC-NNSA joint program. | Funding will support highest-priority activities. |
| Measurement Innovation | $2,915 | $2,000 | -$915 |
| Funding supports the development of innovative and transformative diagnostics. | | The Request will continue to support the development of innovative and transformative diagnostics. | Funding will support highest-priority activities. |
| Quantum Information Science | $10,000 | $10,000 | $ — |
| Funding supports priority research opportunities identified in the 2018 Roundtable Workshop Report. It also continues to support the SC QIS Research Centers. | | The Request will continue to support core research awards selected in FY 2023. It will also continue to support the SC QIS Research Centers. | No change. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Advanced Microelectronics | $5,000 | $15,000 | +$10,000 |
| Funding supports high priority research and the continuation of laboratory awards made through a competitive lab call and review in FY 2021. | | The Request will support priority research opportunities identified in the FY 2022 microelectronics workshop. New Microelectronics Science Research Centers are established, as authorized under the Micro Act. | Funding will support new microelectronics research centers. |
| Other FES Research | $4,185 | $2,500 | -$1,685 |
| Funding supports programmatic activities such as the FES Postdoctoral Research Program, the FES Fusion and Plasma Science Outreach programs, USBPO, peer reviews for FES solicitations and project activities, and FESAC. | | The Request will continue to support programmatic activities such as the FES Postdoctoral Research Program, the FES Fusion and Plasma Science Outreach programs, USBPO, peer reviews for FES solicitations and project activities, and FESAC. | Funding will support highest-priority activities. |
| Reaching a New Energy Sciences Workforce (RENEW) | $6,000 | $11,250 | +$5,250 |
| Funding supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions under-represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC LRP. | | The Request will continue to support targeted efforts to increase participation and retention of individuals from underrepresented groups in FES research activities, including a RENEW graduate fellowship. | This increase will broaden RENEW activities within the FES research portfolio. |
| Funding for Accelerated, Inclusive Research (FAIR) | $2,000 | $4,000 | +$2,000 |
| Funding supports the Funding for Accelerated, Inclusive Research (FAIR) initiative, which provides focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice communities. | | The Request will continue to support the Funding for Accelerated, Inclusive Research (FAIR) initiative efforts to increase participation and retention of individuals from underrepresented groups in FES research activities. | The funding will enhance support of the FAIR initiative within the FES research portfolio. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Accelerate Innovations in Emerging Technologies | $4,000 | $6,000 | +$2,000 |
| Funding supports the Accelerate initiative, which supports scientific research to accelerate the transition of science advances to energy technologies. | | The Request will continue to support scientific research to accelerate the transition of science advances to energy technologies. | The funding will enhance support of the Accelerate initiative within the FES research portfolio. |
| Established Program to Stimulate Competitive Research (EPSCoR) | $2,000 | $2,000 | $ — |
| FY 2023 EPSCoR funding emphasizes Implementation Awards to larger multiple investigator teams. Investment continues in early career research faculty from EPSCoR-designated jurisdictions and in co-investment with other programs for awards to eligible institutions. | | The Request will support EPSCoR State-National Laboratory Partnership awards and early career awards. | No change. |

*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, excluding facility operations.*

**Fusion Energy Sciences**
**Construction**

**Description**
This subprogram supports all line-item construction projects for the entire FES program. All Total Estimated Costs (TEC) are funded in this subprogram.

<u>20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC</u>
The National Academies of Sciences, Engineering, and Medicine (NASEM) 2017 report "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light"[d] recommended that "The Department of Energy should plan for at least one large-scale open-access high-intensity laser facility that leverages other major science infrastructure in the Department of Energy complex." The MEC Petawatt Upgrade project will provide a collaborative user facility that utilizes the LCLS-II light source and is focused on High-Energy-Density Science that will address this NASEM recommendation as well as maintain U.S. leadership in this important field of study. The project received Critical Decision-1 (CD-1), "Approve Alternative Selection and Cost Range," on October 4, 2021. The FY 2024 Request of $10,000,000 will support preliminary design activities. The estimated total project cost range is $264,000,000 to $461,000,000.

<u>14-SC-60 U.S. Contributions to ITER</u>
The ITER facility, currently under construction in Saint Paul-lez-Durance, France, is more than 75 percent complete to First Plasma. ITER is designed to provide fusion power output approaching reactor levels of hundreds of megawatts, sustained as a burning plasma for hundreds of seconds. ITER is a necessary next step toward developing a carbon-free fusion energy pilot plant and will help keep the U.S. competitive internationally. Construction of ITER is a collaboration among the U.S., European Union, Russia, Japan, India, Korea, and China, governed under an international agreement (the "ITER Joint Implementing Agreement"). As a co-owner of ITER, the U.S. contributes in-kind hardware components and financial contributions for the ITER Organization (IO) management and overhead (e.g., design integration, nuclear licensing, quality control, safety, overall project management, and installation and assembly of the components provided by the U.S. and other Members). The U.S. also has over 50 nationals employed by the IO and working at the site.

An independent review of CD-2, "Approve Performance Baseline," for the U.S. Contributions to ITER—First Plasma subproject (SP-1) was completed in November 2016 and then subsequently approved by the Project Management Executive on January 13, 2017, with a total project cost of $2,500,000,000. Responding to Congressional direction in the FY 2021 Appropriations Act, the project aims to baseline the entire project, which will include a rebaseline of SP-1 scope, baseline of Post-First Plasma (SP-2) scope, and financial contributions for the project to CD-4, "Approve Project Completion", by September 2023. SP-1 scope is currently 70 percent complete and will include the delivery of the completed Central Solenoid Magnet System, Steady-state Electrical Network, and Disruption Mitigations System. SP-1 also contains a portion of design and fabrication for the remaining nine systems Scope associated with SP-2 will deliver the balance of completed work to include the Tritium Exhaust Processing System, Ion Cyclotron Heating and Electron Cyclotron Heating Systems, diagnostics, and roughing pumps.

The FY 2024 Request of $240,000,000 will support the continued systems design, fabrication, and delivery of in-kind hardware, and financial contributions for IO construction operations. The estimated total project cost range is $4,700,000,000 to $6,500,000,000, which includes all U.S. in-kind hardware and financial construction contributions through the completion of the ITER project. Upon baselining in calendar year 2023, the range will no longer exist, and reporting will be to the approved Total Project Cost (TPC). ITER Organization will be providing an updated baseline to the ITER council in the FY 2024 timeframe. U.S. Contributions to ITER are estimated to remain within the TPC of $6,500,000.

The U.S. in-kind contribution represents 9.09 percent (1/11$^{th}$) of the overall ITER project but will provide access to 100 percent of the science and engineering associated with what will be the largest magnetically confined burning plasma experiment ever created. The U.S. involvement in ITER will help to advance the promise of carbon-free, inherently safe, and abundant fusion energy.

[d] https://www.nap.edu/read/24939/chapter/1

## Fusion Energy Sciences
## Construction

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Major Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Construction** | **$253,000** | **$250,000** | **-$3,000** |
| 20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC | $11,000 | $10,000 | -$1,000 |
| Funding supports design activities and preparation for developing a project performance baseline. | | The Request will continue to support design activities and preparation for developing a project performance baseline. | Funding will support critical preparation activities for developing the performance baseline. |
| 14-SC-60, U.S. Contributions to ITER (Historical) | $242,000 | $240,000 | -$2,000 |
| Funding supports continued design and fabrication of in-kind hardware systems and requested construction financial contributions. | | The Request will support continued design and fabrication of in-kind hardware systems and requested construction financial contributions. | Funding will support design and fabrication of in-kind hardware and fulfill the U.S. obligations for financial contributions to the ITER Organization. |

## Fusion Energy Sciences
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | | |
| Capital Equipment | N/A | N/A | 34,963 | 14,000 | 22,443 | 41,500 | +19,057 |
| Minor Construction Activities | | | | | | | |
| General Plant Projects | N/A | N/A | 1,500 | – | 1,500 | 1,000 | -500 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **36,463** | **14,000** | **23,943** | **42,500** | **+18,557** |

## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | | |
| Major Items of Equipment | | | | | | | |
| Burning Plasma Science: Long Pulse | | | | | | | |
| Material Plasma Exposure eXperiment (MPEX) | 185,803 | 62,080 | 25,000 | 14,000 | 14,000 | 25,000 | +11,000 |
| Total, MIEs | N/A | N/A | 25,000 | 14,000 | 14,000 | 25,000 | +11,000 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 9,963 | – | 8,443 | 16,500 | +8,057 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **34,963** | **14,000** | **22,443** | **41,500** | **+19,057** |

*Notes:*
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*
- *In FY 2021, additional funding of $7,996,000 above the Enacted level was provided for the MPEX MIE. The adjusted TEC Total is $108,575,000.*

**Fusion Energy Sciences**
**Minor Construction Activities**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| Total GPPs less than $5M | N/A | N/A | – | 1,500 | 1,000 | -500 |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **–** | **1,500** | **1,000** | **-500** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **–** | **1,500** | **1,000** | **-500** |

*Note:*

- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*

Burning Plasma Science: Long Pulse MIEs:

*Material Plasma Exposure eXperiment (MPEX)*

FES is developing a first-of-a-kind, world-leading experimental capability to explore solutions to the plasma-materials interactions challenge. This device, known as MPEX, will be located at ORNL and will enable dedicated studies of reactor-relevant plasma-material interactions at a scale not previously accessible to the fusion program. The overall goal of this project is to create a new class of fusion materials science enabling the study of the combined effects of fusion-relevant heat, particle, and neutron fluxes for the first time anywhere in the world. The project received CD-2/3 "Approve Performance Baseline/Start of Construction" on August 22, 2022, with a TPC of $201,000,000. The FY 2024 Request will allow the project to execute the approved performance baseline and continuation of approved long-lead procurements. MPEX scope includes the design, fabrication, installation, and commissioning of the MPEX linear plasma device, as well as associated facility and infrastructure modifications and reconfiguration.

**Fusion Energy Sciences**
**Construction Projects Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **20-SC-61, Matter in Extreme Conditions (MEC) Upgrade** | | | | | | | |
| Total Estimated Cost (TEC) | 448,700 | 23,487 | 11,000 | 10,000 | 11,000 | 10,000 | -1,000 |
| Other Project Cost (OPC) | 12,300 | 6,900 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **461,000** | **30,387** | **11,000** | **10,000** | **11,000** | **10,000** | **-1,000** |
| **14-SC-60, U.S. Contributions to ITER** | | | | | | | |
| Total Estimated Cost (TEC) | 6,429,698 | 1,855,617 | 242,000 | 256,000 | 242,000 | 240,000 | -2,000 |
| Other Project Cost (OPC) | 70,302 | 70,302 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **6,500,000** | **1,925,919** | **242,000** | **256,000** | **242,000** | **240,000** | **-2,000** |
| **Total, Construction** | | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **253,000** | **266,000** | **253,000** | **250,000** | **-3,000** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **–** | **–** | **–** | **–** | **–** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **253,000** | **266,000** | **253,000** | **250,000** | **-3,000** |

*Note:*
- *In FY 2021, funding was reduced to $800,000 for MEC OPC. The adjusted TPC with FY 2021 Current funding is $461,000,000.*

**Fusion Energy Sciences**
**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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
| **Scientific User Facilities - Type A** | | | | | |
| **DIII-D National Fusion Facility** | **120,390** | **116,643** | **130,000** | **133,600** | **+3,600** |
| Number of Users | 515 | 666 | 700 | 700 | – |
| Achieved Operating Hours | – | 818 | – | – | – |
| Planned Operating Hours | 800 | 818 | 800 | 560 | -240 |
| Unscheduled Down Time Hours | – | 226 | – | – | – |
| **National Spherical Torus Experiment-Upgrade** | **96,000** | **89,551** | **104,000** | **89,350** | **-14,650** |
| Number of Users | 351 | 307 | 300 | 373 | +73 |
| **Total, Facilities** | **216,390** | **206,194** | **234,000** | **222,950** | **-11,050** |
| Number of Users | 866 | 973 | 1,000 | 1,073 | +73 |
| Achieved Operating Hours | – | 818 | – | – | – |
| Planned Operating Hours | 800 | 818 | 800 | 560 | -240 |
| Unscheduled Down Time Hours | – | 226 | – | – | – |

*Note:*
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*

**Fusion Energy Sciences**
**Scientific Employment**

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 916 | 1,025 | 1,492 | +467 |
| Number of Postdoctoral Associates (FTEs) | 113 | 126 | 184 | +58 |
| Number of Graduate Students (FTEs) | 305 | 341 | 497 | +156 |
| Number of Other Scientific Employment (FTEs) | 1,365 | 1,530 | 2,224 | +694 |
| **Total Scientific Employment (FTEs)** | **2,699** | **3,022** | **4,397** | **+1,375** |

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

**20-SC-61 Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC**
**SLAC National Accelerator Laboratory, SLAC**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

### Summary

The FY 2024 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $10,000,000 of Total Estimated Cost (TEC) funding. The project has a preliminary estimated Total Project Cost (TPC) range of $264,000,000 to $461,000,000. Currently, this cost range encompasses the most feasible preliminary alternatives.

The future MEC Petawatt user facility will be a premier research facility to conduct experiments in the field of High Energy Density Plasmas. It will utilize the Linac Coherent Light Source II (LCLS-II) X-Ray Free-Electron Laser (XFEL) beam at SLAC to probe and characterize plasmas and extreme states of matter.

### Significant Changes

The MEC Petawatt Upgrade project was initiated in FY 2019. The project achieved CD-1, "Approve Alternative Selection and Cost Range," on October 4, 2021, and initiated the TEC-funded preliminary design phase.

FY 2022 IRA funding will be utilized to advance the project design as well as replan the path forward to CD-2/3 approval.

FY 2023 and FY 2024 funding will be used to advance the project design and develop the cost and schedule basis in support of baselining efforts planned for end of FY 2024.

A Level III Federal Project Director has been assigned to the MEC Petawatt Upgrade project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2024 | 1/4/19 | 3/9/21 | 10/4/21 | 1Q FY 2025 | Q1 FY 2025 | 1Q FY 2025 | TBD | 1Q FY 2030 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

### Project Cost History

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 23,487 | 425,213 | 448,700 | 12,300 | 12,300 | 461,000 |
| FY 2024 | 55,487 | 393,213 | 448,700 | 12,300 | 12,300 | 461,000 |

*Note:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

## 2. Project Scope and Justification

**Scope**

The scope of the MEC Petawatt Upgrade project includes the development of a user facility that couples long-pulse (1 Kilojoule or higher) and short-pulse (1 petawatt or higher) drive lasers to an X-ray source, as well as a second target chamber that will accommodate laser-only fusion and material science experiments. The lasers will be placed in a dedicated MEC experimental hall (located at the end of the LCLS-II Far Experimental Hall), composed of an access tunnel, experimental hall, control room, and associated safety systems and infrastructure.

**Justification**

The FES mission is to build the scientific foundations needed to develop a fusion energy source and to expand the fundamental understanding of matter at very high temperatures and densities. To meet this mission, there is a scientific need for a petawatt or greater laser facility, which is currently not available in the U.S. The National Academies of Sciences, Engineering, and Medicine (NASEM) 2017 study titled "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[e]" found that about 80 percent to 90 percent of the high-intensity laser systems are overseas, and all the highest-power lasers currently under construction or already built are overseas as well. The report made five recommendations that would improve the nation's position in the field, including a recommendation for DOE to plan for at least one large-scale, open-access, high-intensity laser facility that leverages other major science infrastructures in the DOE complex.

The NASEM report focuses on high-intensity, pulsed petawatt-class lasers (1 petawatt is $10^{15}$ watts). Such laser beams can drive nuclear reactions, heat matter to mimic conditions found in stars, and create electron-positron plasmas. In addition to discovery-driven science, petawatt-class lasers can generate particle beams with potential applications in medicine, intense neutron and gamma ray beams for homeland security applications, directed energy for defense applications, and radiation for extreme ultraviolet lithography.

Co-location of high-intensity lasers with existing infrastructure such as particle accelerators has been recognized as a key advantage of the U.S. laboratories over the Extreme Light Infrastructure concept in Europe. A laser facility with high-power, high-intensity beam parameters that is co-located with hard X-ray laser probing capabilities (i.e., with an X-ray wavelength that allows atomic resolution) will provide the required diagnostic capabilities for fusion discovery science and related fields. Recent research on ultrafast pump-probe experiments using the LCLS at the SLAC National Accelerator Laboratory has demonstrated exquisite ultrafast measurements of the material structural response to radiation. The upgrade includes the petawatt laser beam and the long-pulse laser beam. The latter is required to compress matter to densities relevant to planetary science and fusion plasmas.

FES is pursuing development of a new world-class petawatt laser capability to meet the FES mission and address the recommendations from the NASEM report.

The project will be conducted utilizing the project management principles described in DOE Order 413.3B*, Program and Project Management for the Acquisition of Capital Assets*.

<u>Key Performance Parameters (KPPs)</u>

The KPPs are preliminary and may change during design phase as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The project is in the conceptual design phase, and the KPPs reflect the types of parameters being considered and are notional at this stage.

[e] https://www.nap.edu/catalog/24939/opportunities-in-intense-ultrafast-lasers-reaching-for-the-brightest-light

| Performance Measure | Threshold | Objective |
|---|---|---|
| **Optical Laser Systems** | | |
| ▪ High repetition rate short pulse laser | ▪ 30 Joules of energy<br>▪ 300 fs pulse length<br>▪ 1 Hz frequency | ▪ 150 Joules of energy<br>▪ 150 fs pulse length<br>▪ 10 Hz frequency |
| ▪ High energy long pulse laser | ▪ 200 Joules of energy on target<br>▪ 10 ns pulse length 1 shot per 60 minutes | ▪ 1000 Joules of energy on target<br>▪ 10 ns pulse length 1 shot per 30 minutes |
| **X-ray Beam Delivery** | | |
| ▪ Photon energy | ▪ 5-25 keV energy delivered to target center | ▪ 5-45 keV of energy delivered to target center |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 23,487 | 23,487 | – | – |
| FY 2022 | 11,000 | 11,000 | 23,487 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 11,000 | 11,000 | 11,000 | 10,000 |
| FY 2024 | 10,000 | 10,000 | 10,000 | – |
| **Total, Design (TEC)** | **65,487** | **65,487** | **44,487** | **10,000** |
| Construction (TEC) | | | | |
| Outyears | 383,213 | 383,213 | 394,213 | – |
| **Total, Construction (TEC)** | **383,213** | **383,213** | **394,213** | **–** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 23,487 | 23,487 | – | – |
| FY 2022 | 11,000 | 11,000 | 23,487 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 11,000 | 11,000 | 11,000 | 10,000 |
| FY 2024 | 10,000 | 10,000 | 10,000 | – |
| Outyears | 383,213 | 383,213 | 394,213 | – |
| **Total, TEC** | **448,700** | **448,700** | **438,700** | **10,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 6,900 | 6,900 | 6,088 | – |
| FY 2022 | – | – | 812 | – |
| Outyears | 5,400 | 5,400 | 5,400 | – |
| **Total, OPC** | **12,300** | **12,300** | **12,300** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 30,387 | 30,387 | 6,088 | – |
| FY 2022 | 11,000 | 11,000 | 24,299 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 11,000 | 11,000 | 11,000 | 10,000 |
| FY 2024 | 10,000 | 10,000 | 10,000 | – |
| Outyears | 388,613 | 388,613 | 399,613 | – |
| **Total, TPC** | **461,000** | **461,000** | **451,000** | **10,000** |

*Note:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 42,587 | 14,787 | **N/A** |
| Design - Contingency | 22,900 | 8,700 | **N/A** |
| **Total, Design (TEC)** | **65,487** | **23,487** | **N/A** |
| Construction | 129,093 | 129,093 | **N/A** |
| Equipment | 138,076 | 138,076 | **N/A** |
| Construction - Contingency | 116,044 | 158,044 | **N/A** |
| **Total, Construction (TEC)** | **383,213** | **425,213** | **N/A** |
| **Total, TEC** | **448,700** | **448,700** | **N/A** |
| *Contingency, TEC* | *138,944* | *166,744* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | 350 | 350 | **N/A** |
| Conceptual Planning | 4,650 | 4,650 | **N/A** |
| Conceptual Design | 1,900 | 1,900 | **N/A** |
| Other OPC Costs | 3,800 | 3,800 | **N/A** |
| OPC - Contingency | 1,600 | 1,600 | **N/A** |
| **Total, Except D&D (OPC)** | **12,300** | **12,300** | **N/A** |
| **Total, OPC** | **12,300** | **12,300** | **N/A** |
| *Contingency, OPC* | *1,600* | *1,600* | ***N/A*** |
| **Total, TPC** | **461,000** | **461,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***140,544*** | ***168,344*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 23,487 | 5,000 | — | 1,000 | — | 419,213 | 448,700 |
| | OPC | 6,900 | — | — | — | — | 5,400 | 12,300 |
| | TPC | 30,387 | 5,000 | — | 1,000 | — | 424,613 | 461,000 |
| FY 2024 | TEC | 23,487 | 11,000 | 10,000 | 11,000 | 10,000 | 383,213 | 448,700 |
| | OPC | 6,900 | — | — | — | — | 5,400 | 12,300 |
| | TPC | 30,387 | 11,000 | 10,000 | 11,000 | 10,000 | 388,613 | 461,000 |

*Note:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2030 |
| Expected Useful Life | TBD |
| Expected Future Start of D&D of this capital asset | TBD |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations, Maintenance and Repair | 21,200 | TBD | 931,000 | TBD |

## 7. D&D Information

The new area being constructed for this project is under analysis at this time.

| | Square Feet |
|---|---|
| New area being constructed by this project at SLAC........................................................................ | TBD |
| Area of D&D in this project at SLAC........................................................................................... | TBD |
| Area at SLAC to be transferred, sold, and/or D&D outside the project, including area previously “banked” ........................................................................................................................................ | TBD |
| Area of D&D in this project at other sites ........................................................................................ | TBD |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously “banked” ..................................................................................................................... | TBD |
| Total area eliminated ......................................................................................................................... | TBD |

## 8. Acquisition Approach

FES is proposing that the MEC-U project be acquired by Stanford University under the SLAC Management and Operations (M&O) Contract (DE-AC02-76-SF00515) for DOE. The acquisition of large research facilities is within the scope of the DOE contract for the management and operations of SLAC and consistent with the general expectation of the responsibilities of DOE M&O contractors.

SLAC does not currently possess all the necessary core competencies to design, procure and build the laser systems. To address this, SLAC will collaborate with Lawrence Livermore National Laboratory (LLNL) and University of Rochester—Laboratory for Laser Energetics (LLE) as partners through signed Memorandum of Agreements to perform significant portions of the MEC-U laser systems scope of work. Memorandum Purchase Orders will be used to define work scopes and budgets with LLNL as funds become available. Any work accomplished through LLE will be completed using the standard DOE format university agreements. Procurements authorized by the partner institutions will utilize the approved DOE purchasing systems.

**14-SC-60 U.S. Contributions to ITER**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

### Summary

The FY 2024 Request for the U.S. ITER project is $240,000,000 of Total Estimated Cost (TEC) funding. The Total Project Cost (TPC) for the U.S. Contributions to ITER (U.S. ITER) project is $6,500,000,000, including $2,500,000,000 for Subproject-1 (SP-1), First Plasma Hardware for U.S. ITER and $900,500,000 estimated for construction cash contribution to the ITER Organization (IO). In FY 2023, the entire U.S. ITER project will be baselined, with a top-end cost range of $6,500,000,000, and includes SP-1 and SP-2 scope, as well as the total construction cash contribution. Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project. Research results from the ITER project are expected to contribute to the development of a U.S. fusion pilot plant, as well as other future fusion energy plants. Fusion energy is expected to provide a carbon-free, inherently safe energy source that will be a significant contributor to ameliorating climate change.

### Significant Changes

The U.S. ITER project was initiated in FY 2006. On January 13, 2017, U.S. ITER SP-1 achieved both Critical Decision (CD)-2, "Approve Performance Baseline," and CD-3, "Approve Start of Construction." CD-4, "Project Completion," for SP-1 is currently planned for December 2028.

The Inflation Reduction Act provided $256,000,000 to the U.S. ITER project. $66,000,000 was utilized to provide for Cash Contributions to fulfill U.S. agreements to the ITER Organization (IO). The remaining $190,000,000 will be used to significantly enhance the design and fabrication performance of project scope in FY 2023–2024 to include the full funding of the Central Solenoid agent and the Tokomak Cooling Water System (within SP-1).

In response to Congressional direction articulated in the Consolidated Appropriations Act 2021 to baseline the entire project, the full requirement to complete the U.S. Contributions to ITER project will be baselined in FY 2023.

In FY 2022, the U.S. completed efforts to reinitiate full power testing of the Central Solenoid (CS) magnet modules, as well as continuing in the design, fabrication, and delivery of additional In-kind hardware system components.

In FY 2023, the U.S. is scheduled to deliver the third and fourth (of seven) Central Solenoid magnet modules, as well as continuing the design, fabrication and delivery of additional in-kind hardware system components. The U.S. ITER project will have obligated more than $1,700,000,000 through the end of FY 2023, of which more than 80 percent is to U.S. industry, universities, and DOE laboratories. In addition, the U.S. will baseline the entire U.S. ITER project, including re-baselining SP-1 and the baselining of SP-2 per direction from Congress in the Consolidated Appropriations Act, 2021 and as a result of the IO rebaselining for the overall project due to COVID and first-of-a-kind component delivery delays, material specification and fabrication issues as well as quality challenges.

The FY 2024 Request of $240,000,000 will support the continued design and fabrication of "in-kind" hardware systems and construction financial (cash) contributions to the ITER Organization. This includes continued fabrication and delivery of the CS magnet system.

A Federal Project Director with level I certification has been assigned to this Project and is currently pursuing higher-level certification.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | CD-3 | CD-4 |
|---|---|---|---|---|---|---|
| FY 2024 | 7/5/05 | – | 1/25/08 | 1/13/17 | 1/13/17 | 1Q FY 2028 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-1 Cost Range Update | CD-1R | CD-3B | CD-4A |
|---|---|---|---|---|---|
| FY 2024 | 1/13/17 | 1/13/17 | 1/13/17 | 1/13/17 | 1Q FY 2028 |

**CD-3B** - Approval of the project starting construction under the 2017 approved baseline.
**CD-4A** - Completion of SP-1 and as such encompasses both CD-3A and CD-3B.

**Project Cost History**

At the time of CD-1 approval in January 2008, the preliminary cost range was $1,450,000,000 to $2,200,000,000. Until 2016, however, it was not possible to confidently baseline the project due to delays early in the international ITER construction schedule. Various factors (e.g., schedule delays, design and scope changes, funding constraints, regulatory requirements, risk mitigation, and inadequate project management and leadership issues in the IO at that time) affected the project cost and schedule. Shortly after the arrival of the new Director General in March 2015, the overall ITER Project was baselined for cost and schedule.

In response to a 2013 Congressional request, a DOE SC Independent Project Review (IPR) Committee assessed the project and determined that the existing cost range estimate of $4,000,000,000 to $6,500,000,000 would likely encompass the final TPC (includes SP-1, SP-2, and Cash Contributions). In preparation for baselining SP-1, based on the results of an Independent Project Review, the acting Director for the Office of Science updated the lower end of this range to reflect updated cost estimates, resulting in the current approved CD-1 Revised (CD-1R) range of $4,700,000,000 to $6,500,000,000.

FY 2023 reflects only SP-1 and associated cash contributions. Beginning in FY 2024, the entire U.S. ITER Project will be baselined per Congressional direction in the Consolidated Appropriations Act, 2021. The TPC for the entire project is projected to be $6,500,000,000.

**Subproject 1 (First Plasma Hardware for U.S. ITER) and Cash Contributions**
(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Cash Contributions | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2023 | 483,126 | 1,946,572 | — | 3,330,198 | 70,302 | 70,302 | 3,400,500 |
| FY 2024 | 439,243 | 4,663,877 | 1,067,081 | 6,429,698 | 70,302 | 70,302 | 6,500,000 |

**2. Project Scope and Justification**

ITER, currently one of the largest science experiments in the world, is a major fusion research facility under construction in St. Paul-lez-Durance, France by an international partnership of seven Members or domestic agencies, specifically, the U.S., China, the European Union, India, Korea, Japan, and the Russian Federation. ITER is co-owned and co-governed by the seven Members. The U.S. The Energy Policy Act of 2005 (EPAct 2005), Section 972(c)(5)(C) authorized U.S. participation in ITER. The Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project (Joint Implementation Agreement or JIA), signed on November 21, 2006, provides the legal framework for the four phases of the program: construction, operation, deactivation, and decommissioning. The JIA is a Congressional-Executive Hybrid Agreement that is considered "treaty-like." The other six Members entered the project by treaty. The IO is a designated international legal entity located in France.

**<u>Scope</u>**
U.S. Contributions to ITER – Construction Project Scope

The overall U.S. ITER project includes three major elements:

- In-kind Hardware systems (13 in total), built under the responsibility of the U.S., and then shipped to the ITER site for IO assembly, installation, and operation. Included in this element is cash provided in-lieu of U.S. In-kind component contributions to adjust for certain reallocations of hardware contributions between the U.S. and the IO.
- Funding to the IO to support common expenses, including ITER research and development (R&D), design and construction integration, overall project management, nuclear licensing, IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, installation, safety, quality control and operation.
- Other project costs, including R&D (other than mentioned above) and conceptual design-related activities.

The U.S. is to contribute the agreed-upon in-kind hardware to ITER, the technical components of which are currently split between SP-1 (First Plasma) and SP-2 (Post-First Plasma) subprojects.

**<u>Justification</u>**
The purpose of ITER is to investigate and conduct research in the "burning plasma" regime—a performance region that exists beyond the current experimental state of the art. Creating a self-sustaining burning plasma will provide essential scientific knowledge necessary for practical fusion power. There are two planned experimental outcomes expected from ITER. The first is to investigate the fusion process in the form of a "burning plasma," in which the heat generated by the fusion process exceeds that supplied from external sources (i.e., self-heating). The second is to sustain the burning plasma for a long duration (e.g., several hundred to a few thousand seconds), during which time equilibrium conditions can be achieved within the plasma and adjacent structures. ITER will provide a sustained burning plasma for long term experimentation which is a necessary step toward developing a fusion pilot plant.

Although not classified as a Capital Asset, the U.S. ITER project is being conducted following project management principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets,* to the greatest extent possible.

<u>Key Performance Parameters (KPPs)</u>
The U.S. Contributions to the ITER Project will not deliver an integrated operating facility, but rather in-kind hardware contributions, which represent a portion of the international ITER facility. The U.S. ITER project defines project completion as delivery and IO acceptance of the U.S. in-kind hardware. For SP-1, in some cases (e.g., Tokamak Exhaust Processing and Disruption Mitigation), only the completion of the design is required.

3. **Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 439,243 | 439,243 | 439,243 | – |
| **Total, Design (TEC)** | **439,243** | **439,243** | **439,243** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 1,096,877 | 1,096,899 | 820,795 | – |
| FY 2022 | 181,000 | 181,000 | 170,330 | – |
| FY 2022 - IRA Supp. | 190,000 | 190,000 | – | – |
| FY 2023 | 172,000 | 172,000 | 172,000 | 190,000 |
| FY 2024 | 170,000 | 170,000 | 170,000 | – |
| Outyears | 2,854,000 | 2,854,000 | 3,086,805 | – |
| **Total, Construction (TEC)** | **4,663,877** | **4,663,899** | **4,419,930** | **190,000** |
| Cash Contributions (TEC) | | | | |
| Prior Years | 60,000 | 60,000 | 60,000 | – |
| FY 2022 | 61,000 | 61,000 | 61,000 | – |
| FY 2022 - IRA Supp. | 66,000 | 66,000 | – | 66,000 |
| FY 2023 | 70,000 | 70,000 | 70,000 | – |
| FY 2024 | 70,000 | 70,000 | 70,000 | – |
| Outyears | 740,081 | 740,131 | 794,100 | – |
| **Total, Cash Contributions (TEC)** | **1,067,081** | **1,067,131** | **1,055,100** | **66,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 1,855,617 | 1,855,639 | 1,579,535 | – |
| FY 2022 | 242,000 | 242,000 | 231,330 | – |
| FY 2022 - IRA Supp. | 256,000 | 256,000 | – | 66,000 |
| FY 2023 | 242,000 | 242,000 | 242,000 | 190,000 |
| FY 2024 | 240,000 | 240,000 | 240,000 | – |
| Outyears | 3,594,081 | 3,594,131 | 3,880,905 | – |
| **Total, TEC** | **6,429,698** | **6,429,770** | **6,173,770** | **256,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 70,302 | 70,230 | 70,230 | – |
| **Total, OPC** | **70,302** | **70,230** | **70,230** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 1,925,919 | 1,925,869 | 1,649,765 | – |
| FY 2022 | 242,000 | 242,000 | 231,330 | – |
| FY 2022 - IRA Supp. | 256,000 | 256,000 | – | 66,000 |
| FY 2023 | 242,000 | 242,000 | 242,000 | 190,000 |
| FY 2024 | 240,000 | 240,000 | 240,000 | – |
| Outyears | 3,594,081 | 3,594,131 | 3,880,905 | – |
| **Total, TPC** | **6,500,000** | **6,500,000** | **6,244,000** | **256,000** |

*Notes:*

- *SP-2 is expected to be baselined in FY 2023 and when combined with SP-1 and cash contributions, will bring the entire project TPC to within the CD-1 (R) cost range of $4,700,000,000–$6,500,000,000.*
- *All Appropriations to date for the U.S. Contributions to ITER project include both funding for SP-1 and funding for Cash Contributions.*
- *Obligations and costs through FY 2022 reflect actuals; obligations and costs for FY 2023 and the outyears are estimates.*

**4. Details of Project Cost Estimate**

The overall U.S. Contributions to ITER project has an approved revised CD-1 Cost Range (CD-1R). DOE chose to divide the project hardware scope into two distinct subprojects (First Plasma SP-1, and Post-First Plasma or SP-2) so that an initial portion of the project that was mature enough to baseline could be accomplished. The baseline for SP-1 ($2,500,000,000) was approved in January 2017. Re-baselining of the entire U.S. ITER project (including SP-1, SP-2, and construction cash contribution to the IO) is planned for FY 2023.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 439,243 | 483,126 | 573,660 |
| Design - Contingency | N/A | N/A | 122,365 |
| **Total, Design (TEC)** | **439,243** | **483,126** | **696,025** |
| Construction | 3,720,360 | 1,696,355 | **N/A** |
| Equipment | N/A | N/A | 1,362,521 |
| Construction - Contingency | 943,517 | 250,217 | 371,152 |
| **Total, Construction (TEC)** | **4,663,877** | **1,946,572** | **1,733,673** |
| Cash Contributions | 1,017,000 | 900,500 | **N/A** |
| Cash Contributions Contingency | 309,578 | N/A | **N/A** |
| **Total, Cash Contributions (TEC)** | **1,326,578** | **N/A** | **N/A** |
| **Total, TEC** | **6,429,698** | **3,330,198** | **2,429,698** |
| *Contingency, TEC* | *1,253,095* | *250,217* | *493,517* |
| **Other Project Cost (OPC)** | | | |
| OPC, Except D&D | 70,302 | 70,302 | 70,302 |
| **Total, Except D&D (OPC)** | **70,302** | **70,302** | **70,302** |
| **Total, OPC** | **70,302** | **70,302** | **70,302** |
| *Contingency, OPC* | ***N/A*** | *N/A* | ***N/A*** |
| **Total, TPC** | **6,500,000** | **3,400,500** | **2,500,000** |
| ***Total, Contingency (TEC+OPC)*** | ***1,253,095*** | ***250,217*** | ***493,517*** |

*Notes:*

- *In the table above, the previous total estimate includes cash contributions estimate to align with the TPC budget request. The Baseline information represents only the SP-1 project.*
- *In the table above, the "Original Validated Baseline" reflects SP-1 only.*
- *Current total estimated design reflects work done prior to CD-2/3. SP-2 design work is accounted for in TEC Construction as part of SP-1 scope approved at CD-2/3.*

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 1,855,617 | 221,000 | — | 240,000 | — | 1,013,581 | 3,330,198 |
| | OPC | 70,302 | — | — | — | — | — | 70,302 |
| | TPC | 1,925,919 | 221,000 | — | 240,000 | — | 1,013,581 | 3,400,500 |
| FY 2024 | TEC | 1,855,617 | 242,000 | 256,000 | 242,000 | 240,000 | 3,594,081 | 6,429,698 |
| | OPC | 70,302 | — | — | — | — | — | 70,302 |
| | TPC | 1,925,919 | 242,000 | 256,000 | 242,000 | 240,000 | 3,594,081 | 6,500,000 |

## 6. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations phase is to begin with initial integrated commissioning activities with an assumed useful life of 30 to 35 years. The fiscal year in which commissioning activities begin depends on the international ITER project schedule, which currently indicates 2025. As a result of COVID-19 and other known delays, the overall ITER project is being re-baselined to update cost and schedule estimates that have an anticipated First Plasma date of December 2028.

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2035 |
| Expected Useful Life | 35 years |
| Expected Future Start of D&D of this capital asset | 2070 |

## 7. D&D Information

Since ITER is being constructed in France by a coalition of countries and will not be a DOE asset, the “one-for-one” requirement is not applicable to this project.

The U.S. Contributions to ITER decommissioning phase is assumed to begin no earlier than 30 years after the start of operations. The deactivation phase is also assumed to begin no earlier than 30 years after operations begin and will continue for a period of five years. The U.S. is responsible for 13 percent of the total decommissioning and deactivation cost; this requirement will be collected and escrowed out of research Operations funding.

## 8. Acquisition Approach

The U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory, with its two partner laboratories (Princeton Plasma Physics Laboratory and Savannah River National Laboratory), will procure and deliver in-kind hardware in accordance with the Procurement Arrangements established with the IO. The USIPO will subcontract with a variety of research and industry sources for design and fabrication of its ITER components, ensuring that designs are developed that permit fabrication, to the maximum extent possible, to use fixed-price subcontracts (or fixed-price arrangement documents with the IO) based on performance specifications, or more rarely, on build-to-print designs. USIPO will use cost-reimbursement type subcontracts only when the work scope precludes accurate and reasonable cost contingencies being gauged and established beforehand. USIPO will use best value, competitive source-selection procedures to the maximum extent possible, including foreign firms on the tender/bid list when necessary. Such procedures shall allow for cost and technical trade-offs during source selection. For the large-dollar-value subcontracts (and critical path subcontracts as appropriate), USIPO will utilize unique subcontract provisions to incentivize cost control and schedule performance. In addition, where it is cost effective and it reduces risk, the USIPO will participate in common procurements led by the IO or request the IO to perform activities that are the responsibility of the U.S.

## High Energy Physics

### Overview

The mission of the High Energy Physics (HEP) program is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time. HEP accomplishes its mission through excellence in scientific discovery in particle physics, and through stewardship of world-class scientific user facilities that enable cutting-edge research and development. HEP continues to deliver major construction projects on time and on budget and provides reliable availability and support to users for operating facilities. HEP's work allows the U.S. to remain a global leader in international particle physics research and collaboration.

Our current understanding of the elementary constituents of matter and energy and the forces that govern them is described by the Standard Model of particle physics. However, experimental measurements suggest that the Standard Model is incomplete, and that new physics may be discovered by future experiments. The May 2014 report of the Particle Physics Project Prioritization Panel (P5), "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context"[a] was unanimously approved by the High Energy Physics Advisory Panel (HEPAP) to serve the U.S. Department of Energy (DOE) and National Science Foundation (NSF) as the ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. The P5 report identified five intertwined science drivers of particle physics that provide compelling lines of inquiry with great promise to discover what lies beyond the Standard Model:

- Use the Higgs boson as a new tool for discovery;
- Pursue the physics associated with neutrino mass;
- Identify the new physics of dark matter;
- Understand cosmic acceleration: dark energy and inflation; and
- Explore the unknown: new particles, interactions, and physical principles.

The DOE and NSF charged HEPAP in December 2022 meeting to form a new P5 subpanel to formulate a ten-year plan for the field. The P5 subpanel expects to present its final report at the HEPAP meeting in late 2023.

The HEP program enables scientific discovery and supports cutting edge research and development (R&D):

- Energy Frontier Experimental Physics, where researchers accelerate particles to the highest energies ever made by humanity and collide them to produce and study the fundamental constituents of matter.
- Intensity Frontier Experimental Physics, where researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, to study some of the rarest interactions predicted by the Standard Model, and to search for new physics.
- Cosmic Frontier Experimental Physics, where researchers use naturally occurring cosmic particles and phenomena to reveal the nature of dark matter, understand the cosmic acceleration caused by dark energy and inflation, infer certain neutrino properties, and explore the unknown.
- Theoretical, Computational, and Interdisciplinary Physics provides the framework to explain experimental observations and gain a deeper understanding of nature.
- The Advanced Technology R&D subprogram fosters fundamental research into particle acceleration and detection techniques and instrumentation.

Innovative research methods and enabling technologies that emerge from R&D into accelerators, instrumentation, quantum information science (QIS), and artificial intelligence/machine learning (AI/ML) will advance scientific knowledge in high energy physics and in a broad range of related fields, advancing DOE's strategic goals for science. Many of the advanced technologies, research tools, and analysis techniques originally developed for high energy physics have proved widely applicable to other scientific disciplines as well as for health services, national security, and the private sector.

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[a] High Energy Physics Advisory Panel, Department of Energy. Report of the Particle Physics Project Prioritization Panel (P5). Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context. May 2014. https://science.osti.gov/~/media/hep/hepap/pdf/May-2014/FINAL_P5_Report_053014.pdf

**Highlights of the FY 2024 Request**

The FY 2024 Request of $1,226.3 million focuses resources toward the highest priorities in fundamental research, operation and maintenance of scientific user facilities, facility upgrades, and projects identified in the P5 report.

Key elements in the FY 2024 Request include:

<u>Research</u>

The Request will provide continued support for university and laboratory researchers carrying on critical core competencies, enabling high priority theoretical and experimental activities in pursuit of discovery science. The Request will provide support to foster a diverse, highly skilled, American workforce, and to build R&D capacity and conduct world-leading R&D through the following activities and initiatives:

- Reaching a New Energy Sciences Workforce (RENEW): Expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in Office of Science (SC)-sponsored research.
- Funding for Accelerated, Inclusive Research (FAIR): Improve the capability of Historically Black Colleges and Universities (HBCUs), minority serving institutions (MSIs), and emerging research institutions to propose and perform competitive research; and build beneficial relationships between these institutions and DOE national laboratories and facilities.
- Established Program to Stimulate Competitive Research (EPSCoR): Funding continues support for research in states and territories with historically lower levels of Federal academic research funding.
- Accelerate Initiative: Promotes scientific research to accelerate the transition of science advances to energy technologies.
- QIS: Co-development of quantum information, theory, and technology aligned with HEP science drivers and exploring new capabilities in quantum sensing and computing. HEP will continue support of the Superconducting Quantum Materials and Systems (SQMS) Center led by the Fermi National Accelerator Laboratory (FNAL).
- AI/ML: Tackle the challenges of extracting signals of signature particle physics from HEP experimental and simulated data with increasingly high volumes and complexity; seek solutions for operating accelerators and detectors in real-time and extremely high data rate environments; and address cross-cutting challenges in coordination with DOE investments in AI/ML efforts.
- Accelerator Science and Technology Initiative (ASTI): Mid- to long-term R&D to maintain a leading position in key accelerator technologies that define SC's competitive advantage.
- Microelectronics: Accelerate the advancement of sensor materials, devices, and front-end electronics.
- Advanced Computing: Ensure broad access to exascale computing resources.
- Within available resources, HEP will assist Advanced Scientific Computing Research (ASCR) in transitioning researchers, software, and technologies through the conclusion of the Exascale Computing Project into core research efforts as appropriate for HEP priorities.

<u>Facility Operations</u>

HEP supports two scientific user facilities, the Fermilab Accelerator Complex and the Facility for Advanced Accelerator Experimental Tests II (FACET-II). These facilities will operate 5,200 and 3,300 hours, respectively, while addressing critical upgrades, improvements, and deferred maintenance. HEP also supports laboratory-based accelerator and detector test facilities, and supports the maintenance and operations of large-scale experiments and facilities that are not based at a DOE national laboratory, such as the U.S. A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) detectors at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland; Sanford Underground Research Facility (SURF) in Lead, South Dakota; Vera C. Rubin Observatory in Chile; and Dark Energy Spectroscopic Instrument (DESI) at the Mayall telescope in Kitt Peak, Arizona.

<u>Projects</u>

The Request will continue support for the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) and Proton Improvement Plan II (PIP-II). The Request will also continue four Major Item of Equipment (MIE) projects: 1) Accelerator Controls Operations Research Network (ACORN), 2) Cosmic Microwave Background Stage 4 (CMB-S4), 3) High Luminosity Large Hadron Collider (HL-LHC) ATLAS Detector Upgrade, and 4) HL-LHC CMS Detector Upgrade Projects.

**High Energy Physics**
**Funding**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **High Energy Physics** | | | | |
| Energy Frontier, Research | 71,833 | 76,833 | 71,833 | -5,000 |
| Energy Frontier, Facility Operations and Experimental Support | 49,850 | 54,000 | 54,000 | – |
| Energy Frontier, Projects | 65,000 | 50,000 | 35,700 | -14,300 |
| **Total, Energy Frontier Experimental Physics** | **186,683** | **180,833** | **161,533** | **-19,300** |
| Intensity Frontier, Research | 65,994 | 72,644 | 68,144 | -4,500 |
| Intensity Frontier, Facility Operations and Experimental Support | 165,345 | 194,555 | 187,898 | -6,657 |
| Intensity Frontier, Projects | 10,000 | 6,000 | 10,199 | +4,199 |
| **Total, Intensity Frontier Experimental Physics** | **241,339** | **273,199** | **266,241** | **-6,958** |
| Cosmic Frontier, Research | 46,012 | 51,552 | 49,512 | -2,040 |
| Cosmic Frontier, Facility Operations and Experimental Support | 38,500 | 56,550 | 61,830 | +5,280 |
| Cosmic Frontier, Projects | 23,000 | 1,000 | 9,000 | +8,000 |
| **Total, Cosmic Frontier Experimental Physics** | **107,512** | **109,102** | **120,342** | **+11,240** |
| Theoretical, Computational, and Interdisciplinary Physics, Research | 158,922 | 171,746 | 173,746 | +2,000 |
| **Total, Theoretical, Computational, and Interdisciplinary Physics** | **158,922** | **171,746** | **173,746** | **+2,000** |
| Advanced Technology R&D, Research | 75,344 | 80,871 | 74,611 | -6,260 |
| Advanced Technology R&D, Facility Operations and Experimental Support | 40,200 | 52,249 | 53,861 | +1,612 |
| **Total, Advanced Technology R&D** | **115,544** | **133,120** | **128,472** | **-4,648** |
| **Subtotal, High Energy Physics** | **810,000** | **868,000** | **850,334** | **-17,666** |

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Construction** | | | | |
| 18-SC-42 Proton Improvement Plan II (PIP-II), FNAL | 90,000 | 120,000 | 125,000 | +5,000 |
| 11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment | 176,000 | 176,000 | 251,000 | +75,000 |
| 11-SC-41 Muon to Electron Conversion Experiment, FNAL | 2,000 | 2,000 | – | -2,000 |
| **Subtotal, Construction** | **268,000** | **298,000** | **376,000** | **+78,000** |
| **Total, High Energy Physics** | **1,078,000** | **1,166,000** | **1,226,334** | **+60,334** |

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $22,179,000 and STTR $3,119,000
- FY 2023 Enacted: SBIR $13,911,000 and STTR $1,956,000
- FY 2024 Request: SBIR $13,073,000 and STTR $1,838,000

## High Energy Physics
## Explanation of Major Changes

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Energy Frontier Experimental Physics**<br>The Request will provide reduced funding for the HL-LHC Upgrade projects, as funding from the FY 2022 Inflation Reduction Act (IRA) accelerated planned outyear funding. The HL-LHC Accelerator Upgrade received final planned funding in FY 2023 to support the completion of the project. Within the requested funding, fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades will continue as planned. Research support will focus on studying high-priority research topics for the LHC. | **-19,300** |
| **Intensity Frontier Experimental Physics**<br>The Request will support the Fermilab Accelerator Complex to operate 5,200 hours, and will focus support on expanding user access to detector systems, scientific computing, and experimental data. The Request will increase support for the ACORN MIE, and will prioritize support for SURF operations over SURF infrastructure improvements. Research support will focus on studying high-priority research topics. | **-6,958** |
| **Cosmic Frontier Experimental Physics**<br>The Request will increase support for the CMB-S4 MIE and for operations of the Vera C. Rubin Observatory. Research support will focus on exploiting the physics capabilities of new facilities and experiments. | **+11,240** |
| **Theoretical, Computational, and Interdisciplinary Physics**<br>The Request will increase support to broaden the RENEW and FAIR initiatives and focus support on new theoretical directions to unlock the mysteries of neutrinos and dark matter. The Request supports EPSCoR State-National Laboratory Partnership awards and early career awards. | **+2,000** |
| **Advanced Technology R&D**<br>The Request will support FACET-II to operate 3,300 hours, and will focus support on enhanced cross-cutting advanced technology R&D in coordination with the Office of Science and increased access and utilization of accelerator and detector test facilities at the DOE national laboratories. | **-4,648** |
| **Construction**<br>The Request will increase support and enable a subproject tailoring approach to LBNF/DUNE in accordance with DOE Order 413.3B that has been developed to reorganize the project’s scope into five independent subprojects for improved planning and management control. Baselining the entire scope of the project at once introduced too many uncertainties and was no longer viewed as being in the best interest of DOE. Support also increases for PIP-II and decreases for Mu2e as the project completes funding in FY 2023. | **+78,000** |
| **Total, High Energy Physics** | **+60,334** |

**Basic and Applied R&D Coordination**
The HEP General Accelerator R&D (GARD) research activity within the Advanced Technology R&D subprogram provides the fundamental building blocks of accelerator technology needed for the HEP mission. The GARD activity is based on input from the community, including high-level advice on long term facility goals from HEPAP and P5, and more detailed technical advice developed through a series of Roadmap Workshops. The GARD activity is coordinated with other SC programs and other federal agencies to optimize synergy and foster strong U.S. capability in this key technology area.

The HEP QIS research activity has coordinated partnerships with the Department of Defense's Office of Basic Research as well as the Air Force's Office of Scientific Research on synergistic research connecting foundational theory research with quantum error correction and control systems for sensors, and a partnership with the Department of Commerce's National Institute of Standards and Technology on quantum metrology and quantum sensor development for experimental discovery along HEP science drivers and for improving understanding of fundamental constants. Furthermore, the SC National QIS Research Center (NQISRC) effort is a partnership across all SC programs and engages industry to inform use-inspired research and connect to applied and development activities.

**Program Accomplishments**
*The LUX-ZEPLIN (LZ) dark matter search experiment successfully started operations and delivered its first results as the world's most sensitive dark matter detector (Cosmic Frontier Experimental Physics).*
On July 7, 2022, the LZ collaboration announced their first results from the dark matter experiment's first 60 "live days" of testing. These data were collected over a three-and-a-half-month span of initial operations beginning at the end of December. With its initial run, LZ is already the world's most sensitive detector of dark matter—the elusive particles thought to account for most of the matter in the universe. Dark matter particles have never actually been detected, but dark matter's presence and gravitational pull are nonetheless fundamental to our understanding of the universe. For example, the presence of dark matter, shapes the form and movement of galaxies, and it is invoked by researchers to explain what is known about the large-scale structure and expansion of the universe. The LZ experiment is managed by the Lawrence Berkeley National Laboratory (LBNL) and located a mile underground at the Sanford Underground Research Facility in Lead, South Dakota. The heart of the detector is comprised of two nested titanium tanks filled with nearly 10 tons of pure liquid xenon and viewed by two arrays of photomultiplier tubes that can detect faint sources of light due to dark matter particles colliding with xenon nuclei. The full dataset will eventually include about 1000 days of exposure. The LZ experiment is expected to improve on the sensitivity of the previous generation of detectors by a factor of 50.

*LHC data enables sensitive studies for detecting extremely rare processes where the Higgs boson is produced in pairs (Energy Frontier Experimental Physics).*
Researchers at the LHC are continuously extending our knowledge of the Higgs boson by searching for extremely rare processes that include the Higgs particles being produced in pairs within high energy particle collisions. Such studies can enable an understanding of how the Higgs interacts with itself which is possible when two Higgs bosons are produced instead of just one. This challenging di-Higgs process, including the various decaying particles resulting from each Higgs boson, can be easily confused with other processes that look similar. Therefore, to enhance the sensitivity to detection, the ATLAS and CMS collaborations have each applied AI/ML techniques to help distinguish signal type events from the large backgrounds and thereby scrape away the uninteresting events with increasing precision. Such machine learning algorithms can learn the subtle differences between signal and unwanted backgrounds above and beyond conventional analysis techniques. The present analyses by ATLAS and CMS suggest that an observation will be possible with additional data particularly from that acquired during the future era of the HL-LHC where at least ten times more data is expected. Moreover, these studies, in addition to the entire suite of other precision Higgs boson measurements presently being undertaken at the LHC, continue to demonstrate how the Higgs can be used as a tool for future discoveries of new physics.

*Quantum network between two national labs achieves record (Theoretical, Computational, and Interdisciplinary Physics).*
A team of researchers with the Illinois-Express Quantum Network (IEQNET) successfully deployed a long-distance quantum network between two DOE laboratories using local fiber optics. The experiment marked the first time that quantum-encoded photons and classical signals were simultaneously delivered across a metropolitan-scale distance with an unprecedented level of synchronization. The IEQNET collaboration includes the DOE's Fermi National Accelerator and Argonne National laboratories, Northwestern University and Caltech. Because they had only two fiber strands between the two labs, the researchers had to send the clock on the same fiber that carried the entangled photons. The way to separate the clock from the quantum signal is to use different wavelengths, but that comes with its own challenge. Ultimately, the two were properly assigned and controlled, and the timing signal and photons were distributed from sources at FNAL. As the photons arrived at each location, measurements were performed and recorded using Argonne's superconducting nanowire single photon detectors. The network was synchronized so accurately that it recorded only a five trillionth of a second time difference in the clocks at each location. Such precision will allow scientists to accurately identify and manipulate entangled photon pairs for supporting quantum network operations over metropolitan distances in real-world conditions. Building on this accomplishment, the IEQNET team is getting ready to perform experiments to demonstrate entanglement swapping. This process enables cross-entanglement between photons from different initially entangled pairs, thus creating longer quantum communication channels.

*First demonstration of a new particle beam technology at FNAL (Advanced Technology R&D).*
Researchers at the DOE's FNAL have published in *Nature* on their first successful demonstration of a new technique that improves the quality of particle beams. The new technique is called optical stochastic cooling. It was first proposed in the early 1990s, and while significant theoretical progress was made, an experimental demonstration of the technique remained elusive until now. Conventional stochastic cooling, which earned its inventor, Simon van der Meer, a share of the 1984 Nobel Prize, works by using light in the microwave range with wavelengths of several centimeters. In contrast, optical stochastic cooling uses visible and infrared light, which have wavelengths around a millionth of a meter. The shorter wavelength means scientists can sense the particles' activity more precisely and make more accurate corrections. To prepare a particle beam for experiments, accelerator operators send it on several passes through the cooling system. The improved resolution of optical stochastic cooling provides more exact kicks to smaller groups of particles, so fewer laps around the storage ring are needed. With the beam cooled more quickly, researchers can spend more time using those particles to produce experimental data. Scientists at FNAL used the lab's newest storage ring, the Integrable Optics Test Accelerator (IOTA), to demonstrate and explore optical stochastic cooling technology. This first demonstration at IOTA used a medium-energy electron beam and a configuration called "passive cooling," which doesn't amplify the light pulses from the particles. The team successfully observed the effect and achieved about a tenfold increase in cooling rate compared to the natural "radiation damping" that the beam experiences in IOTA. They were also able to control whether the beam cools in one, two or all three dimensions. Finally, scientists also ran experiments studying the cooling of a single electron stored in the accelerator. With the initial experiment completed, the team is developing an improved system at IOTA that will use an optical amplifier to strengthen the light from each particle by about a factor of 1,000 and apply machine learning to add flexibility to the system.

*New results from Micro Booster Neutrino Experiment (MicroBooNE) further our understanding of the nature of neutrinos (Intensity Frontier Experimental Physics).*
The MicroBooNe collaboration released the results of four complementary analyses that reached the same and notable conclusion: there is no sign of the sterile neutrino, which would be a signal of new physics. Hosted at FNAL, MicroBooNE detector is a 40-foot-long cylindrical container filled with 170 tons of pure liquid argon and has operated since 2015. The MicroBooNE experiment studies interactions of neutrinos, the most abundant fundamental particle with mass. Due to their very weak interactions with normal matter, neutrinos are shrouded with unanswered physics questions: Why are their masses so vanishingly small? Are neutrinos responsible for matter's dominance over antimatter in our universe? This makes neutrinos a unique window into exploring how the universe works at the smallest scales. The sterile neutrino proposed by theorists studied in this experiment has remained a promising explanation for anomalies seen in earlier physics experiments. Finding a new particle would be a major discovery and a radical shift in our understanding of the universe. With sterile neutrinos further disfavored as the explanation for anomalies spotted in neutrino data, scientists are investigating other possibilities. These include light created by other known processes during neutrino collisions, or exotic explanation such as new kinds of dark matter, unexplained physics related to the Higgs boson, or other physics beyond the Standard Model.

## High Energy Physics
## Energy Frontier Experimental Physics

### Description

The Energy Frontier Experimental Physics subprogram's focus is to support the U.S. researchers participating in the LHC program. The LHC hosts two large multi-purpose particle detectors, ATLAS and CMS, which are partially supported by DOE and NSF and are used by large international collaborations of scientists. U.S. researchers, including the next generation of scientists and engineers, participating in the LHC program account for approximately 20 percent and 25 percent of the ATLAS and CMS collaborations, respectively, and play critical leadership roles in all aspects of each experiment. Data collected by ATLAS and CMS are used to address three of the five science drivers as explained below:

- *Use the Higgs boson as a new tool for discovery.*
  In the Standard Model of particle physics, the Higgs boson is a key ingredient responsible for generating the mass for fundamental particles. Experiments at the LHC continue to actively measure the Higgs's properties to establish its exact character and to discover if there are additional effects that are the result of new physics beyond the Standard Model.
- *Explore the unknown: new particles, interactions, and physical principles.*
  Researchers at the LHC probe for evidence of what lies beyond the Standard Model such as supersymmetry, mechanisms for black hole production, extra dimensions, and other exotic phenomena. The upgraded LHC detectors will be increasingly more sensitive to potential deviations from the Standard Model that may be exposed by the highest energy collisions in the world.
- *Identify the new physics of dark matter.*
  LHC collisions may possibly produce dark matter particles, and their general properties may be inferred through the behavior of the accompanying normal matter. This "indirect" detection of dark matter is complementary to the ultra-sensitive direct detection experiments in the Cosmic Frontier and Intensity Frontier Experimental Physics subprograms.

<u>Research</u>

The Energy Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of the ATLAS and CMS collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and performing scientific simulations and data analyses. This activity also supports Advanced Computing to ensure broad access to exascale computing resources for HEP researchers.

<u>Facility Operations and Experimental Support</u>

U.S. LHC Detector Operations supports the maintenance of U.S.-supplied detector systems for the ATLAS and CMS detectors in the LHC at CERN, and the U.S.-based computer infrastructure used by U.S. physicists to analyze LHC data, including the Tier 1 computing centers at Brookhaven National Laboratory (BNL) and FNAL. The Tier 1 centers provide around-the-clock support for the worldwide LHC Computing Grid; are responsible for storing a portion of raw and processed data; perform large-scale data reprocessing; and store the corresponding output.

<u>Projects</u>

CERN is implementing a major upgrade to the LHC machine to increase the particle collision rate by a factor of at least five, to explore new physics beyond its current reach. Through the HL-LHC Accelerator Upgrade Project, HEP is contributing to this upgrade by constructing and delivering the next-generation of superconducting accelerator components, where U.S. scientists have critical expertise. After the upgrade, the HL-LHC collisions will lead to very challenging conditions in which the ATLAS and CMS detectors must operate. As a result, the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades are critical investments to enable the experiments to operate for an additional decade and collect at least a factor of ten more data.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Energy Frontier Experimental Physics** | **$180,833** | **$161,533** | **-$19,300** |
| Research | $76,833 | $71,833 | -$5,000 |
| Funding supports the Advanced Computing initiative and continues to support U.S. leadership roles in all aspects of the ATLAS and CMS experimental programs. This includes the analyses of the large physics datasets collected during the LHC run, as well as scientific personnel support for the HL-LHC ATLAS and CMS Detector upgrade activities. | | The Request will continue supporting the Advanced Computing initiative and leading roles by U.S. researchers in all aspects of the ATLAS and CMS experimental programs. | Funding will focus on U.S. researchers studying high-profile research topics that search for new physics during the present LHC run, which incorporates upgraded ATLAS and CMS Detectors installed during the last technical stop of the LHC. |
| Facility Operations and Experimental Support | $54,000 | $54,000 | $ — |
| Funding continues to support ATLAS and CMS detector maintenance and operations activities at CERN and the U.S.-based computing infrastructure and resources required to collect, store, and analyze the large volume of LHC data from the LHC run. | | The Request will continue supporting ongoing ATLAS and CMS detector maintenance and operations activities at CERN and data taking using the U.S.-based computing infrastructure and resources. | No change. |
| Projects | $50,000 | $35,700 | -$14,300 |
| Funding supports the production of quadrupole magnets and crab cavities for the HL-LHC Accelerator Upgrade, and ramp-up of fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades. | | The Request will support fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades. No funding is requested for the HL-LHC Accelerator Upgrade. | Within the requested funding, the HL-LHC Detector Upgrade projects will continue fabrication activities. The HL-LHC Accelerator Upgrade received its final funding in FY 2023. Funding from the FY 2022 Inflation Reduction Act accelerated outyear funding. |

*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, excluding facility operations.*

## High Energy Physics
## Intensity Frontier Experimental Physics

### Description

The Intensity Frontier Experimental Physics subprogram supports the investigation of some of the rarest processes in nature. This HEP subprogram relies on high-power beams or other intense sources such as reactors to make precision measurements of fundamental particle properties. These measurements probe for new phenomena that are not directly observable at the Energy Frontier, because either they occur at much higher energies and their effects may only be indirectly observed, or their interactions are too weak for detection in high-background conditions. Data collected from Intensity Frontier experiments are used to address three of the five science drivers as explained below:

- *Pursue the physics associated with neutrino mass.*
  Of all known particles, neutrinos are perhaps the most enigmatic and elusive. HEP researchers working at U.S. facilities discovered all the three known varieties of neutrinos. HEP supports research into fundamental neutrino properties that may reveal important clues about the unification of forces and the very early history of the universe.
- *Explore the unknown: new particles, interactions, and physical principles.*
  Several observed phenomena are not described by the Standard Model, including the imbalance of matter and antimatter in the universe today. Precision measurements of the properties of known particles may reveal information about what new particles and forces might explain these discrepancies and whether the known forces unify at energies beyond the reach of the LHC.
- *Identify the new physics of dark matter.*
  The lack of experimental evidence from the current generation of dark matter detectors has led to proposed theoretical models with new particles and forces that rarely interact with normal matter. Experiments outfitted with highly-efficient detectors and inserted within intense accelerator beams at national laboratories may offer an opportunity to explore these models.

<u>Research</u>

The Intensity Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and they perform scientific simulations and physics data analyses. This activity also supports Advanced Computing to ensure broad access to exascale computing resources for HEP researchers.

The largest component of the Intensity Frontier subprogram is the support for research in accelerator-based neutrino physics centered at FNAL with multiple experiments running concurrently in two separate neutrino beams with different beam energies. The Neutrinos at the Main Injector (NuMI) beam is used by the NuMI Off-Axis $\nu_e$ Appearance (NOvA) long-baseline neutrino experiment to detect oscillations between different types of neutrinos through 810 km of earth in a far detector in Ash River, Minnesota. The Booster Neutrino Beam is used by the Short-Baseline Neutrino (SBN) program at FNAL to definitively address measurements of additional neutrino types beyond the three currently described in the Standard Model. LBNF/DUNE will be the centerpiece of a U.S. hosted world-leading neutrino research facility, using the world's most intense neutrino beam and large, sensitive underground detectors to make transformative discoveries.

The research activity includes efforts to search for rare physics processes. The Mu2e experiment at FNAL will search for extremely rare muon decays that, if detected, will provide clear evidence of new physics. The Tokai-to-Kamioka (T2K) long-baseline neutrino experiment in Japan is complementary to NOvA, and a combined measurement from these two experiments will offer the best to date available information on neutrino oscillations prior to LBNF/DUNE. At the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, the Belle II experiment searches for new physics produced in electron-positron collisions at the SuperKEKB accelerator.

<u>Facility Operations and Experimental Support</u>

The Intensity Frontier Experimental Physics subprogram supports several distinct facility operations and experimental activities, the largest of which is the Fermilab Accelerator Complex User Facility. This activity includes the operations of all accelerators and beamlines at FNAL, the operation of the detectors that use those accelerators, the computing support needed by both the accelerators and detectors, and scientific collaboration support. General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding supports improvements to FNAL facilities.

HEP has a cooperative agreement with the South Dakota Science and Technology Authority (SDSTA), a quasi-state agency created by the State of South Dakota for the operation of the SURF. Experiments supported by DOE, NSF, and other government and private entities are conducted there, including the HEP-supported LZ experiment. SURF will be the home of the DUNE far site detectors being built by the LBNF/DUNE project. The SURF cooperative agreement provides basic services to LBNF/DUNE, and other experiments located at the site and supports critical infrastructure upgrades.

Projects

In support of LBNF/DUNE, a lease with SDSTA provides the framework for DOE and FNAL to construct federally funded buildings and facilities on non-federal land and to establish a long-term (multi-decade) arrangement for DOE and FNAL to use SDSTA space to host the DUNE neutrino detector. Other Project Costs (OPC) have been identified by the LBNF/DUNE project and DOE for the cost of SURF services used by LBNF/DUNE beyond the basic operational support covered by the SURF cooperative agreement mentioned above.

FNAL will upgrade its dated accelerator control system with a modern system, which is maintainable, sustainable, and capable of utilizing advances in AI/ML to create a high-performance accelerator for the future. The Accelerator Controls Operations Research Network (ACORN) MIE is critical as the control system of the Fermilab Accelerator Complex initiates particle beam production; controls beam energy and intensity; steers particle beams to their ultimate destination; measures beam parameters; and monitors beam transport through the complex to ensure safe, reliable, and effective operations.

## High Energy Physics
## Intensity Frontier Experimental Physics

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Intensity Frontier Experimental Physics** | **$273,199** | **$266,241** | **-$6,958** |
| Research | $72,644 | $68,144 | -$4,500 |
| Funding supports core research efforts in all phases of experiments: data collection, analysis, and dissemination; pre-operations activities for Mu2e, and science planning and development for LBNF/DUNE. Funding also supports the Advancing Computing initiative to support new software and networking technologies, which will be developed to transport and analyze very large neutrino datasets on exascale computers. | | The Request will continue to support research activities on NOvA, SBN Program, Belle II, and T2K experiments; researchers participating in commissioning of Mu2e; science planning and development for LBNF/DUNE; design and planning for intermediate neutrino and dark matter concepts; and the Advanced Computing initiative. | Funding will focus support on studying high-profile research topics that search for new physics, preparing for early physics capabilities of the Mu2e experiment, and scientists' contributions to the LBNF/DUNE project. |
| Facility Operations and Experimental Support | $194,555 | $187,898 | -$6,657 |
| Funding supports SURF operations and infrastructure improvements, and the continued fabrication and installation of the SBND experiment and operations of ICARUS as part of the SBN program. The Fermilab Accelerator Complex support includes a baseline change request to increase support for a GPP, the Target Systems Integration Building (TSIB). Additional funds are needed to complete the project due to inflation. Support for Special Process Spares are provided for efficient recovery from unexpected downtime. | | The Request will continue to support the Fermilab Accelerator Complex including funding for detector and computing operations, scientific collaboration support, and minor GPP; Special Process Spares for efficient recovery from unexpected downtime; and SURF operations. | Funding will focus support on the Fermilab Accelerator Complex by delivering more particle beams at peak power and expanding user access to detector systems, scientific computing, and experimental data. Support for SURF operations will be prioritized over infrastructure improvements. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Projects | $6,000 | | $10,199 | +$4,199 |
| Funding supports the ACORN MIE system design and other related engineering activities, and OPC execution support costs at SURF for LBNF/DUNE such as electric power for excavation and construction. | | The Request will support the ACORN MIE system design and other related engineering activities, as well as OPC execution support costs at SURF for LBNF/DUNE such as electric power for excavation and construction. | | Funding will increase to ramp-up ACORN MIE system design activities to prepare for Critical Decision (CD)-1. |

*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, excluding facility operations.*

## High Energy Physics
## Cosmic Frontier Experimental Physics

### Description

The Cosmic Frontier Experimental Physics subprogram uses measurements of naturally occurring cosmic particles and observations of the universe to probe fundamental physics questions and offer new insight about the nature of dark matter, cosmic acceleration in the forms of dark energy and inflation, neutrino properties, and other phenomena. The activities in this subprogram use diverse tools and technologies to carry out experiments typically not sited at national laboratories but at ground-based observatories and facilities, space-based missions, and detectors deep underground to address four of the five science drivers as described below:

- *Identify the new physics of dark matter.*
  Experimental evidence reveals that dark matter accounts for five times as much matter in the universe as ordinary matter. A staged series of direct-detection experiments search for the leading theoretical candidate particles using multiple technologies to cover a wide range in mass with increasing sensitivity. Accelerator-based dark matter searches performed in the Intensity Frontier and the Energy Frontier subprograms are complementary to these experiments.
- *Understand cosmic acceleration: dark energy and inflation.*
  The nature of dark energy, which drives the accelerating expansion of the universe, continues as one of the most perplexing questions in science. A staged series of experiments to carry out imaging and spectroscopic surveys of galaxies will determine the nature of dark energy. The cosmic microwave background (CMB), the oldest observable light in the universe, informs researchers about the era of inflation, the rapid expansion in the early universe shortly after the Big Bang. Researchers use measurements of this ancient CMB light and light from distant galaxies to map the acceleration of the universe over time and to unravel the nature of dark energy and inflation.
- *Pursue the physics associated with neutrino mass.*
  The study of the largest physical structures in the Universe may reveal the properties of particles with the smallest known cross section: neutrinos. Experiments studying dark energy and the CMB will put constraints on the number of neutrino species and their masses, complementary to the ultra-sensitive measurements made in the Intensity Frontier.
- *Explore the unknown: new particles, interactions, and physical principles.*
  High-energy cosmic rays and gamma rays probe energy scales well beyond what may be produced with man-made particle accelerators, albeit not in a controlled experimental setting. Searches for new phenomena and indirect signals of dark matter in these surveys may yield surprising discoveries about the fundamental nature of the universe.

<u>Research</u>

The Cosmic Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design and optimization, fabrication, commissioning, and operations as well as performing scientific simulations and data analyses for these experiments. The research makes use of advanced and high performance computing resources.

Two complementary next-generation, dark energy "Stage 4" experiments provide increased precision in measuring the history of the expansion of the universe. The Dark Energy Spectrographic Instrument (DESI) collaboration is carrying out a five-year survey to make light-spectrum measurements of 40 million galaxies and quasars that span over two-thirds of the history of the universe. The Vera C. Rubin Observatory will carry out a ten-year wide-field, ground-based optical and near-infrared imaging Legacy Survey of Space and Time (LSST) that will be used by the Dark Energy Science Collaboration (DESC). Together the datasets will enable studies on whether acceleration of the expansion of the universe is due to an unknown force, a cosmological constant, or if Einstein's General Theory of Relativity breaks down at large distances.

The next-generation Cosmic Microwave Background Stage 4 (CMB-S4) experiment, with its unprecedented sensitivity and precision, will enable researchers to peer into the inflationary era in the early moments of the universe, at a time scale unreachable by other types of experiments.

Two complementary next-generation, dark matter particle search experiments use complementary technologies to search for weakly interacting massive particles (WIMP) over a wide range of masses, with LZ searching for heavier WIMPs and Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) sensitive to lighter WIMPs. A third next-generation experiment, Axion Dark Matter Experiment Generation-2 (ADMX-G2), searches for axions, another type of possible dark matter particles. In addition, planning efforts are continuing for potential small projects to use new technologies and search for dark matter in areas not previously investigated.

Facility Operations and Experimental Support

This activity supports the DOE share of expenses necessary to carry out the successful operating phase of Cosmic Frontier experiments, including instrumentation maintenance, operation, data collection, and data processing and serving. Support is provided for the experiments currently operating and for pre-operations activities for the next-generation experiments in the design or fabrication phase. HEP conducts planning reviews to ensure readiness as each experiment transitions from project fabrication to science operations, and periodic reviews during the operations phase.

The DESI instrumentation is mounted on the NSF's Mayall Telescope at Kitt Peak National Observatory with both the instrumentation and telescope operations supported by DOE. DESI started its five-year science survey in May 2021. As of early FY 2023, DESI has made precision measurements of spectra of over 26 million galaxies, more than all other spectroscopic surveys combined.

The Vera C. Rubin Observatory in Chile, using the DOE-provided three billion-pixel LSST camera (LSSTCam), will carry out final commissioning activities and achieve first light in FY 2024. DOE and NSF are full partners in the Rubin facility operations to carry out the ten-year LSST survey. SLAC National Accelerator Laboratory (SLAC) manages the Rubin U.S. Data Facility and the LSSTCam during operations as part of DOE's responsibilities.

The LZ dark matter detector began science operations underground in the Sanford Underground Research Facility (SURF) in Lead, South Dakota in December 2021. Science Run 2 began in FY 2023 and will continue in FY 2024. The SuperCDMS-SNOLAB dark matter detector, located at the Sudbury Neutrino Observatory in Sudbury, Canada starts science operations with its full detector suite in FY 2024. The ADMX-G2 dark matter axion search experiment, located at the University of Washington in Seattle, WA, continues operations in FY 2024.

Projects

The next-generation CMB-S4 project is being planned as a partnership with NSF, with DOE roles led by Lawrence Berkeley National Laboratory. CMB-S4 will consist of an array of small and large telescopes working in concert at two locations, the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. Both arrays are required to reach the full science capabilities. The project is developing a design that will carry out the science goals within the available infrastructure and logistics capabilities at the sites.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Cosmic Frontier Experimental Physics** | **$109,102** | **$120,342** | **+$11,240** |
| Research | $51,552 | $49,512 | -$2,040 |
| Funding supports continued research activities on the ADMX-G2, DESI, LZ, and SuperCDMS-SNOLAB experiments, physics preparation for the Vera C. Rubin Observatory, the associated DESC for LSST, and design and planning for new dark matter concepts. | | The Request will support continued research activities on the dark matter experiments (ADMX-G2, LZ, and SuperCDMS-SNOLAB), on dark energy science (DESI and Vera C. Rubin Observatory, with its associated DESC) and design and planning for CMB-S4 and the dark matter concepts. | Funding will focus support on research efforts to exploit the new physics capabilities of the Vera C. Rubin Observatory and the SuperCDMS-SNOLAB experiment. |
| Facility Operations and Experimental Support | $56,550 | $61,830 | +$5,280 |
| Funding supports continued operations of DESI, LZ, ADMX-G2, and the start of operations for SuperCDMS-SNOLAB. Commissioning and pre-operations planning efforts continue for the Vera C. Rubin Observatory and the DESC planning for the LSST survey. | | The Request will support continued operations of DESI, LZ, ADMX-G2, the start of full operations of SuperCDMS-SNOLAB. Final commissioning activities for the Vera C. Rubin Observatory will be carried out in preparation for the start of the science survey in FY 2025. | Funding will increase to support the ramp up in operations needed for the Vera C. Rubin Observatory. |
| Projects | $1,000 | $9,000 | +$8,000 |
| Funding supports engineering and design efforts for the CMB-S4 project. | | The Request will support engineering and design efforts for the CMB-S4 project. | Funding will increase to ramp up design activities for the CMB-S4. |

*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, excluding facility operations.*

## High Energy Physics
## Theoretical, Computational, and Interdisciplinary Physics

### Description

The Theoretical, Computational, and Interdisciplinary Physics subprogram provides the mathematical, phenomenological, computational, and technological framework to understand and extend our knowledge of the dynamics of particles and fields, and the nature of space and time. This research is essential for proper interpretation and understanding of the experimental research activities described in other HEP subprograms, and cuts across all five science drivers and the Energy, Intensity, Cosmic Frontier Experimental Physics, and Advanced Technology R&D subprograms.

#### Theory

The HEP theory activity supports world-leading Research groups at U.S. academic and research institutions and national laboratories, which play important roles in addressing the leading research areas discussed above. Laboratory groups are typically more focused on data-driven theoretical investigations and precise calculations of experimentally observable quantities. University groups usually focus on building models of physics beyond the Standard Model and studying their phenomenology, as well as on formal and mathematical theory.

This activity supports the Advanced Computing initiative to ensure broad access to exascale computing resources.

#### Computational HEP

The Computational HEP activity supports advanced simulations and computational science that extends the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. Computation is necessary at all stages of HEP experiments, from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis for scientific discovery in HEP. The multi-laboratory HEP Center for Computational Excellence (CCE) is supported to advance HEP computing by developing common software tools and exploiting the latest architectures in high performance computing platforms and exascale systems. Computational HEP partners with ASCR, including via the Scientific Discovery through Advanced Computing (SciDAC) activity, to optimize the HEP computing ecosystem for the near- and long-term future. Computational traineeships develop the technical expertise of engineers and scientists critical to delivering HEP discovery science.

#### Quantum Information Science

The HEP QIS activity supports the “science first” approach of the National Quantum Strategy through National QIS Research Centers and individual research grants, applying HEP techniques to QIS and vice versa. Topics include quantum computing; quantum simulation for HEP theory and experiments; and ultrasensitive quantum sensors. The five National QIS Research Centers, jointly supported across SC programs, apply concepts and technology from core research to QIS and foster collaborative partnerships in support of the SC mission. HEP is the lead program supporting the Superconducting Quantum Materials and Systems (SQMS) Center led by the Fermi National Accelerator Laboratory. SQMS is focused on extending the lifetime of quantum states to reduce error rates in quantum computing and enable the construction and deployment of quantum sensors for precision measurements.

#### Artificial Intelligence and Machine Learning

The HEP AI/ML activity supports research to tackle challenges not possible with more traditional computing due to increasingly high data volumes and complexity or to make connections across the experimental, theoretical and technical HEP frontiers. Priorities include advancing HEP research through development and applications of AI/ML for more efficient processing of large datasets, modeling and mitigation of systematic uncertainties, and improved operations of particle accelerators and detectors. Research also seeks to use unique aspects of HEP such as datasets or theory to improve understanding of fundamental AI/ML techniques and their potential and limitations. This program additionally supports strategic directions in HEP AI/ML that are well aligned with programmatic priorities and includes input from open community workshops and relevant federal advisory committees. The HEP AI/ML research activity is conducted in coordination with DOE and SC programs, other federal agencies, and the private sector.

Broadening Engagement in HEP

This activity will support the RENEW initiative to provide undergraduate and graduate training opportunities for diverse students and academic institutions not currently well represented in the U.S. science and technology ecosystem, including through a RENEW graduate fellowship, and the FAIR initiative to provide focused investment on enhancing research at HBCUs and minority serving institutions and emerging research institutions. The FAIR and RENEW initiatives aim to improve the infrastructure and competitiveness at institutions under-represented in the HEP program, and support research and training activities that broadens engagement in HEP science. RENEW and FAIR are conducted in coordination with DOE SC programs. This activity provides support for the DOE EPSCoR that funds research in states and territories with historically lower levels of Federal academic research funding. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single PI and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards. Funding for EPSCoR within the HEP program provides dedicated support for HEP research conducted at institutions in EPSCoR states, including special-purpose funding opportunities. These activities also broaden engagement and build capabilities in HEP science that reach communities and institutions which are under-represented in the HEP portfolio.

## High Energy Physics
## Theoretical, Computational, and Interdisciplinary Physics

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Theoretical, Computational, and Interdisciplinary Physics** | **$171,746** | **$173,746** | **+$2,000** |
| Research | $171,746 | $173,746 | +$2,000 |
| *Theory* | *$54,050* | *$50,050* | *-$4,000* |
| Funding supports world-leading theoretical particle physics research at U.S. universities and national laboratories and the Advanced Computing initiative. | | The Request will continue to support the HEP theory activity and the Advanced Computing initiative. | Funding will focus support on theoretical investigations to unlock the mysteries of neutrinos and dark matter. |
| *Computational HEP* | *$14,130* | *$14,130* | *$ —* |
| Funding supports the multi-laboratory HEP CCE, HEP-ASCR SciDAC partnerships, and the Traineeship Program in Computational HEP. | | The Request will continue to support HEP CCE, HEP-ASCR SciDAC partnerships, and the Traineeship Program in Computational HEP. Within available resources, HEP will assist ASCR in transitioning researchers, software, and technologies through the conclusion of the Exascale Computing Project into core research efforts as appropriate for HEP priorities. | No changes. |
| *Quantum Information Science* | *$50,566* | *$50,566* | *$ —* |
| Funding supports interdisciplinary HEP-QIS consortia and lab programs for focused research at the intersection of HEP and QIS. Funding also supports SQMS as part of the National QIS Research Centers in partnership with other SC program offices. | | The Request will continue to support interdisciplinary HEP QIS consortia and the SQMS National QIS Research Center. | No changes. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| *Artificial Intelligence and Machine Learning* *$40,000* | *$40,000* | *$ —* |
| Funding supports AI/ML research and development to improve HEP physics and build an AI/ML community around cross-cutting challenges that fulfill the HEP mission, including "seed" awards to explore emerging opportunities. | The Request will support innovation and new opportunities in embedding AI into sensors and experimental design in extreme environments; and developing operations and controls AI/ML techniques for accelerators and open access to HEP datasets. | No changes. |
| *Broadening Engagement in HEP* *$13,000* | *$19,000* | *+$6,000* |
| Funding supports the RENEW and FAIR initiatives which expand targeted efforts to increase participation and retention of underrepresented individuals and institutions in SC research activities. Dedicated funding for EPSCoR expands participation in HEP research, particularly at historically under-represented institutions. | The Request will continue the HEP participation in the RENEW and FAIR initiatives. Funding supports EPSCoR State-National Laboratory Partnership awards and early career awards in EPSCoR jurisdictions. | Funding will increase support for the RENEW and FAIR initiative activities, including through a RENEW graduate fellowship. Continued support for research in EPSCoR jurisdictions. |

*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, excluding facility operations.*

## Description

The Advanced Technology R&D subprogram fosters cutting-edge basic research in the physics of particle beams, accelerator technology R&D, and R&D for particle and radiation detection. These activities are necessary for continued progress in high energy physics.

General Accelerator R&D

The HEP General Accelerator R&D (GARD) activity supports the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator performance, size, cost, beam intensity, and control. The GARD activity supports groups at U.S. academic and research institutions and national laboratories performing research activities categorized into five areas: 1) accelerator and beam physics; 2) advanced acceleration concepts; 3) particle sources and targetry; 4) radio-frequency acceleration technology; and 5) superconducting magnets and materials. A community study aimed at establishing a technology roadmap for the accelerator and beam physics thrust was conducted in FY 2022; the roadmap report will be published in FY 2023. Community studies for most other HEP GARD thrusts were completed in the past five years.[b] Input on strategic directions from regular, open, community studies as well as future Basic Research Needs workshops, will inform funding decisions in subsequent years.

The state-of-the-art SC facilities attract the world's leading researchers, bringing knowledge and ideas that enhance U.S. science and create high technology jobs. As competing accelerator-based facilities are built abroad, they are beginning to draw away scientific and technical talent. Sustaining world-class accelerator-based SC facilities requires continued, transformative advances in accelerator science and technology, and a workforce capable of performing leading accelerator research for future application. In coordination with the Office of Accelerator R&D and Production, the SC Accelerator Science and Technology Initiative (ASTI) will address these needs by reinforcing high-risk, high-reward accelerator R&D that will invest in SC facilities to stay at the global forefront and develop a world-leading workforce to build and operate future generations of facilities.

The GARD activity supports the highly successful U.S. Particle Accelerator School (USPAS). GARD also supports the Traineeship Program for Accelerator Science and Engineering to revitalize education, training, and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. The Traineeship Program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP holds a competition for traineeship awards for graduate level students to increase workforce development in areas of critical need. These traineeships leverage existing GARD research activities as well as the capabilities and assets of DOE laboratories.

This activity also supports the Accelerate initiative which will support scientific research to accelerate the transition of science advances to energy technologies.

Detector R&D

The Detector R&D activity supports the development of the next generation instrumentation and particle and radiation detectors necessary to maintain U.S. scientific leadership in a worldwide experimental endeavor that is broadening into new research areas, such as quantum sensors. To meet this challenge, HEP aims to foster an appropriate balance between evolutionary, near-term, low-risk detector R&D and revolutionary, long-term, high-risk detector R&D, while training the next generation of experts. The Detector R&D activity consists of groups at U.S. academic and research institutions and national laboratories performing research into the fundamental physics underlying the interactions of particles and radiation in detector materials. This activity also supports technology development that turns these insights into working detectors. Input on strategic directions from regular, open community studies will inform funding decisions in subsequent years.

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[b] https://science.osti.gov/hep/Community-Resources/Reports

The Detector R&D activity supports the Traineeship Program for HEP Instrumentation to address critical, targeted workforce development in fields of interest to the DOE mission. The program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP held a competition for traineeship awards for graduate level students to revitalize education, training, and innovation in the physics of particle detectors and next generation instrumentation for the benefit of HEP and other SC and DOE programs that rely on these enabling technologies. These traineeship awards leverage existing Detector R&D research activities as well as the capabilities and assets of DOE laboratories.

SC is in a unique position to both play a critical role in the advancement of microelectronic technologies over the coming decades, and to benefit from the resultant capabilities in detection, computing, and communications. Five SC programs—ASCR, Basic Energy Sciences, Fusion Energy Sciences, HEP, and Nuclear Physics—are working together to advance microelectronics technologies. This activity is focused on establishing the foundational knowledge base for future microelectronics technologies for sensing, communication, and computing that are complementary to quantum computing. Radiation and particle detection specifically will benefit from detector materials R&D, device R&D, advances in front-end electronics, and integrated sensor/processor architectures.

Facility Operations and Experimental Support

This activity supports GARD laboratory experimental and test facilities: Berkeley Lab Laser Accelerator (BELLA), the laser-driven plasma wakefield acceleration facility at Lawrence Berkeley National Laboratory (LBNL); FACET-II, the beam-driven plasma wakefield acceleration facility at SLAC National Accelerator Laboratory (SLAC); Argonne Wakefield Accelerator (AWA) in structure-based advanced acceleration concepts; and superconducting radio-frequency accelerator and magnet facilities at FNAL. This activity also supports detector test beam and fabrication facilities at FNAL.

## High Energy Physics
## Advanced Technology R&D

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Advanced Technology R&D** | **$133,120** | **$128,472** | **-$4,648** |
| Research | $80,871 | $74,611 | -$6,260 |
| *General Accelerator R&D* | *$54,342* | *$49,082* | *-$5,260* |
| Funding supports capitalizing on the science opportunities at the newly completed FACET-II facility and the second beamline at BELLA; other accelerator R&D activities at DOE national laboratories and universities, including ASTI efforts in superconducting magnet and SRF; and the Traineeship Program for Accelerator Science and Technology. The funding also supports the Accelerate initiative. | | The Request will support accelerator R&D activities at DOE national laboratories and universities, ASTI and Accelerate initiatives, and the Traineeship Program for Accelerator Science and Engineering. | Funding will focus support on enhanced cross-cutting accelerator R&D themes across the Office of Science, increased access and utilization of accelerator facilities, and broader engagement in scientific training. |
| *Detector R&D* | *$26,529* | *$25,529* | *-$1,000* |
| Funding supports world-leading, innovative Detector R&D; advanced microelectronics technologies and AI/ML implementations; and the Traineeship Program in HEP Instrumentation. | | The Request will continue support of world-leading, innovative Detector R&D; advanced microelectronics technologies and AI/ML implementations; and the Traineeship Program in HEP Instrumentation. | Funding will focus support on the highest-priority efforts in the program. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Facility Operations and Experimental Support $52,249 | $53,861 | +$1,612 |
| Funding supports testing and beam time for experiments at the accelerator test facilities at Argonne National Laboratory, FNAL, LBNL and SLAC; and detector and test beam facilities at FNAL. The funding supports facility operations for FACET-II. | The Request will support testing and beam time for experiments at the accelerator and detector test facilities at Argonne National Laboratory, FNAL, LBNL and SLAC including expanded opportunities at the upgraded facilities at FACET-II and BELLA. | Funding will support increased user access to FACET-II at SLAC and to cryogenic, magnet, and SRF testing at FNAL; new two-beam laser wakefield acceleration experiments at LBNL; and modernization of the detector facilities at FNAL. |

*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, excluding facility operations.*

## High Energy Physics
## Construction

**Description**
This subprogram supports all line-item construction for the entire HEP program. All Total Estimated Costs (TEC) are funded in this subprogram, including engineering, design, and construction.

18-SC-42, Proton Improvement Plan II (PIP-II), FNAL
The PIP-II project will enhance the Fermilab Accelerator Complex to enable it to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics. The project is constructing an 800 megaelectronvolt (MeV) superconducting radio-frequency (SRF) proton linear accelerator and beam transfer line. The PIP-II project is also modifying the existing FNAL Booster, Recycler, and Main Injector synchrotrons downstream from the new linear accelerator to accept the increased beam intensity. Some of the new components and the cryoplant will be provided through international, in-kind contributions. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3 (Approve Construction), approved on April 18, 2022, with a Total Project Cost (TPC) of $978,000,000. The CD-4 milestone date is 1Q FY 2033.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL
The LBNF/DUNE construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. LBNF/DUNE will study the transformations of muon neutrinos that occur as they travel from FNAL, where they are produced in a high-energy proton beam, to a large detector in South Dakota, 800 miles away from FNAL. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the puzzling imbalance of matter and antimatter that enables our existence in a matter-dominated universe.

The LBNF/DUNE project is a national flagship particle physics initiative and will be the first-ever large-scale, international science facility hosted by the U.S. The LBNF/DUNE project consists of two multinational collaborative efforts. LBNF is responsible for the beamline at FNAL and other experimental and civil infrastructure at FNAL and at the SURF in South Dakota. DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, construction and commissioning of the detectors and subsequent research.

DOE’s High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE-US. LBNF, with DOE/FNAL leadership and participation by a small number of international partners including CERN, will construct a megawatt-class neutrino source and related facilities at FNAL (the “Near Site”), as well as underground caverns and cryogenic facilities in South Dakota (the “Far Site”) needed to house the DUNE detectors. DUNE has international leadership and participation by over 1,400 scientists and engineers from over 200 institutions in over 30 countries. DOE will fund about half of DUNE under the name DUNE-US.

Critical Decision CD-3A, approved on September 1, 2016, allowed for Initial Far Site Construction. Following this approval, excavation and construction for the LBNF Far Site conventional facilities started to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. DOE conducted an independent project review in July 2022 to evaluate a new cost range and the alternative selection. The most recent DOE Order 413.3B approved CD is CD-1RR (Update cost range, reaffirm the alternative selection, and approve a new tailoring strategy for baselining the project in multiple subprojects), approved on February 16, 2023, with a TPC Point Estimate of $3,277,000,000. This TPC Point Estimate serves for planning purposes and will be refined as the project matures and each subproject is baselined. As each subproject is baselined, the aggregate of the baselined subproject TPCs must be below the upper end of the approved cost range. When the last subproject is baselined, the LBNF/DUNE-U.S. TPC will be the aggregate of all subproject TPCs plus any contingency being held by the parent LBNF/DUNE-U.S. project. The CD-1RR approval reaffirms that the previously selected alternative for an international and more capable deep underground detector is still a reasonable decision based on the matured understanding of factors. The reaffirmed alternative is the best opportunity for the U.S. to host a truly world-leading international neutrino program based upon optimized rate of data collection and unmatched sensitivities and precision. The reaffirmed alternative strengthens the U.S.'s international partnerships in particle physics and allows for future upgrades to the detectors and beam intensity if DOE chooses to do so.

11-SC-41, Muon to Electron Conversion Experiment, FNAL
Mu2e, under construction at FNAL, will search for evidence that a muon can undergo direct (neutrinoless) conversion into an electron, a process that would violate lepton flavor conservation and probe new physics at energy scales beyond the collision energy of the Large Hadron Collider. If observed, this major discovery would signal the existence of new particles or new forces beyond the Standard Model. The Mu2e project completed its technical design phase (CD-3) on July 14, 2016 and moved into full construction at that time. Civil construction of the underground detector housing and the surface building for the experiment were completed in 2017. The funding profile through FY 2019 supported the originally approved TPC of $273,677,000 and the originally approved CD-4 milestone date of 1Q FY 2023.

External factors negatively impacted the performance of the Mu2e project: the COVID-19 pandemic and associated work restrictions at most of the participating institutions; supply chain and workforce disruptions; and vendor delays of critical project components. Mitigating the impacts required additional budget authority and schedule beyond what remained in the authorization for the original performance baseline. Following thorough review and evaluation by an Independent Cost Review and an Independent Project Review, a Baseline Change Proposal for the Mu2e project was approved on December 21, 2022. The new baseline added $42,023,000 to the total project cost and moved the CD-4 milestone date for project completion to January 2028. Funds provided by the FY 2022 Inflation Reduction Act and the FY 2023 Enacted Appropriations completed the funding for this project. No funding is requested in the FY 2024 Request.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Construction** | **$298,000** | **$376,000** | **+$78,000** |
| 18-SC-42, Proton Improvement Plan II (PIP-II), FNAL | $120,000 | $125,000 | +$5,000 |
| Funding supports initiation of civil construction for the balance of the linear accelerator facilities as well as continuation of procurement and fabrication of technical systems. | | The Request will support continuation of civil construction and fabrication of technical systems. | Funding will increase and support a ramp-up of construction for the linear accelerator facilities. |
| 11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL | $176,000 | $251,000 | +$75,000 |
| Funding supports continuation of the Far Site civil construction activities for excavation of the underground equipment caverns and connecting drifts (tunnels). Design activities will be completed for the far site detectors and cryogenics systems and the beamline design will be finalized. | | The Request will support continued excavation of the far detector caverns; execution of the Far Site Conventional Facilities Building and Site Infrastructure, and Far Detectors and Cryogenic Infrastructure subprojects; and design and planning for the Near Site Conventional Facilities and Beamline, and Near Detector subprojects to prepare for baseline and approval of construction. | Funding will increase and support all five of the subprojects. |
| 11-SC-41, Muon to Electron Conversion Experiment, FNAL | $2,000 | $ — | -$2,000 |
| Funding supports continued implementation of corrective actions due to schedule delays caused by pandemic response at FNAL and collaborating universities, and by fabrication delays for the tracking detector and two superconducting magnets being fabricated by a vendor. | | No funding is requested for this activity. | The Mu2e project received final funding in FY 2023. |

## High Energy Physics
## Capital Summary

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| | (dollars in thousands) | | | | | | |
| **Capital Operating Expenses** | | | | | | | |
| Capital Equipment | N/A | N/A | 107,915 | 105,740 | 73,620 | 58,200 | -15,420 |
| Minor Construction Activities | | | | | | | |
| General Plant Projects | N/A | N/A | – | – | 4,000 | 4,200 | +200 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **107,915** | **105,740** | **77,620** | **62,400** | **-15,220** |

## High Energy Physics
## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | | |
| Major Items of Equipment | | | | | | | |
| Energy Frontier Experimental Physics | | | | | | | |
| High Luminosity Large Hadron Collider Accelerator Upgrade Project | 259,952 | 166,597 | 25,000 | 38,355 | 30,000 | – | -30,000 |
| High Luminosity Large Hadron Collider ATLAS Upgrade Project | 183,485 | 68,000 | 20,000 | 32,785 | 10,000 | 16,200 | +6,200 |
| High Luminosity Large Hadron Collider CMS Upgrade Project | 158,550 | 48,238 | 20,000 | 34,600 | 10,000 | 19,500 | +9,500 |
| Intensity Frontier Experimental Physics | | | | | | | |
| Accelerator Controls Operations Research Network | 121,201 | – | 500 | – | – | 5,000 | +5,000 |
| Cosmic Frontier Experimental Physics | | | | | | | |
| Cosmic Microwave Background - Stage 4 | 354,000 | 1,000 | – | – | – | 9,000 | +9,000 |
| Lunar Surface Electromagnetics Experiment Night | 14,000 | – | 14,000 | – | – | – | – |
| Total, MIEs | N/A | N/A | 79,500 | 105,740 | 50,000 | 49,700 | -300 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 28,415 | – | 23,620 | 8,500 | -15,120 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **107,915** | **105,740** | **73,620** | **58,200** | **-15,420** |

*Note:*

- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*

## High Energy Physics
## Minor Construction Activities

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| GPPs (greater than or equal to $5M and less than $30M) | | | | | | |
| Target Systems Integration Building | 5,500 | 1,500 | – | 4,000 | – | -4,000 |
| Total GPPs (greater than or equal to $5M and less than $30M) | N/A | N/A | – | 4,000 | – | -4,000 |
| Total GPPs less than $5M | N/A | N/A | – | – | 4,200 | +4,200 |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **–** | **4,000** | **4,200** | **+200** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **–** | **4,000** | **4,200** | **+200** |

*Note:*
- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*
- *The Target Systems Integration Building includes $11,400,000 obligated in FY 2022 that brings the total project amount to $16,900,000 pending a baseline change approval.*

**High Energy Physics**
**Major Items of Equipment Description(s)**

Energy Frontier Experimental Physics MIEs:
*High-Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC Accelerator Upgrade Project)*
The HL-LHC Accelerator Upgrade Project received CD-3 approval on December 21, 2020. Following the major upgrade, the CERN LHC machine will further increase the particle collision rate by at least a factor of five to explore new physics beyond its current reach. This project is delivering components for which U.S. scientists have critical expertise: interaction region focusing quadrupole magnets, and special superconducting radiofrequency cavities that can generate transverse electric fields. The magnets are being assembled at LBNL, BNL, and FNAL, exploiting special expertise and unique capabilities at each laboratory. The project was stalled by shutdowns at the national laboratories due to COVID-19 and has seen increased costs as a result. In all other respects the project is performing well. A rebaseline review of the project was held December 13-15, 2022, which supports a new Total Estimated Cost (TEC) of $259,952,000 with the Baseline Change Proposal approval scheduled for March 2023. Due to the $38,355,000 provided in the FY 2022 Inflation Reduction Act, and the project receiving final funding needed in FY 2023 Enacted Appropriation, no additional funding is requested in FY 2024.

*High-Luminosity Large Hadron Collider ATLAS Detector Upgrade Project (HL-LHC ATLAS)*
The HL-LHC ATLAS Detector Upgrade Project received CD-2/3 approval on January 31, 2023, with a TPC of $200,000,000. The ATLAS detector will integrate a higher amount of data per run by at least a factor of ten compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the ATLAS detector requires upgrades to the silicon pixel and strip tracker detectors, the muon detector systems, the calorimeter detectors and associated electronics, as well as the trigger and data acquisition systems. The National Science Foundation (NSF) approved support for a Major Research Equipment and Facility Construction (MREFC) project in FY 2020 to provide different scope to the HL-LHC ATLAS detector upgrade. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2024 Request for TEC funding of $16,200,000 will focus on completion of the final design and ramp-up of fabrication activities.

*High-Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)*
The HL-LHC CMS project received CD-1 approval on December 19, 2019, and CD-3B approval on June 24, 2022. A CD-2/3 review of the project was held January 24-27, 2023. The proposed TPC shown at the review was $200,000,000. CD-2/3 approval is planned for 2Q of FY 2023. The CMS detector will integrate a higher amount of data per run by at least a factor of ten compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the CMS detector requires upgrades to the silicon pixel tracker detectors, the outer tracker detector, the muon detector systems, the calorimeter detectors and associated electronics, the trigger and data acquisition systems, and the addition of a novel timing detector. NSF approved support for a MREFC Project in FY 2020 to provide different scope to the HL-LHC CMS detector upgrade. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2024 Request for TEC funding of $19,500,000 will focus on completion of the final design and ramp-up of fabrication activities.

Intensity Frontier Experimental Physics MIE:
*Accelerator Controls Operations Research Network (ACORN)*
The ACORN project received CD-0 approval on August 28, 2020, with an estimated cost range of $100,000,000 to $142,000,000. This project will replace FNAL’s dated accelerator control system with a modern system which is maintainable, sustainable, and capable of utilizing advances in Artificial Intelligence and Machine Learning to create a high-performance accelerator for the future. The control system of the Fermilab Accelerator Complex initiates particle beam production; controls beam energy and intensity; steers particle beams to their ultimate destination; measures beam parameters; and monitors beam transport through the complex to ensure safe, reliable, and effective operations. ACORN will provide FNAL with an accelerator control system that will be compatible with PIP-II. FNAL plans to collaborate with other national labs that have experience with accelerator control systems. This project is expected to receive CD-1 approval in FY 2024. The FY 2024 Request for TEC funding of $5,000,000 will fund system design and other related engineering activities.

Cosmic Frontier Experimental Physics MIE:

*Cosmic Microwave Background Stage 4 (CMB-S4)*

The CMB-S4 project received CD-0 approval on July 25, 2019, with an estimated cost range of $320,000,000 to $395,000,000. The project is expected to be carried out as a partnership with NSF, with DOE as the lead agency and a distribution of scope planned to be determined by the end of FY 2023. The project consists of fabricating an array of small and large telescopes at two locations: the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. LBNL was selected in August 2020 to lead the efforts in providing the DOE scope for the project. The FY 2024 Request for TEC funding of $9,000,000 will support engineering and design efforts.

*Lunar Surface Electromagnetics Experiment Night (LuSEE-Night)*

The LuSEE-Night MIE is a BNL managed project that follows the BNL Standards-Based Management System in which Project Decision (PD) reviews are analogous to DOE CD reviews. LuSEE-Night received PD-1 approval on May 16, 2022, with a TPC of $15,000,000. LuSEE-Night is an experiment on the far side of the moon to study fundamental physics in the early universe. LuSEE's radio spectrometer will make the most precise measurements of the low-frequency radio sky, which is inaccessible from Earth, seeking to detect the fossil radiation emitted 100 million years after the Big Bang when the first structures were forming. LuSEE-Night is a collaboration between NASA and DOE. The mission is led by NASA-funded Space Sciences Laboratory at the University of California, Berkeley. NASA provides for the delivery to the Moon via the Commercial Lunar Payload Services program. DOE LuSEE-Night MIE responsibilities are for the science antennae and preamplifiers, the inner electronics box including the spectrometer, the communication system, and the power management. The FY 2022 Enacted Appropriation provided full funding to complete all DOE deliverables.

## High Energy Physics
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **18-SC-42, Proton Improvement Plan II** | | | | | | | |
| Total Estimated Cost (TEC) | 891,200 | 160,000 | 90,000 | 10,000 | 120,000 | 125,000 | +5,000 |
| Other Project Cost (OPC) | 86,800 | 73,594 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **978,000** | **233,594** | **90,000** | **10,000** | **120,000** | **125,000** | **+5,000** |
| **11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment** | | | | | | | |
| Total Estimated Cost (TEC) | 3,167,335 | 678,781 | 176,000 | 125,000 | 176,000 | 251,000 | +75,000 |
| Other Project Cost (OPC) | 109,665 | 93,625 | 8,000 | – | 4,000 | 4,000 | – |
| **Total Project Cost (TPC)** | **3,277,000** | **772,406** | **184,000** | **125,000** | **180,000** | **255,000** | **+75,000** |
| **11-SC-41, Muon to Electron Conversion Experiment** | | | | | | | |
| Total Estimated Cost (TEC) | 292,023 | 252,000 | 2,000 | 36,023 | 2,000 | – | -2,000 |
| Other Project Cost (OPC) | 23,677 | 23,677 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **315,700** | **275,677** | **2,000** | **36,023** | **2,000** | **–** | **-2,000** |
| **Total, Construction** | | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **268,000** | **171,023** | **298,000** | **376,000** | **+78,000** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **8,000** | **–** | **4,000** | **4,000** | **–** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **276,000** | **171,023** | **302,000** | **380,000** | **+78,000** |

**High Energy Physics**
**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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Scientific User Facilities - Type A** | | | | | |
| **Fermilab Accelerator Complex** | **131,500** | **129,754** | **152,984** | **150,630** | **-2,354** |
| Number of Users | 2,300 | 2,095 | 2,700 | 2,700 | – |
| Achieved Operating Hours | – | 5,154 | – | – | – |
| Planned Operating Hours | 5,180 | 5,180 | 5,740 | 5,200 | -540 |
| Unscheduled Down Time Hours | – | 1,880 | – | – | – |
| **Facility for Advanced Accelerator Experimental Tests II (FACET II)** | **13,000** | **13,152** | **15,500** | **15,572** | **+72** |
| Number of Users | 225 | 120 | 120 | 125 | +5 |
| Achieved Operating Hours | – | 3,969 | – | – | – |
| Planned Operating Hours | 2,700 | 2,700 | 3,300 | 3,300 | – |
| Unscheduled Down Time Hours | – | 600 | – | – | – |
| **Total, Facilities** | **144,500** | **142,906** | **168,484** | **166,202** | **-2,282** |
| Number of Users | 2,525 | 2,215 | 2,820 | 2,825 | +5 |
| Achieved Operating Hours | – | 9,123 | – | – | – |
| Planned Operating Hours | 7,880 | 7,880 | 9,040 | 8,500 | -540 |
| Unscheduled Down Time Hours | – | 2,480 | – | – | – |

*Note:*

- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*

**High Energy Physics**
**Scientific Employment**

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 775 | 785 | 785 | – |
| Number of Postdoctoral Associates (FTEs) | 388 | 400 | 380 | -20 |
| Number of Graduate Students (FTEs) | 500 | 530 | 540 | +10 |
| Number of Other Scientific Employment (FTEs) | 1,560 | 1,635 | 1,540 | -95 |
| **Total Scientific Employment (FTEs)** | **3,223** | **3,350** | **3,245** | **-105** |

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

**18-SC-42, Proton Improvement Plan II (PIP-II), FNAL**
**Fermi National Accelerator Laboratory, FNAL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Proton Improvement Project II (PIP-II) is $125,000,000 of Total Estimated Cost (TEC) funding. The project has an approved Total Project Cost (TPC) of $978,000,000.

The PIP-II project will enhance the Fermilab Accelerator Complex to enable it to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics. The project will design and construct an 800 megaelectronvolt (MeV) superconducting radio frequency (SRF) proton linear accelerator and beam transfer line. The PIP-II project also will modify the existing Fermi National Accelerator Laboratory (FNAL) Booster, Recycler, and Main Injector synchrotrons downstream from the new linear accelerator to accept the increased beam intensity. Some of the new components and the cryo-plant will be provided through international, in-kind contributions.

**Significant Changes**

This project was initiated in FY 2018. The most recent DOE Order 413.3B Critical Decision (CD) is CD-3 (Approve Construction), approved on April 18, 2022. The planned date for CD-4, Project Completion, is 1Q FY 2033.

Anticipated in-kind technical contributions from international partners total $330,000,000 (equivalent to DOE costing). Legally binding agreements with all countries but France have been signed to cover the planned work. The legally binding agreement with France has been drafted and signatures are expected by the end of 2023. Non-binding Project Planning Documents (PPDs) that provide additional technical details beyond those provided in the legally binding agreements are being signed by the international partners; so far PPDs have been signed with Italian, Polish, and UK partner institutions. The PPD, with the India's Department of Atomic Energy laboratories, is expected to be signed in 2023.

The FY 2022 Enacted Appropriations supported continuation of construction of the Early Conventional Facilities (ECF) cryo-plant building, site preparation for the linear accelerator complex, completion of design for CD-3, and initiation of preconstruction procurement for the accelerator's technical systems as designs are completed.

The design was completed ahead of schedule during FY 2022 and, consequently, savings of previously estimated 'design' cost were redirected to offset cost increases and risk-based contingency estimates for 'construction' procurements, including civil construction and technical equipment and specialized materials and processes (such as niobium and superconducting RF cavities), due to inflation and supply chain issues.

The Inflation Reduction Act provided $10,000,000 for PIP-II to advance the project's procurements to reduce schedule risk.

The FY 2023 Enacted Appropriations support initiation of civil construction for the linear accelerator complex as well as initiation of procurement and fabrication for the accelerator's technical systems.

The FY 2024 Request will support continuation of construction of the conventional facilities as well as continuation of procurement and fabrication for the technical systems.

A Federal Project Director (FPD) has been assigned to this project and has approved this construction project datasheet. The FPD has a Level III certification.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 11/12/15 | 7/23/18 | 7/23/18 | 12/14/20 | 4/18/22 | 4/18/22 | 1Q FY 2033 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 12/14/20 | 3/16/21 |

**CD-3A** – Approve long-lead procurement of niobium for superconducting radio frequency (SRF) cavities and other long lead components for SRF cryomodules

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 177,000 | 714,200 | 891,200 | 86,800 | 86,800 | 978,000 |
| FY 2024 | 135,895 | 755,305 | 891,200 | 86,800 | 86,800 | 978,000 |

**2. Project Scope and Justification**

**Scope**

Specific scope elements of the PIP-II project include construction of (a) the superconducting radio frequency (SRF) Linac, (b) cryoplant to support SRF operation, (c) beam transfer line, (d) modifications to the Booster, Recycler and Main Injector synchrotrons, and (e) conventional facilities:

a) 800-MeV Superconducting $H^-$ Linac consisting of a 2.1 MeV warm (normal-conducting) front-end injector and five types of SRF cryomodules that are continuous wave capable but operating initially in pulsed mode. The cryomodules include Half Wave Resonator cavities (HWR) at 162.5 MHz, two types of Single Spoke Resonator cavities (SSR1 and SSR2) at 325 MHz, Low-Beta and High-Beta elliptical cavities at 650 MHz (LB-650 and HB-650). The warm front-end injector consists of an $H^-$ ion source, Low Energy Beam Transport (LEBT), Radiofrequency Quadrupole (RFQ) and Medium Energy Beam Transport (MEBT) that prepare the beam for injection into the SRF cryomodules. The scope includes the associated electronic power sources, instrumentation, and controls to support Linac operation.

   The PIP-II Injector Test Facility at FNAL is an R&D prototype for the low-energy proton injector at the front-end of the Linac, consisting of $H^-$ ion source, LEBT, RFQ, MEBT, HWR, and one SSR1 cryomodule. It was developed to reduce technical risks for the project, with participation and in-kind contributions from the India Department of Atomic Energy (DAE) Labs. The Test Facility has successfully completed its program and has been converted to a cryomodule test stand for testing the cryomodules for the project.

b) Cryoplant with storage and distribution system to support SRF Linac operation. The cryoplant is an in-kind contribution by the India DAE Labs that is similar to the cryoplant being designed and constructed for a high-intensity superconducting proton accelerator project in India.[c]
c) Beam Transfer Line from the Linac to the Booster Synchrotron, including accommodation of a beam dump and future delivery of beam to the FNAL Muon Campus.
d) Modification of the Booster, Recycler and Main Injector synchrotrons to accommodate a 50 percent increase in beam intensity and construction of a new injection area in the Booster to accommodate 800-megaelectronvolt (MeV) injection.
e) Civil construction of conventional facilities, including housings, service buildings, roads, access points and utilities with the special capabilities required for the linac and beam transport line. A portion of the civil construction scope comprises the ECF subproject. That subproject scope includes the cryogenics plant building and site work. ECF subproject total estimated cost is $36,000,000; $8,000,000 in FY 2020, $22,000,000 in FY 2021 and $6,000,000 in FY 2022. The ECF subproject's building and site work will be completed in FY 2023. If the ECF subproject is completed for less than its full budget, DOE may authorize redistribution of those funds to remaining PIP-II project scope.

Significant pieces of the Linac and cryogenic scope (a and b above) will be delivered as in-kind international contributions not funded by DOE. These include assembly and/or fabrication of Linac SRF components and the cryoplant. The rationale or motivation behind these contributions are institutional and/or industrial technical capability, and interest in SRF technology, as well as interest in LBNF/DUNE. The construction phase scope of in-kind contributions is divided between U.S. DOE national laboratories, India Department of Atomic Energy (DAE) Labs, Italy National Institute for Nuclear Physics (INFN) Labs, French Atomic Energy Commission (CEA) and National Center for Scientific Research (CNRS)-National Institute of Nuclear and Particle Physics (IN2P3) Labs, UK Science & Technology Facilities Council (STFC) Labs, and Wroclaw University of Science and Technology in Poland, tentatively as indicated in the following table of Scope Responsibilities for PIP-II.

**Construction-phase Scope Responsibilities for PIP-II Linac RF Components**

| Components | Quan-tity | Freq. (MHz) | SRF Cavities | Responsibility for Cavity Fabrication | Responsibility for Module Assembly | Responsibility for RF Amplifiers | Cryogenic Cooling Source and Distribution System |
|---|---|---|---|---|---|---|---|
| RFQ | 1 | 162.5 | N/A | N/A | U.S. DOE (LBNL) | U.S. DOE (FNAL) | N/A |
| HWR Cryomodule | 1 | 162.5 | 8 | U.S. DOE (ANL) | U.S. DOE (ANL) | U.S. DOE (FNAL) | India DAE Labs, Poland WUST |
| SSR1 Cryomodule | 2 | 325 | 16 | U.S. DOE (FNAL), India DAE Labs | U.S. DOE (FNAL) | India DAE Labs | India DAE Labs, Poland WUST |
| SSR2 Cryomodule | 7 | 325 | 35 | France CNRS (IN2P3 Lab) | U.S. DOE (FNAL) | India DAE Labs | India DAE Labs, Poland WUST |
| LB-650 Cryomodule | 9 | 650 | 36 | Italy INFN (LASA) | France CEA (Saclay Lab) | India DAE Labs | India DAE Labs, Poland WUST |
| HB-650 Cryomodule | 4 | 650 | 24 | UK STFC Labs | UK STFC Labs, U.S. DOE (FNAL) | India DAE Labs | India DAE Labs, Poland WUST |

**Justification**

The PIP-II project will enhance the Fermilab Accelerator Complex by providing the capability to deliver higher-power proton beams to the neutrino-generating target that serves the LBNF/DUNE program for groundbreaking discovery in neutrino physics, a major field of fundamental research in high energy particle physics. Increasing the neutrino beam intensity requires increasing the proton beam power on target. PIP-II will raise the proton beam power from 800 kW to 1,200 kW over an energy range of 60-120 GeV and will enable the eventual increase to 2,400 kW with upgrades to the Booster accelerator. The PIP-II project will provide more flexibility for future science-driven upgrades to the entire accelerator complex and increase the system's overall reliability by addressing some of the accelerator complex's elements that are far beyond their design life.

[c] See Section 8.

PIP-II was identified as one of the highest priorities in the 10-year strategic plan for U.S. High Energy Physics developed by the High Energy Physics Program Prioritization Panel (P5) and unanimously approved by the High Energy Physics Advisory Panel (HEPAP), advising DOE and NSF, in 2014.[d]

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Linac Beam Energy | H- beam will be accelerated to 600 MeV. | H- beam will be accelerated to 700 MeV. Linac systems required for 800 MeV will be installed and tested. |
| Linac Beam Intensity | H- beam will be delivered to the beam absorber at the end of the linac. | H- beam with intensity of $1.3 \times 10^{12}$ particles per pulse at 20 Hz pulse-repetition rate will be delivered to the Beam Transfer Line absorber. |
| Booster, Recycler and Main Injector Synchrotron Upgrades | Upgrades of the Booster, Recycler and Main Injector Synchrotrons, required to support delivery of 1.2 MW onto the LBNF target, will be installed and tested without beam. | Linac beam will be injected into and circulated in the Booster. |

[d] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context," HEPAP, 2014.

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 125,000 | 125,000 | 99,945 | – |
| FY 2022 | 10,895 | 10,895 | 35,950 | – |
| **Total, Design (TEC)** | **135,895** | **135,895** | **135,895** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 35,000 | 35,000 | 17,194 | – |
| FY 2022 | 79,105 | 79,105 | 20,104 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 120,000 | 120,000 | 110,000 | 10,000 |
| FY 2024 | 125,000 | 125,000 | 125,000 | – |
| Outyears | 386,200 | 386,200 | 473,007 | – |
| **Total, Construction (TEC)** | **755,305** | **755,305** | **745,305** | **10,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 160,000 | 160,000 | 117,139 | – |
| FY 2022 | 90,000 | 90,000 | 56,054 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 120,000 | 120,000 | 110,000 | 10,000 |
| FY 2024 | 125,000 | 125,000 | 125,000 | – |
| Outyears | 386,200 | 386,200 | 473,007 | – |
| **Total, TEC** | **891,200** | **891,200** | **881,200** | **10,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 73,594 | 73,594 | 73,410 | – |
| FY 2022 | – | – | 9 | – |
| FY 2023 | – | – | 175 | – |
| Outyears | 13,206 | 13,206 | 13,206 | – |
| **Total, OPC** | **86,800** | **86,800** | **86,800** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 233,594 | 233,594 | 190,549 | – |
| FY 2022 | 90,000 | 90,000 | 56,063 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 120,000 | 120,000 | 110,175 | 10,000 |
| FY 2024 | 125,000 | 125,000 | 125,000 | – |
| Outyears | 399,406 | 399,406 | 486,213 | – |
| **Total, TPC** | **978,000** | **978,000** | **968,000** | **10,000** |

*Note:*
- *Prior Years and FY 2022 reflect actual costs; remaining years are cost estimates.*

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 135,895 | 146,314 | 146,314 |
| Design - Contingency | N/A | 30,686 | 30,686 |
| **Total, Design (TEC)** | **135,895** | **177,000** | **177,000** |
| Construction | 151,000 | 124,009 | 124,009 |
| Site Preparation | 13,000 | 12,783 | 12,783 |
| Equipment | 433,905 | 378,705 | 378,705 |
| Construction - Contingency | 157,400 | 198,703 | 198,703 |
| **Total, Construction (TEC)** | **755,305** | **714,200** | **714,200** |
| **Total, TEC** | **891,200** | **891,200** | **891,200** |
| *Contingency, TEC* | *157,400* | *229,389* | *229,389* |
| **Other Project Cost (OPC)** | | | |
| R&D | 67,117 | 67,117 | 67,117 |
| Conceptual Planning | 8,324 | 8,324 | 8,324 |
| Conceptual Design | 2,855 | 2,855 | 2,855 |
| OPC - Contingency | 8,504 | 8,504 | 8,504 |
| **Total, Except D&D (OPC)** | **86,800** | **86,800** | **86,800** |
| **Total, OPC** | **86,800** | **86,800** | **86,800** |
| *Contingency, OPC* | *8,504* | *8,504* | *8,504* |
| **Total, TPC** | **978,000** | **978,000** | **978,000** |
| ***Total, Contingency (TEC+OPC)*** | ***165,904*** | ***237,893*** | ***237,893*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 160,000 | 90,000 | — | 120,000 | — | 521,200 | 891,200 |
| | OPC | 73,594 | — | — | — | — | 13,206 | 86,800 |
| | TPC | 233,594 | 90,000 | — | 120,000 | — | 534,406 | 978,000 |
| FY 2024 | TEC | 160,000 | 90,000 | 10,000 | 120,000 | 125,000 | 386,200 | 891,200 |
| | OPC | 73,594 | — | — | — | — | 13,206 | 86,800 |
| | TPC | 233,594 | 90,000 | 10,000 | 120,000 | 125,000 | 399,406 | 978,000 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2033 |
| Expected Useful Life | 20 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2053 |

FNAL will operate the PIP-II Linac as an integral part of the entire Fermilab Accelerator Complex. Related funding estimates for operations, utilities, maintenance, and repairs are incremental to the balance of the FNAL accelerator complex for which the present cost of operation, utilities, maintenance, and repairs is approximately $100,000,000 annually.

Related Funding Requirements
(dollars in thousands)

| | **Annual Costs** | | **Life Cycle Costs** | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | 4,000 | 4,000 | 80,000 | 80,000 |
| Utilities | 3,000 | 3,000 | 60,000 | 60,000 |
| Maintenance and Repair | 2,000 | 2,000 | 40,000 | 40,000 |
| Total, Operations and Maintenance | 9,000 | 9,000 | 180,000 | 180,000 |

### 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | **Square Feet** |
|---|---|
| New area being constructed by this project at FNAL | 127,676 |
| Area of D&D in this project at FNAL | — |
| Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | — |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | 127,676 |
| Total area eliminated | — |

The one-for-one replacement will be met through banked space. A waiver from the one-for-one requirement to eliminate excess space at FNAL to offset PIP-II and other projects was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to FNAL 575,104 square feet of excess space to accommodate new facilities including Mu2e, LBNF, DUNE, and other facilities, as-yet unbuilt, from space that was banked at other DOE facilities. The PIP-II Project is following all current DOE procedures for tracking and reporting space utilization.

### 8. Acquisition Approach

DOE is acquiring the PIP-II project through Fermi Research Alliance (FRA), the Management and Operating (M&O) contractor responsible for FNAL, rather than have the DOE compete a contract for fabrication to a third party. FRA has a strong relationship with the high energy physics community and its leadership, including many FNAL scientists and engineers. This arrangement will facilitate close cooperation and coordination for PIP-II with an experienced team of project leaders managed by FRA, which will have primary responsibility for oversight of all subcontracts required to execute the project. The arrangement is expected to include subcontracts for the purchase of components from third party vendors as well as delivery of in-kind contributions from non-DOE partners.

Project partners will deliver significant pieces of scope as in-kind international contributions, not funded by U.S. DOE. The rationale or motivation behind these contributions are institutional and/or industrial technical capability, long-standing collaborations in the physics programs at FNAL that PIP-II will support, and interest in SRF technology. Scientific institutions from several countries, tabulated below, are engaged in discussion of potential PIP-II scope contributions within the framework of international, government-to-government science and technology agreements.

**Scientific Agencies and Institutions Discussing Potential Contributions of Scope for PIP-II**

| Country | Funding Agency | Institutions |
|---|---|---|
| U.S. | Department of Energy | Fermi National Accelerator Laboratory;<br>Lawrence Berkeley National Laboratory;<br>Argonne National Laboratory |
| India | Department of Atomic Energy | Bhabha Atomic Research Centre, Mumbai;<br>Inter University Accelerator Centre, New Delhi;<br>Raja Ramanna Centre for Advanced Technology, Indore;<br>Variable Energy Cyclotron Centre, Kolkata |
| Italy | National Institute for Nuclear Physics | Laboratory for Accelerators and Applied Superconductivity, Milan |
| France | Atomic Energy Commission<br>National Center for Scientific Research | Saclay Nuclear Research Center;<br>National Institute of Nuclear & Particle Physics, Paris |
| UK | Science & Technology Facilities Council | Daresbury Laboratory |
| Poland | Wroclaw University of Science and Technology | Wroclaw University of Science and Technology |

For example, joint participation by U.S. DOE and the India DAE in the development and construction of high intensity superconducting proton accelerator projects at FNAL and in India is codified in Annex I to the “Implementing Agreement between DOE and Indian Department of Atomic Energy in the Area of Accelerator and Particle Detector Research and Development for Discovery Science for High Intensity Proton Accelerators,” signed in January 2015 by the U.S. Secretary of Energy and the India Chairman of DAE. FNAL and DAE Labs subsequently developed a “Joint R&D Document” outlining the specific roles and goals of the collaborators during the R&D phase of the PIP-II project. This R&D agreement is expected to lead to a similar agreement for the construction phase, describing roles and in-kind contributions. DOE and FNAL are developing similar agreements with Italy, France, and the UK for PIP-II.

SC is putting mechanisms into place to facilitate joint consultation between the partnering funding agencies, such that coordinated oversight and actions will ensure the success of the overall program. SC is successfully employing similar mechanisms for international partnering for the DOE LBNF/DUNE project and for DOE participation in LHC-related projects hosted by CERN.

Domestic engineering and construction subcontractors will perform the civil construction at FNAL. FNAL is utilizing a firm fixed-price contract for architectural-engineering services to complete all remaining designs for conventional facilities with an option for construction support. The general construction subcontract will be placed on a firm-fixed-price basis.

All subcontracts will be competitively bid and awarded based on best value to the government. Fermi Site Office provides contract oversight for FRA’s plans and performance. Project performance metrics for FRA are included in the M&O contractor’s annual performance evaluation and measurement plan.

**11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL**
**Fermi National Accelerator Laboratory, FNAL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) is $251,000,000 of Total Estimated Cost (TEC) funding and $4,000,000 in Other Project Cost (OPC) funding.

**Significant Changes**

In November 2015, a preliminary cost and schedule was approved with Critical Decision (CD)-1, replacing an earlier CD-1 approval and including enhanced scope recommended by P5. The approved cost range was $1,260,000,000 to $1,860,000,000. Cost increases from a number of factors, including a lack of experience with working underground, overoptimistic estimates of international contributions, and delays due to COVID-19, supply chain, and funding profiles, led to the TPC exceeding 50 percent above the CD-1 range which required a new CD-1 cost and schedule range as part of a CD-1 Reaffirmation (CD-1RR). Lessons learned were developed around these issues to ensure the new cost estimate would be more reliable. The CD-1RR was approved on February 16, 2023, and established a cost range of $3,160,000,000 to $3,677,000,000.

At the time of CD-1RR approval, the Total Project Cost (TPC) Point Estimate is $3,277,000,000. This TPC Point Estimate is for planning purposes and will be refined as the project matures and each subproject is baselined. The aggregate of the new baselined subproject TPCs must be below the upper end of the approved cost range. When the last subproject is baselined, the LBNF/DUNE-U.S. TPC will be the aggregate of all subproject TPCs plus any contingency being held by the parent LBNF/DUNE-U.S. project. The CD-1RR approval reaffirmed that the previously selected alternative for an international and more capable deep underground detector is still a reasonable decision based on the matured understanding of factors. The reaffirmed alternative is the best opportunity for the U.S. to host a truly world-leading international neutrino program based upon optimized rate of data collection and unmatched sensitivities and precision. The reaffirmed alternative strengthens the U.S.'s international partnerships in particle physics and allows for future upgrades to the detectors and beam intensity if DOE chooses to do so.

The Inflation Reduction Act provided $125,000,000 for LBNF/DUNE. These funds will be used for the Far Site Conventional Facilities—Buildings and Site Infrastructure subproject, which is described below. The TPC estimate is not changed. The funding profile is advanced, but the schedule remains unchanged. The project has allocated contingency earlier in the project as recommended in an Office of Science peer review of the project in order to reduce schedule risk.

The scale of LBNF/DUNE and various other factors, including annual funding levels and research and development needs, resulted in the major scope elements of the project maturing at different rates. Baselining the entire scope of the project at once introduced too many uncertainties and was no longer viewed as being in the best interest of DOE. Therefore, a subproject tailoring approach in accordance with DOE Order 413.3B has been developed to reorganize the project's scope into several independent subprojects for improved planning and management control.

The five subprojects are:

- Far Site Conventional Facilities – Excavation (FSCF-EXC)
- Far Site Conventional Facilities – Buildings and Site Infrastructure (FSCF-BSI)
- Far Detectors and Cryogenic Infrastructure (FDC)
- Near Site Conventional Facilities and Beamline (NSCF+B)
- Near Detector (ND)

The approach to managing subprojects was approved at CD-1RR. The first subproject to be baselined authorizes the completion of cavern excavation at the Far Site. The FSCF-EXC subproject was approved for baseline and start of construction in August 2022. The FSCF-BSI and FDC subprojects will be baselined in FY 2023 and FY 2024, respectively.

FY 2023 Enacted Appropriations funding support continued excavation of the far detector caverns; long-lead procurement items for FDC and NSCF+B; site preparation activities for NSCF+B including site clearing and grading activities in advance of CD-3; initiate construction of FSCF-BSI infrastructure including HVAC, electric, plumbing, etc.; and design and other planning efforts for FDC, NSCF+B and ND in preparation for baseline and approval of construction.

The FY 2024 Request will complete excavation of the far detector caverns; continue construction of FSCF-BSI; begin installation of far detector components for FDC; continue design and other planning efforts for NSCF+B and ND; and continue site preparation of the conventional facilities of NSCF+B.

A Federal Project Director with a certification level 4 is assigned to this project and has approved this CPDS.

**Critical Milestone History**

| | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| LBNF/DUNE-Overall | 1/8/10 | 11/5/15 | 11/5/15 | 3Q FY 2025 | 4Q FY 2026 | 1Q FY 2027 | 1Q FY 2035 |
| Far Site Conventional Facilities-Excavation | – | – | – | 8/19/22 | 12/31/20 | 8/19/22 | 1Q FY 2027 |
| Far Site Conventional Facilities-Buildings and Site Infrastructure | – | – | – | 2Q FY 2024 | 11/20/20 | 2Q FY 2024 | 4Q FY 2028 |
| Far Detectors and Cryogenic Infrastructure | – | – | – | 4Q FY 2024 | 4Q FY 2024 | 4Q FY 2024 | 1Q FY 2033 |
| Near Site Conventional Facilities and Beamline | – | – | – | 2Q FY 2025 | 2Q FY 2025 | 2Q FY 2025 | 2Q FY 2033 |
| Near Detector | – | – | – | 3Q FY 2025 | 4Q FY 2026 | 1Q FY 2027 | 1Q FY 2035 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| | Performance Baseline Validation | CD-1R | CD-1RR | CD-3A |
|---|---|---|---|---|
| LBNF/DUNE-Overall | 3Q FY 2025 | 11/5/15 | 2/16/23 | 1Q FY 2026 |
| Far Site Conventional Facilities-Excavation | 8/19/22 | — | 2/16/23 | 10/27/21 |
| Far Site Conventional Facilities-Buildings and Site Infrastructure | 2Q FY 2024 | — | 2/16/23 | – |
| Far Detectors and Cryogenic Infrastructure | 4Q FY 2024 | — | 2/16/23 | 2/21/23 |
| Near Site Conventional Facilities and Beamline | 2Q FY 2025 | — | 2/16/23 | 2Q FY 2024 |
| Near Detector | 3Q FY 2025 | — | 2/16/23 | 1Q FY 2026 |

**CD-1R** – Refresh of CD-1 approval for the new Conceptual Design.

**CD-1RR** – Update cost range, reaffirm the alternative selection, and approve a new tailoring strategy for baselining the project in multiple subprojects.

**CD-3A** – Approve initial construction and long lead procurements in order to mitigate risks and avoid delays. The CD-3A scope for the Far Detectors and Cryogenic Infrastructure subproject is long-lead procurement of certain components of the detector electronics, photon detectors, and the anode plane assemblies. The CD-3A scope for the Near Site Conventional Facilities and Beamline subproject is long-lead procurement of shielding and accelerator kicker components, early fabrication of magnetic horn components, and wetlands work that must be completed before the corresponding USACE permit expires. The CD-3A scope for the Near Detector is currently under development.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 455,464 | 2,410,911 | 2,866,375 | 133,625 | 133,625 | 3,000,000 |
| FY 2024 | 550,447 | 2,616,888 | 3,167,335 | 109,665 | 109,665 | 3,277,000 |

*Notes:*

- *The project is Pre-CD-2 for most subprojects. All estimates are preliminary. The preliminary TPC range for CD-1RR is $3,160,000,000 to $3,677,000,000.*
- *No construction, other than site preparation and approved civil construction or long-lead procurement, will be performed prior to validation of the Performance Baseline and approval of CD-3 for each subproject.*

## 2. Project Scope and Justification

**Scope**

LBNF/DUNE will be composed of a neutrino beam created by new construction as well as modifications to the existing Fermilab Accelerator Complex, massive neutrino detectors (up to 40,000 tons in total) and associated cryogenics infrastructure located in one or more large underground caverns to be excavated at least 800 miles “downstream” from the neutrino source, and a much smaller neutrino detector at FNAL for monitoring the neutrino beam near its source. A primary beam of protons will produce a neutrino beam directed into a target for converting the protons into a secondary beam of particles (pions and muons) that decay into neutrinos, followed by a decay tunnel hundreds of meters long where the decay neutrinos will emerge and travel through the earth to the massive detector. The Neutrinos at the Main Injector (NuMI) beam at FNAL is an existing example of this type of configuration for a neutrino beam facility. The new LBNF beam line will provide a neutrino beam of lower energy and greater intensity than the NuMI beam and would point to far detector modules at a greater distance than is used with NuMI experiments.[e]

For the LBNF/DUNE project, FNAL will be responsible for design, construction and operation of the major components of facilities which enable the DUNE research program (LBNF) including: the primary proton beam, neutrino production target, focusing structures, decay pipe, absorbers and corresponding beam instrumentation; the conventional facilities and experiment infrastructure on the FNAL site required for the near detector; and the conventional facilities and experiment infrastructure at SURF for the large detectors including the cryostats and cryogenics systems.

**Justification**

Recent international progress in neutrino physics, celebrated by the Nobel Prizes for Physics in 1988, 1995, 2002, and 2015, provides the basis for further discovery opportunities. Determining relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model of particle physics. The study and observation of the different behavior of neutrinos and antineutrinos will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance.

The LBNF/DUNE construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. Neutrinos are intimately involved in nuclear decay processes and high energy nuclear reactions. LBNF/DUNE will study the transformations of muon neutrinos into electron neutrinos, which occur as they travel to large detectors in South Dakota, 800 miles away from FNAL, where they are produced in a high-energy beam. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the puzzling matter-antimatter asymmetry that enables our existence in a matter-dominated universe.

The LBNF/DUNE project comprises a national flagship particle physics initiative. LBNF/DUNE will be the first-ever large-scale international science facility hosted by the United States. As part of implementation of High Energy Physics Advisory Panel (HEPAP)-Particle Physics Project Prioritization Panel (P5) recommendations, the LBNF/DUNE project consists of two multinational collaborative efforts:

- LBNF is responsible for the beamline and other experimental and civil infrastructure at FNAL and at the Sanford Underground Research Facility (SURF) in South Dakota. It is currently operated by the South Dakota Science and Technology Authority (SDSTA), an agency of the State of South Dakota, and hosts experiments supported by DOE, the National Science Foundation, and major research universities.

- DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, fabrication of detector components and subsequent research program.

DOE's High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE. LBNF, with DOE/FNAL leadership and minority participation by international partners including CERN, will construct a megawatt-class neutrino source and related facilities at FNAL (the "Near Site"), as well as underground caverns and cryogenic facilities in South Dakota (the "Far Site") needed to house the DUNE detectors. DUNE has international leadership and participation of over 1,400 scientists and engineers from over 200 institutions in over 30 countries. DOE will fund approximately one half of the DUNE detectors. This excludes the cryostats that hold the detectors. The cryostats will be provided by CERN. The

[e] Detailed analyses of alternatives compared the NuMI beam to a new, lower-energy neutrino beam directed toward SURF in South Dakota, and also compared different neutrino detection technologies for the DUNE detector.

project continues to refine the development of the design and cost estimates as the U.S. DOE contributions to the multinational effort now are better understood. The cost estimate for DOE contributions will be updated as planning continues in preparation for baselining the various subprojects.

FNAL and DOE have confirmed contributions to LBNF documented in international agreements from CERN, the UK, India, Poland, and Brazil. Discussions are ongoing with several other countries for additional contributions, including significant additional contributions from CERN that are in the process of being finalized. For the DUNE detectors, the collaboration put in place a process to complete a technical design of the detectors and divide the work of building the detectors between the collaborating institutions. The review of the detector design with a complete set of funding responsibilities by the Long Baseline Neutrino Committee began in 2019, and development of the set of funding responsibilities has made significant progress and continues to advance. New commitments for detector contributions are being finalized now. SC will manage all DOE contributions to the facility and the detectors according to DOE Order 413.3B, and FNAL will provide unified project management reporting.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)
The KPPs are preliminary and will be finalized and approved with each subproject.

The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Far Site Conventional Facilities – Excavation (FSCF-EXC) | 1) Provide power capacity at the 4850L capable of supporting 10 MW demand.<br>2) Provide a ventilation route capable of exhausting 200,000 CFM though the spray chamber.<br>3) Complete the Ross Shaft brow enlargement and the excavation of all ancillary spaces and access drifts to create a minimum of 71,500 GSF.<br>4) Complete the excavation of three caverns with the following volumes including all required ground support, shotcrete placement and networked geotechnical monitoring system:<br>a. North cavern (102,000 CY)<br>b. South cavern (102,000 CY)<br>c. Central utility cavern (46,800 CY)<br>5) Provide a minimum of 170,000 GSF of concrete floor. | All Threshold KPPs |

| Performance Measure | Threshold | Objective |
|---|---|---|
| Far Site Conventional Facilities – Buildings and Site Infrastructure (FSCF-BSI) | 1) 1200A at 12.47kV power capacity installed in the CUC (sufficient to support four cryostats/detectors).<br>2) Power distribution at 120/240V, 480V, and 4160V installed at the 4850L to support two detectors, along with all general use power installed at the 4850L and 4910L.<br>3) Heat rejection cooling tower installed with 2,000-ton (7 MW) rejection capacity (sufficient to support four detectors.<br>4) 1,600 ton (5.6 MW) chilled water capacity installed to support two detectors and all general cooling loads at the 4850L. | Expanded power distribution and chilled water systems installed to support four cryostats/detectors. This adds 400 tons (1.4 MW) for a total of 2000 tons (7 MW) of chilled water capacity and transformers/power distribution specific to detectors 3 and 4. |
| **FDC Subproject:** Far Site Cryogenic Infrastructure | 1) Nitrogen System engineered to support 4 cryostat / detector modules (400 kW).<br>2) Nitrogen System for two cryostats/detectors installed and commissioned: confirmation of delivery of 300 kW of refrigeration at end of distribution to Argon Condensers.<br>3) Surface receiving facilities installed, tested and ready to accept cryogens.<br>4) Argon purification, regeneration and circulation and Argon condensers system for two cryostats/detectors installed and tested.<br>5) Process controls for two cryostats/detectors installed and tested.<br>6) All cryogenics systems reviewed and approved for filling two cryostats with liquid Argon (LAr).<br>7) First Cryostat reviewed and approved for cryostat filling with LAr.<br>8) Set up contract with options to procure Argon for multiple detectors and buy Argon for first detector.<br>9) Second Cryostat reviewed and approved for cryostat filling with LAr.<br>10) Buy Argon for second detector. | All Threshold KPPs and<br>1) Successfully filled first cryostat/detector with LAr.<br>2) Fill second cryostat to 30 percent level with liquid argon. |

| Performance Measure | Threshold | Objective |
|---|---|---|
| **FDC Subproject:** Far Detector – Horizontal Drift Detector | Using parts and components provided by both the project and in kind by international partners:<br>1) Fabricate and deliver to SURF anode plane assemblies, high voltage field cage structures and cathode planes; Time Projection Chamber (TPC) electronics; components of the photon detector system; part of the DAQ servers; and purity monitors for one horizontal-drift LAr TPC according to specifications.<br>2) Install in the cryostat anode plane assemblies; high voltage field cage structures and cathode planes; TPC electronics; components of the photon detector system; and purity monitors for one horizontal-drift LAr TPC according to specifications. Install the corresponding detector parts and services on top of the cryostat.<br>3) Prior to the final closure of the cryostat, demonstrate continuous readout of the TPC electronics and of the photon detector system through the data acquisition system for one week with a live time of at least 50 percent and a minimum of 96 percent fully functional electronic readout channels, prior to the final closure of the cryostat.<br>*Note that threshold KPPs can be satisfied without filling the cryostat. | All threshold KPPs, with the minimum number of functional channels increased to 98 percent at room temperature.<br><br>*one cryostat/detector module is equivalent to 17-kiloton detector mass |
| **FDC Subproject:** Far Detector – Vertical Drift Detector | Using parts and components provided by both the project and in kind by international partners:<br>1) Fabricate and deliver to SURF charge readout planes for the bottom drift volume, high voltage field cage; electronics for the readout of the bottom charge readout planes; components of the photon detector system; part of the DAQ servers; and purity monitors for one vertical-drift LAr TPC according to specification.<br>2) Install in the cryostat high voltage field cage structures and cathode modules; electronics for the bottom charge readout planes; and components of the photon detector system for one vertical-drift LAr Time Projection Chamber (TPC) according to specifications. Install the corresponding detector parts on top of the cryostat.<br>3) Prior to the final closure of the cryostat, demonstrate continuous readout of the electronics for the bottom charge readout planes through the data acquisition system for one week with a live time of at least 50 percent and a minimum of 96 percent fully functional electronic readout channels, prior to the final closure of the cryostat.<br>*Note that threshold KPPs can be satisfied without filling the cryostat. | All threshold KPPs, with the minimum number of functional channels increased to 98 percent at room temperature.<br><br>*one cryostat/detector module is equivalent to 17-kiloton detector mass |

| Performance Measure | Threshold | Objective |
|---|---|---|
| **FDC Subproject:**<br>Far Detector<br>Far Site Integration | Achieve the threshold KPPs for both the Horizontal and Vertical Drift Detectors. The threshold KPPs in both cases can be satisfied without filling the cryostats. | 1) Once the first cryostat is completely full, observe cosmic ray tracks with the charge and light detection systems.<br>2) Once the second cryostat is filled at the 30 percent level, demonstrate that all the readout channels that can be operated at that point in liquid Argon are fully functional with a minimum number of 94 percent of the total number of channels.<br><br>*Note that objective KPPs do require a completely filled cryostat for one of the two detectors, and a partially filled cryostat for the second one. |
| Near Site Conventional Facilities and Beamline (NSCF+B) | 1) Primary Beamline:<br>• Conventional facilities and beamline constructed to be capable of 2.4MW operation<br>• Beamline under vacuum with all magnets ramped on 120 GeV operations cycle<br>2) Neutrino Beamline:<br>• Conventional facilities constructed to support 2.4MW proton beam<br>• Target Hall to support a three-horn focusing system optimized for oscillation science<br>• Decay Region minimum 635 ft in length<br>• Shielding and absorber constructed to support 2.4MW operation<br>• Horns, target, radioactive water system, and beam windows fabricated for 1.2 MW proton beam<br>• Operation of target pile, decay pipe, horn, and absorber cooling systems<br>• Two-horn focusing system pulsed in situ to 240kA<br>• Target cooling system flow demonstrated in situ<br>• Target shield pile sealed to outside air<br>3) ND Complex:<br>• Cavern space with minimum volume of 700,000 cubic ft<br>• Power infrastructure has a capacity of 2,700kVA running load<br>• Cooling infrastructure includes a minimum of 650 tons of chiller capacity | 1) Primary Beamline:<br>• 120GeV protons delivered to the absorber with the target removed<br>2) Neutrino Beamline:<br>• Three horns pulsed in situ to 300kA<br>• Muons observed downstream of absorber<br>3) Near Detector Complex<br>• All threshold KPPs |

| Performance Measure | Threshold | Objective |
|---|---|---|
| Near Detector | Hardware installed for a neutrino beam monitor capable of detecting a 1 percent shift in the horn current within a period of one week of nominal 1.2MW exposure with performance verified by simulation. | 1) All Threshold KPPs<br>2) Using parts and components provided by both the project and in-kind by international partners:<br>• Deliver a LAr Time Projection Chamber (TPC) detector system capable of measuring neutrino interactions in argon at the near site with similar performance as specified for the Far Detector to directly support long-baseline physics measurements in the DUNE FD<br>• Ability to move the LAr TPC near detector system to an off-axis location<br>• Ability to monitor the on-axis neutrino beam when the LAr TPC near detector system is off-axis |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 374,464 | 374,464 | 329,701 | – |
| FY 2022 | 81,000 | 81,000 | 61,987 | – |
| FY 2023 | 67,743 | 67,743 | 128,189 | – |
| FY 2024 | 24,710 | 24,710 | 27,400 | – |
| Outyears | 2,530 | 2,530 | 3,170 | – |
| **Total, Design (TEC)** | **550,447** | **550,447** | **550,447** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 304,317 | 304,317 | 172,526 | – |
| FY 2022 | 95,000 | 95,000 | 93,374 | – |
| FY 2022 - IRA Supp. | 125,000 | 125,000 | – | – |
| FY 2023 | 108,257 | 108,257 | 188,835 | 13,000 |
| FY 2024 | 226,290 | 226,290 | 212,100 | 104,750 |
| Outyears | 1,758,024 | 1,758,024 | 1,825,053 | 7,250 |
| **Total, Construction (TEC)** | **2,616,888** | **2,616,888** | **2,491,888** | **125,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 678,781 | 678,781 | 502,227 | – |
| FY 2022 | 176,000 | 176,000 | 155,361 | – |
| FY 2022 - IRA Supp. | 125,000 | 125,000 | – | – |
| FY 2023 | 176,000 | 176,000 | 317,024 | 13,000 |
| FY 2024 | 251,000 | 251,000 | 239,500 | 104,750 |
| Outyears | 1,760,554 | 1,760,554 | 1,828,223 | 7,250 |
| **Total, TEC** | **3,167,335** | **3,167,335** | **3,042,335** | **125,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 93,625 | 93,625 | 91,696 | – |
| FY 2022 | 8,000 | 8,000 | 785 | – |
| FY 2023 | 4,000 | 4,000 | 3,757 | – |
| FY 2024 | 4,000 | 4,000 | 2,500 | – |
| Outyears | 40 | 40 | 10,927 | – |
| **Total, OPC** | **109,665** | **109,665** | **109,665** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 772,406 | 772,406 | 593,923 | – |
| FY 2022 | 184,000 | 184,000 | 156,146 | – |
| FY 2022 - IRA Supp. | 125,000 | 125,000 | – | – |
| FY 2023 | 180,000 | 180,000 | 320,781 | 13,000 |
| FY 2024 | 255,000 | 255,000 | 242,000 | 104,750 |
| Outyears | 1,760,594 | 1,760,594 | 1,839,150 | 7,250 |
| **Total, TPC** | **3,277,000** | **3,277,000** | **3,152,000** | **125,000** |

*Note:*
- *Prior years and FY 2022 reflect actual costs; remaining years are cost estimates.*

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 528,377 | 397,568 | **N/A** |
| Design - Contingency | 22,070 | 57,896 | **N/A** |
| **Total, Design (TEC)** | **550,447** | **455,464** | **N/A** |
| Construction | 1,344,860 | 1,134,000 | **N/A** |
| Equipment | 571,488 | 700,000 | **N/A** |
| Construction - Contingency | 700,540 | 576,911 | **N/A** |
| **Total, Construction (TEC)** | **2,616,888** | **2,410,911** | **N/A** |
| **Total, TEC** | **3,167,335** | **2,866,375** | **N/A** |
| *Contingency, TEC* | *722,610* | *634,807* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | 16,000 | 20,625 | **N/A** |
| Conceptual Planning | 44,958 | 30,000 | **N/A** |
| Conceptual Design | 31,977 | 35,000 | **N/A** |
| Other OPC Costs | 13,540 | 27,625 | **N/A** |
| OPC - Contingency | 3,190 | 20,375 | **N/A** |
| **Total, Except D&D (OPC)** | **109,665** | **133,625** | **N/A** |
| **Total, OPC** | **109,665** | **133,625** | **N/A** |
| *Contingency, OPC* | *3,190* | *20,375* | ***N/A*** |
| **Total, TPC** | **3,277,000** | **3,000,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***725,800*** | ***655,182*** | ***N/A*** |

*Notes:*

- *The validated baseline does not occur until all subprojects reach CD-2.*
- *Construction involves excavation of caverns at SURF, 4850 ft. below the surface, for technical equipment including particle detectors and cryogenic systems and construction of the housing for the neutrino-production beam line and the near detector.*
- *Technical equipment in the DOE scope, estimated here, will be supplemented by in-kind contributions of additional technical equipment, for the accelerator beam and particle detectors, from non-DOE partners as described in Section 2.*
- *"Other OPC Costs" include execution support costs including electrical power for construction* and equipment installation.

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 678,781 | 176,000 | — | 176,000 | — | 1,835,594 | 2,866,375 |
| | OPC | 93,625 | 4,000 | — | 4,000 | — | 32,000 | 133,625 |
| | TPC | 772,406 | 180,000 | — | 180,000 | — | 1,867,594 | 3,000,000 |
| FY 2024 | TEC | 678,781 | 176,000 | 125,000 | 176,000 | 251,000 | 1,760,554 | 3,167,335 |
| | OPC | 93,625 | 8,000 | — | 4,000 | 4,000 | 40 | 109,665 |
| | TPC | 772,406 | 184,000 | 125,000 | 180,000 | 255,000 | 1,760,594 | 3,277,000 |

*Note:*
- *All estimates are preliminary.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2035 |
| Expected Useful Life | 20 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2055 |

Operations and maintenance funding of this experiment will become part of the existing Fermilab Accelerator Complex. Annual related funding estimates include the incremental cost of 20 years of full operation, utilities, maintenance, and repairs with the accelerator beam on. The estimates also include operations and maintenance for the remote site of the large detector. New operations and maintenance estimates were developed in 2022 based on a new study and detailed estimating. Current estimate represents an average annual cost in FY 2022 dollars.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 9,000 | 22,000 | 180,000 | 440,000 |
| Utilities | 8,000 | 6,000 | 160,000 | 120,000 |
| Maintenance and Repair | 1,000 | 14,000 | 20,000 | 280,000 |
| Total, Operations and Maintenance | 18,000 | 42,000 | 360,000 | 840,000 |

**7. D&D Information**

The new area being constructed in this project is replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at FNAL | 79,100 |
| New area being constructed by this project at Sanford Underground Research Facility (SURF) | 185,700 |
| Area of D&D in this project at FNAL | — |
| Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | 79,100 |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | 185,700 |
| Total area eliminated | — |

The new facility square footage estimates are based on the current design and updating the calculation to be consistent with DOE's real estate guidance. New facilities information will be identified and reported in accordance with DOE guidance.

**8. Acquisition Approach**

The Acquisition Strategy, approved as part of CD-1, documents the acquisition approach. DOE is acquiring design, construction, fabrication, and operation of LBNF through the M&O contractor responsible for FNAL, Fermi Research Alliance (FRA). FRA and FNAL, through the LBNF Project based at FNAL, is responsible to DOE to manage and complete construction of LBNF at both the near and remote site locations. FRA and FNAL are assigned oversight and management responsibility for execution of the international DUNE project, to include management of the DOE contributions to DUNE. The basis for this choice and strategy is that:

- FNAL is the site of the only existing neutrino beam facility in the U.S. and, in addition to these facilities, provides a source of existing staff and expertise to be utilized for beamline and detector construction.
- FNAL can best ensure that the design, construction, and installation of key LBNF and DUNE components are coordinated effectively and efficiently with other research activities at FNAL.
- FNAL has a DOE-approved procurement system with established processes and acquisition expertise needed to obtain the necessary components and services to build the scientific hardware, equipment and conventional facilities for the accelerator beamline, and detectors for LBNF and DUNE.
- FNAL has extensive experience in managing complex construction, fabrication, and installation projects involving multiple national laboratories, universities, and other partner institutions, building facilities both on-site and at remote off-site locations.
- FNAL, through the LBNF Project, has established a close working relationship with SURF and the SDSTA, organizations that manage and operate the remote site for the far detector in Lead, SD.
- FNAL has extensive experience with management and participation in international projects and international collaborations, including most recently the LHC and CMS projects at CERN, as well as in the increasingly international neutrino experiments and program.

The LBNF/DUNE construction project is a federal, state, private and international partnership. Leading the LBNF/DUNE Project, FNAL will collaborate and work with many institutions, including other DOE national laboratories (e.g. BNL, LBNL and SLAC), dozens of universities, foreign research institutions, and the SDSTA. FNAL will be responsible for overall project management, Near Site conventional facilities, and the beamline. FNAL will work with SDSTA to complete the conventional facilities construction at the remote site needed to house and outfit the DUNE far detector. With the DUNE collaboration, FNAL is also responsible for technical and resource coordination to support the DUNE far and near detector design and construction. DOE will be providing in-kind contributions to the DUNE collaboration for detector systems, as agreed upon with the international DUNE collaboration.

International participation in the design, construction, and operation of LBNF and DUNE will be of essential importance because the field of High Energy Physics is international by nature; necessary talent and expertise are globally distributed, and DOE does not have the procurement or technical resources to self-perform all of the required construction and fabrication work. Contributions from other nations will be predominantly through the delivery of components built in their own countries by their own researchers. DOE will negotiate agreements in cooperation with the Department of State on a bilateral basis with all contributing nations to specify their expected contributions and the working relationships during the construction and operation of the experiment.

DOE will provide funding for the LBNF/DUNE Project directly to FNAL and collaborating DOE national laboratories via approved financial plans, and under management control of the LBNF/DUNE Project Office at FNAL, which will also manage and control DOE funding to the combination of university subcontracts and direct fixed-price vendor procurements that are anticipated for the design, fabrication, and installation of LBNF and DUNE technical components. All actions will perform in accordance with DOE approved procurement policies and procedures.

FNAL staff, or by subcontract, temporary staff working directly with FNAL personnel will perform much of the neutrino beamline component design, fabrication, assembly, and installation. The acquisition approach includes both new procurements based on existing designs, and re-purposed equipment from the Fermilab Accelerator Complex. For some highly specialized components, FNAL will have the Rutherford Appleton Laboratory (RAL) in the United Kingdom design and fabricate the components. RAL is a long-standing FNAL collaborator who has proven experience with such components.

FNAL has chosen the Construction Manager/General Contractor (CM/GC) model to execute the delivery of LBNF conventional facilities at the SURF Far Site. The Laboratory contracted with an architect/engineer (A/E) firm for design of LBNF Far Site conventional facilities at SURF and with a CM/GC subcontractor to manage the construction of LBNF Far Site facilities. FNAL selected this strategy to reduce risk, enhance quality and safety performance, provide a more collaborative approach to construction, and offer the opportunity for reduced cost and shortened construction schedules, via options for the CM/GC to self-perform or competitively bid subcontract award packages. FNAL determined that excavation scope should be openly competed as provided by the subcontract. An excavation subcontract was awarded within budget and excavation construction activities began in FY 2021.

For the LBNF Near Site conventional facilities at FNAL, the laboratory will subcontract with an A/E firm for design and plan to utilize a traditional design-bid-build construction method supported by additional procurements for preconstruction and construction phase services from a professional construction management firm.

For the LBNF Far Site conventional facilities at SURF, DOE entered into a land lease with SDSTA on May 20, 2016, covering the area on which the DOE-funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease and related realty actions provides the framework for DOE and FNAL to construct federally-funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and FNAL to use SDSTA space to host the DUNE experiment. Modifications, repairs, and improvements to the SDSTA infrastructure to support the LBNF/DUNE project are costed to the project. Repairs and improvements for the overall facility are costed to the cooperative agreement between HEP and SDSTA for operation of the facility. Protections for DOE's real property interests in these infrastructure tasks are acquired through the lease with SDSTA, contracts and other agreements such as easements. DOE plans for FNAL to have responsibility for managing and operating the LBNF and DUNE far detector and facilities for a useful lifetime of 20 years and may contract with SDSTA for day-to-day management and maintenance services. At the end of useful life, federal regulations permit transfer of ownership to SDSTA, which is willing to accept ownership as a condition for the lease. FNAL developed an appropriate decommissioning plan prior to lease signing.

# Nuclear Physics

## Overview

The mission of the Nuclear Physics (NP) program is to explore one of the enduring mysteries of the universe, the nature of matter: its basic constituents and how they interact to form the elements and the properties we observe. Solving this mystery involves discovering, exploring, and understanding all forms of nuclear matter, not only the familiar forms of matter we see around us, but also exotic forms that existed in the first moments after the Big Bang and that may exist today inside neutron stars. The aim is to understand why matter takes on the specific forms observed in nature and how that knowledge can benefit society in the areas of energy, climate, commerce, medicine, and national security.

Understanding all forms of nuclear matter requires an enormous range of capabilities: from probing quarks and gluons inside protons, to searching for the largest nuclei that can exist. It also encompasses discovery through time and the evolution of the universe. The epoch in the cosmos when quarks and gluons first combined to form protons was millionths of a second after the Big Bang. Events in the cosmos creating heavy nuclei are still occurring today.

Theoretical approaches to further our understanding are based largely on calculations of the interactions of quarks and gluons described by the theory of Quantum Chromodynamics (QCD). An exciting vision is the prospect of Quantum Computing (QC), a revolutionary new paradigm for future computers capable of solving many-body QCD problems currently intractable with today's capabilities. Experimental approaches use large accelerators at scientific user facilities to collide particles at nearly the speed of light, producing short-lived forms of nuclear matter for investigation. Comparison of experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for experimental and theoretical research. The many forms in which nuclear matter can exist requires a suite of accelerators with complementary capabilities. NP oversees operations at four accelerator facilities.

The Facility for Rare Isotope Beams (FRIB) uniquely affords access to 80 percent of all isotopes predicted to exist in nature, including over 1,000 never produced on earth. The Relativistic Heavy Ion Collider (RHIC) recreates new forms of matter and phenomena that occurred in the extremely hot, dense environment that existed in the infant universe. The Continuous Electron Beam Accelerator Facility (CEBAF) extracts information on quarks and gluons bound inside protons and neutrons that formed shortly after the universe began to cool. The Argonne Tandem Linear Accelerator System (ATLAS) "gently" accelerates nuclei to energies typical of nuclear reactions in the cosmos to further our understanding of the ongoing synthesis of heavy elements such as gold and platinum. Stewardship of these facilities is a priority role and goal of NP, as affirmed in the Nuclear Science Advisory Committee's (NSAC) 2015 Long Range Plan for Nuclear Science (LRP), *Reaching for the Horizon*.

The Electron-Ion Collider (EIC) construction project will provide unprecedented ability to x-ray the proton and discover how the mass of everyday objects is dynamically generated by the interaction of quark and gluon fields inside protons and neutrons. The EIC will maintain U.S. leadership in nuclear physics and in accelerator science and technology of colliders.

One equally exciting NP frontier does not involve accelerators, but envisions the nucleus itself as a laboratory for observing nature's fundamental symmetries. Chief among these experiments is the search, also given high priority in the 2015 NSAC Long Range Plan, for a nuclear decay predicted to happen once in $10^{28}$ years and only if the elusive neutrino particle turns out to be its own anti-particle. The observation of so-called neutrino-less double beta decay would result in a disruptive change in our current understanding of the elementary constituents of nuclear matter and the forces that govern them. Additional experiments include improving the precision of the current value of the neutron lifetime and expanding the limits on a possible electric dipole moment of the neutron. These studies have the potential to change our understanding of the physical world.

NP is the primary steward of the nation's fundamental nuclear physics research portfolio providing approximately 95 percent of the U.S. investment in this area. It also supports the National Nuclear Data Center which collects, evaluates, curates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies. In collaboration with other Office of Science (SC) programs, NP continues to support development of quantum sensors and quantum control techniques, as well as efforts on artificial intelligence and machine learning which can benefit nuclear physics research and NP accelerator operations. NP also stewards accelerator research and development (R&D), pursuing next generation electron ion source developments and advancing approaches in superconducting radio frequency (SRF) technologies.

**Highlights of the FY 2024 Request**

The FY 2024 Request for $811.4 million supports high priority efforts and capabilities in fundamental nuclear physics research; operations, maintenance, and upgrades of scientific user facilities; and projects.

Research

- *Core Research*: Primary fundamental research thrusts include:
  - The search for a Critical Point and characterization of the quark-gluon plasma at RHIC and the Large Hadron Collider (LHC)
  - Unraveling the mechanism underlying quark confinement at CEBAF and RHIC
  - Exploring the fundamental structure of nucleons at the sub-femtometer scale at CEBAF and the future EIC
  - The search for new exotic particles and anomalous violations of nature's symmetries at CEBAF
  - Probing the limits of nuclear existence; site & process for heavy element production in the cosmos at FRIB and ATLAS
  - Discovery of whether the neutrino is its own anti-particle via neutrino-less double beta decay
  - Precision measurement of the neutron's properties to search for new physics
  - Research on the strong force in many-body systems leading to precision predictions from QCD of nuclear properties and nuclear reactions via Scientific Discovery Through Advanced Computing (SciDAC)
  - Curation of reliable, accurate Nuclear Data for basic nuclear research and nuclear technologies
  - Niche capabilities and unique "hands-on" experiences in nuclear science at NP University Centers of Excellence
- *Quantum Information Science (QIS)*: Support continues for the SC National QIS Research Centers (NQISRCs) along with discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS.
- *Artificial Intelligence and Machine Learning (AI/ML)*: R&D to targeted to automate optimization of accelerator availability and performance, as well as software enabling data-analytics-driven discovery.
- *Reaching a New Energy Sciences Workforce (RENEW)*: Expanded efforts, including a RENEW graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC research.
- *Microelectronics:* In coordination with other SC programs, support for research and development of detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures.
- *Funding for Accelerated, Inclusive Research (FAIR):* Focused investment on enhancing research at minority serving institutions (MSIs) to improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.
- *Accelerate Innovations in Emerging Technologies (Accelerate):* Scientific research to accelerate the transition of science advances to energy technologies. The goal is to drive scientific discovery to sustainable production of new technologies across the innovation continuum, including relevant experiences for the future workforce.
- *Established Program to Stimulate Competitive Research (EPSCoR):* Funding continues support for research in states and territories with historically lower levels of Federal academic research funding.
- Within available resources, NP will prioritize transitioning Exascale Computing Project (ECP) researchers, software, and technologies into core research efforts and DOE priorities research areas as ECP concludes.

Facility Operations

Funding supports operations of the NP scientific user facilities to enable world-class science:

- RHIC operates 2,580 hours (94 percent optimal funding) to begin the sPHENIX scientific program.
- CEBAF operates 3,350 hours (88 percent optimal funding) for the highest priority 12 GeV experiments.
- ATLAS operates 5,800 hours (91 percent optimal funding) for compelling research in nuclear structure and astrophysics.
- FRIB continues to move towards full operations, operating for 3,350 hours (94 percent optimal funding).

Projects

The Request for Construction and Major Items of Equipment (MIEs) includes:

- Continuation of research, Project Engineering and Design (PED) activities, and long-lead procurements for the Electron-Ion Collider.
- Continuation of the Ton-scale Neutrinoless Double Beta Decay (TSNLDBD) MIE to determine whether the neutrino is its own antiparticle. Funding supports the management team and coordination of the collaboration.
- Continuation of the High Rigidity Spectrometer (HRS) research project at FRIB to maximize the rate of rare neutron-rich nuclei of central importance for understanding the synthesis of heavy elements in cosmic events.

## Nuclear Physics
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Nuclear Physics** | | | | |
| Medium Energy, Research | 53,404 | 59,083 | 55,555 | -3,528 |
| Medium Energy, Operations | 142,709 | 149,834 | 141,930 | -7,904 |
| **Total, Medium Energy Physics** | **196,113** | **208,917** | **197,485** | **-11,432** |
| Heavy Ion, Research | 46,505 | 46,149 | 47,454 | +1,305 |
| Heavy Ion, Operations | 183,943 | 182,087 | 176,195 | -5,892 |
| Heavy Ion, Projects | 25,013 | 20,000 | 2,850 | -17,150 |
| **Total, Heavy Ion Physics** | **255,461** | **248,236** | **226,499** | **-21,737** |
| Low Energy, Research | 73,935 | 77,651 | 78,409 | +758 |
| Low Energy, Operations | 107,831 | 128,579 | 127,624 | -955 |
| Low Energy, Projects | 17,400 | 23,940 | 9,259 | -14,681 |
| **Total, Low Energy Physics** | **199,166** | **230,170** | **215,292** | **-14,878** |
| Theory, Research | 57,260 | 67,873 | 77,142 | +9,269 |
| **Total, Nuclear Theory** | **57,260** | **67,873** | **77,142** | **+9,269** |
| **Subtotal, Nuclear Physics** | **708,000** | **755,196** | **716,418** | **-38,778** |
| **Construction** | | | | |
| 20-SC-52 Electron Ion Collider (EIC), BNL | 20,000 | 50,000 | 95,000 | +45,000 |
| **Subtotal, Construction** | **20,000** | **50,000** | **95,000** | **+45,000** |
| **Total, Nuclear Physics** | **728,000** | **805,196** | **811,418** | **+6,222** |

SBIR/STTR funding:

- FY 2022 Enacted: SBIR $21,390,000 and STTR $3,006,000
- FY 2023 Enacted: SBIR $8,336,000 and STTR $1,173,000
- FY 2024 Request: SBIR $7,541,000 and STTR $1,060,000

## Nuclear Physics
## Explanation of Major Changes

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Medium Energy Physics** The Request provides support for the CEBAF accelerator complex to support 3,350 operating hours (88 percent optimal funding). The Request includes support to participate in the SC initiatives for QIS, AI/ML, Microelectronics, and Accelerate. | **-11,432** |
| **Heavy Ion Physics** The Request provides funding for the RHIC accelerator complex for a 2,580 hour run (94 percent optimal funding). The Request supports the first full year of science with the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX), which will study high rate jets of particles at RHIC. Funding supports heavy ion nuclear physics at universities and national laboratories. The Request includes support the SC initiatives for QIS and AI/ML. The Request continues other project costs (OPC) for the EIC, which will enable scientists to play a leading role in R&D and the development of scientific instrumentation and accelerator components for the EIC. The Request also supports EPSCoR State-National Laboratory Partnership awards and early career awards in EPSCoR jurisdictions. | **-21,737** |
| **Low Energy Physics** The Request provides support for operations of two low energy user facilities: the ATLAS facility, which operates for 5,800 hours (91 percent optimal funding), and FRIB, which provides beam time for 3,350 hours (94 percent of optimal funding). The Request sustains operations of the 88-Inch Cyclotron at the Lawrence Berkeley National Lab (LBNL) for a limited in-house nuclear science program and an electronics irradiation capability for Department of Defense (DOD) and National Aeronautics and Space Administration (NASA). Funding supports nuclear structure and astrophysics at universities and national laboratories. No funds are requested for the Gamma-Ray Energy Tracking Array (GRETA) and Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIEs, which received their final funding in FY 2023. Funding continues for the HRS to exploit the fast beam capabilities at FRIB and for the TSNLDBD experiment. | **-14,878** |
| **Nuclear Theory** Funding supports theory research efforts at laboratories and universities, the U.S. Nuclear Data Program, specialized Lattice QCD computing hardware at Thomas Jefferson National Accelerator Facility (TJNAF), and participation in the SciDAC program. The Request supports QIS, quantum computing, and AI/ML. Increased funding supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. Science and Technology Directorate (S&T) ecosystem, including a RENEW graduate fellowship. The FAIR initiative increases to provide focused investment on enhancing research at MSIs and emerging research institutions. | **+9,269** |
| **Construction** The Request provides funding for the EIC to continue Project Engineering and Design activities, and begin long-lead procurements. | **+45,000** |
| **Total, Nuclear Physics** | **+6,222** |

**Basic and Applied R&D Coordination**

The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and/or technical expertise through the SciDAC projects and Lattice QCD research to determine the properties of as-yet unobserved exotic particles predicted by the theory of QCD, advance progress towards a model of nuclear structure with predictive capability, and dramatically improve modeling of neutrino interactions during core collapse supernovae. The U.S. Nuclear Data Program provides evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics such as innovative reactor design (e.g., of interest to the NE and Fusion Energy Sciences [FES] programs), materials under extreme conditions (of interest to the BES and FES programs), and nuclear forensics (National Nuclear Administration [NNSA] and the Federal Bureau of Investigations [FBI]). NP leads an Interagency working group including NNSA, Department of Homeland Security (DHS), Nuclear Energy (NE), the Isotope R&D and Production (DOE IP) and other Federal Agencies to coordinate targeted experimental efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives, as well to meet emerging challenges such as generating new nuclear data relevant for space exploration. Capabilities and techniques developed for nuclear physics at NP accelerator facilities are used by DOD and NASA to test electronics for radiation sensitivity in furtherance of their missions. NP research develops technological advances relevant to clean energy and the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health [NIH]); accelerator research and enhancing U.S.-based supply chains for critical accelerator technologies (ARDAP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening (NNSA, DHS, and the FBI).

**Program Accomplishments**

*Advancing Knowledge of the Cosmos.*

When a supernova explodes, or neutron stars collide, often extremely dense object such as black holes or neutron stars result. Knowledge of these fascinating objects remains limited. But recently, nuclear theorists at Low Alamos National Laboratory (LANL), in collaboration with an international group of researchers, have combined theory, cosmological observations, and terrestrial nuclear physics experiments to better understand the matter inside the interior of neutron stars. Their advanced theoretical modeling employed high performance supercomputers combined with neutron-star observations and results from recent terrestrial experiments. The results constrain the radius of a typical neutron star (1.4 times the mass of the sun) to be approximately 12.0 kilometers. This work demonstrates how joint analyses can shed light on the properties of neutron-rich supranuclear matter over the full density range probed in neutron stars.

*Beginning a New Journey of Discovery*.

FRIB at Michigan State University in East Lansing, Michigan, was completed ahead of schedule and on budget. This new Office of Science National User Facility, which took 13 years to plan, design, and construct, began operation on May 2, 2022, with a ribbon-cutting presided over by U. S. Secretary of Energy Granholm. Only weeks after the ribbon cutting ceremony, FRIB was preparing to publish “first time ever” scientific results on the structure of an isotope of magnesium with 14 “extra” neutrons beyond the number that magnesium nuclei ordinarily contain. This result signals the start of research on thousands of new neutron rich isotopes that FRIB will produce to explore the limits of nuclear existence.

*Finding the Boiling Point for Quark-Gluon Soup*.

When water is boiled, it undergoes a phase transition from a liquid to a gas (steam). Knowing the temperature where water turns to steam tells us about the forces between water molecules and their degrees of freedom. Similarly, inside nuclei, quarks, and gluons (the building blocks of protons and neutrons) are normally trapped. But adding energy can cause a phase transition where quarks and gluons enter a liquid-like state called the quark-gluon plasma, or QGP. Knowing the precise temperature where a transition to the QGP occurs can provides invaluable insight on forces binding quarks and gluons. To do this requires advanced particle detectors like the Solenoidal Tracker at RHIC (STAR) detector at Brookhaven National Laboratory (BNL). Recent measurements at STAR have allowed scientists to significantly narrow the window on the temperature and pressure where the phase transition to a QGP occurs. This research will significantly advance our understanding of quarks and gluons, and by extension, protons, neutrons, and the nuclei they form as well.

*Filling in the gaps*.

The analysis of nuclear fuel cycle is one of the most important topics for applied nuclear physics. New experiments performed with the Oak Ridge National Laboratory's Modular Total Absorption Spectrometer (MTAS) carried out at the ATLAS at the Argonne National Laboratory (ANL) have now corrected outdated data on energy release patterns (decay heat) dating from decades ago. The new decay heat data not only allow for improved reactor designs but also elucidate the properties of anti-neutrino emission in nuclear reactions and contribute to non-proliferation studies as well.

*Predicting the Neutron Skin Thickness of Heavy Nuclei*.

Using high performance computers and experimental data from the Lead Radius Experiment (PREX) experiment at Thomas Jefferson National Accelerator Facility, heavy-ion experiments at the Gesellschaft für Schwerionenforschung (GSI) Helmholtz Centre for Heavy Ion Research in Germany, and research data from Brookhaven National Laboratory and Lawrence Berkeley National Laboratory, theorists in the NUCLEI SciDAC collaboration performed state-of-the art theoretical computations which predicted the neutron skin thickness for Lead 208 would be about one third of a femtometer, in excellent agreement with experimental results. The same study provided stringent new constraints on the possible radii of neutron stars.

*Discovering the Origin of Meteoritic Stardust Grains.*

Small inclusions in meteorites (called stardust) have an isotopic composition that can only be explained by assuming that they originated from stellar explosions. Using the Laboratory for Experimental Nuclear Astrophysics (LENA), newly acquired data allow an accurate prediction of the silicon isotopic ratios in different types of stellar explosions to determine if an observed meteoritic grain originated from a supernova or a nova that occurred sometime before the solar system was born. LENA is part of the Triangle Universities Nuclear Laboratory (TUNL), run by a consortium of Duke University, North Carolina Central University, North Carolina State University, and the University of North Carolina at Chapel Hill.

## Medium Energy Physics

### Description

The Medium Energy Physics subprogram focuses primarily on experimental tests of the theory of the strong interaction, known as Quantum Chromodynamics (QCD). According to QCD, all observed nuclear particles, collectively known as hadrons, arise from the strong interaction of quarks, antiquarks, and gluons. The protons and neutrons inside nuclei are the best-known examples of hadrons. QCD, although difficult to solve computationally, predicts what hadrons exist in nature, and how they interact and decay. Specific questions addressed within this subprogram include:

- What is the internal landscape of the protons and neutrons (collectively known as nucleons)?
- What does QCD predict for the properties of strongly interacting matter?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?

Scientists use various experimental approaches to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Experiments that scatter electrons off protons, neutrons and nuclei are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear medium on the quarks and gluons. The subprogram also supports experimental searches for higher-mass "excited states" and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

The Medium Energy subprogram supports research at and operation of the subprogram's primary research facility, the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF). In addition, the subprogram provides support for spin physics research at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), which is the only collider in the world that can provide polarized proton beams.

CEBAF provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons from measurements of how the electrons scatter when they collide with nuclei. CEBAF also uses highly-polarized electrons to make very challenging precision measurements to search for processes that violate a fundamental symmetry of nature, called parity, in order to search for physics beyond what is currently described by the Standard Model of particle physics. These capabilities are unique in the world. The increase in beam energy provided by the 12 GeV CEBAF Upgrade continues to open up exciting new scientific opportunities and secures continued U.S. world leadership in this area of physics. Research at RHIC using colliding beams of spin-polarized protons, is providing information on the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone. Research support for CEBAF and RHIC includes laboratory and university scientific and technical staff needed to conduct high priority data analysis to extract scientific results. Complementary, focused experiments that require different capabilities can be conducted at the High Intensity Gamma-Ray Source (HIGS) at the Triangle Universities Nuclear Laboratory (TUNL), a University Center of Excellence; Fermi National Accelerator Laboratory (FNAL); European laboratories; and elsewhere. The Research and Engineering Center (REC) of the Massachusetts Institute of Technology has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment for the nuclear physics community.

A high scientific priority for this community is addressing an outstanding grand challenge question of modern physics: how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The EIC, to be located at BNL, plans to address this science. Scientists and accelerator physicists from the Medium Energy subprogram are strongly engaged and play significant leadership roles in the development of the scientific agenda and implementation of the EIC.

Transformative accelerator R&D efforts advanced approaches in SRF technology and accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics. Nuclear physicists participate in activities related to quantum information science (QIS) and quantum computing (QC), in coordination with other SC research programs. NP-specific efforts include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. Scientists develop cutting-edge techniques based on artificial intelligence and machine learning (AI/ML) of relevance to nuclear science research and accelerator facility operations. NP continues support for applications of artificial neural networks in the analysis of nuclear physics data. Additionally, NP is supporting technical development at the intersections between real-time ML and control and the optimization of accelerator systems operations and detector design using AI/ML models. Scientists participate in the SC initiative on Microelectronics research and development, emphasizing unique microelectronics that survive in cryogenic and high radiation environments.

The Request also continues support for honoraria for awards, including the Enrico Fermi Awards and the Ernest Orlando Lawrence Awards.

Research

The Research activity supports high priority research at universities, TJNAF, BNL, ANL, LANL, and LBNL and carries out high priority experiments at CEBAF, RHIC, and elsewhere. Scientists conduct research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities, primarily for CEBAF and the EIC. Scientists participate in the development and implementation of targeted advanced instrumentation, including state-of-the-art detectors for experiments that may also have application in areas such as medical imaging instrumentation in coordination with NIH and homeland security. Scientists are engaged in experimental QIS research. TJNAF staff focus on the 12 GeV experimental program, including implementation of select experiments, acquisition of data, and data analysis at CEBAF's four experimental halls. Staff also participate in the RHIC spin program and play critical roles in instrumentation development for the EIC. Researchers participate in the development of scientific and experimental plans for the EIC. The subprogram also supports a visiting scientist program at TJNAF and bridge positions with regional universities as a cost-effective approach to augmenting scientific expertise at the laboratory and boosting research experience opportunities.

TJNAF scientists and university groups play leadership roles in new experiments in the 12 GeV scientific program, and are engaged in commissioning experiments, instrumentation development, and data taking. Scientists at several national laboratories are engaged in planning for the construction of the EIC and its scientific instrumentation. ANL researchers continue precise measurements of the electric dipole moments of laser-trapped atoms as part of an intensive world-wide effort to set limits on QCD parameters and contribute to the search for possible explanations of the excess of matter over antimatter in the universe. LANL scientists continue to lead an experiment at Fermilab to study whether anti-quarks are in orbit about the spin axis of the proton. Research groups at BNL and LBNL play leading roles in RHIC data analysis critical for determining the spin structure of the proton. Researchers at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

Accelerator R&D research at universities and laboratories advance technology and core competencies essential for improving operations of the complex user facilities or developing new facilities within the NP program, including the development of transformative technology for the Nation, including innovative, efficient and cost-effective cryogenic systems, high gradient SRF cavities, and novel in-situ plasma processing of cryomodules. Researchers are also engaged in developing ML techniques focused on improving efficiencies of accelerator operations.

This activity also supports the Accelerate initiative which will support scientific research to accelerate the transition of science advances to energy technologies.

Operations

The Operations activity provides accelerator operations funding for CEBAF, which boasts unique features of continuous wave polarized beam to four experimental halls and serves over 1,700 U.S. and international users. Funding for this activity supports a team of accelerator physicists at TJNAF that operate CEBAF, as well as for power costs of operations and maintenance of the 12 GeV CEBAF. The highest priority investments in cryomodule refurbishment, spares and critical maintenance are supported to address and improve machine performance and reliability. The Request supports high priority accelerator improvements aimed at providing enhanced capabilities, and high priority capital equipment for research and facility instrumentation. Targeted efforts in developing advances in SRF technology to improve operations of the existing machine continue. The core competency in SRF technology plays a crucial role in supporting DOE projects and facility operations outside of nuclear physics and has broad applications from medicine to homeland security. TJNAF also has developed award-winning cryogenics techniques that have led to more cost-effective operations at TJNAF and several other SC facilities; their cryogenics expertise benefitted several SC superconducting accelerator projects. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with nearby universities and other institutions with accelerator physics expertise. Accelerator scientists play critical roles in the design development of the EIC. The subprogram provides Experimental Support for scientific and technical staff, as well as for critical materials and supplies needed for the implementation, integration, assembly, and operation of the large and complex CEBAF experiments.

**Nuclear Physics**
**Medium Energy Physics**

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Medium Energy Physics** | **$208,917** | **$197,485** | **-$11,432** |
| Research | $59,083 | $55,555 | -$3,528 |
| Funding continues to support core research. Scientists, resident at TJNAF, RHIC, universities, and other national laboratories, will participate in high priority experiments to acquire data; develop, implement, and maintain scientific instrumentation; analyze data and publish experimental results; and train students in nuclear science and accelerator science. Funding supports analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin. Funding supports the development of detector design to be used at the EIC and further develop the scientific program. Funding continues to support researchers to pursue transformative accelerator science to improve operations of current and future NP facilities including applications of AI/ML. Research on Microelectronics is continued to study detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures. Scientists conduct research on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions. Funding supports the Accelerate Innovations in Emerging Technologies (Accelerate) initiative. | | The Request will continue to support core research. Scientists, resident at TJNAF, RHIC, universities, and other national laboratories, will participate in high priority experiments to acquire data; develop, implement, and maintain scientific instrumentation; analyze data and publish experimental results; and train students in nuclear science and accelerator science. The Request will continue analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin. The Request will support the development of detector design to be used at the EIC and further develop the scientific program. The Request will continue to support researchers to pursue transformative accelerator science to improve operations of current and future NP facilities including applications of AI/ML. Research on Microelectronics is continued to study detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures. Scientists conduct research on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions. The Request supports the Accelerate initiative. | The Request will support high priority core scientific workforce at universities and national laboratories conducting research related to CEBAF, RHIC, EIC and other facilities, as well as the Accelerate initiative. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Operations | $149,834 | $141,930 | -$7,904 |
| Funding for operations of the CEBAF facility supports the continuation of the high priority experiments in the 12 GeV science program. Funding provides 4,100 operational hours (96 percent optimal funding) for research, tuning, and beam studies. Funding supports CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, activities to improve accelerator performance and reliability, high priority facility and instrumentation capital equipment, high priority accelerator improvement and GPP projects, and the key computing capabilities for data taking and analysis. Funding supports maintenance of critical core competencies and accelerator scientists, engineers, and technicians, and operations staff. Funding supports targeted facility capital equipment and accelerator improvements to modernize SRF equipment. Lab GPP investments advance the most urgent components of the Campus Strategy for infrastructure. Funding also supports the participation of accelerator scientists in accelerator R&D activities, including those for the EIC. | | The Request for operations of the CEBAF facility will support the continuation of the high priority experiments in the 12 GeV science program. The Request will provide 3,350 operational hours (88 percent optimal funding) for research, beam development, and beam studies. The Request will support CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, activities to improve accelerator performance and reliability, high priority facility and instrumentation capital equipment, high priority accelerator improvement and GPP projects, and the key computing capabilities for data taking and analysis. The Request also will support maintenance of critical core competencies and accelerator scientists, engineers, and technicians, and operations staff. The Request will support targeted facility capital equipment and accelerator improvements to modernize SRF equipment. Lab GPP investments will advance the most urgent components of the Campus Strategy for infrastructure. The Request will also support the participation of accelerator scientists in accelerator R&D activities, including those for the EIC. | The Request will support CEBAF run time hours. The decrease in funding will reduce run time and only support the highest priority equipment and efforts to improve CEBAF reliability and performance. |

*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, excluding facility operations.*

## Nuclear Physics
## Heavy Ion Physics

**Description**
The Heavy Ion Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering overarching questions in nuclear physics, including:

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What governs the transition of quarks and gluons into pions and nucleons?
- What determines the key features of QCD and their relation to the nature of gravity and space-time?

At the Relativistic Heavy Ion Collider (RHIC), scientists continue to pioneer the study of condensed quark-gluon matter at the extreme temperatures, characteristic of the infant universe. The goal is to explore and understand unique manifestations of QCD in this many-body environment and their influence on the universe's evolution. In the aftermath of collisions at RHIC and at the Large Hadron Collider (LHC) at CERN, researchers have seen signs of the same QGP that is believed to have existed shortly after the Big Bang. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the QGP including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma, establishing the threshold conditions (minimum nucleus mass and energy) under which the plasma can be formed, and discovering whether a critical point exists demonstrating a first order phase transition between normal nuclear matter and the QGP.

RHIC places heavy ion research at the frontier of discovery in nuclear physics. RHIC is uniquely flexible, providing a full range of colliding nuclei at variable energies spanning the transition to the quark gluon plasma discovered at RHIC. The facility continues to set new records in performance for both integrated Au-Au luminosity at full energy and a number of other beam settings. This flexibility and performance enable a groundbreaking science program to answer outstanding questions about this exotic and fundamental form of matter and whether a critical point exists in the phase diagram of nuclear matter. Scientists participate in instrumentation upgrades, such as enhancements to the capabilities of the Solenoid Tracker at RHIC (STAR) detector and the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) detector, which will be commissioned in FY 2023. Accelerator physicists conduct accelerator R&D at RHIC in critical areas that include various types of cooling of high-energy hadron beams, high intensity polarized electron sources, and high-energy, high-current energy recovery linear accelerators. The RHIC facility is typically used by more than 1,000 DOE, National Science Foundation (NSF), and foreign agency-supported researchers annually.

A compelling, persistent, high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how QCD, the theory of the strong force, which explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. In 2018, a National Academies study gave a strong endorsement to a U.S.-based EIC and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D[a]. In January 2020, BNL was selected as the location for the EIC, BNL is partnering with TJNAF to design and establish the EIC, and in June 2021, DOE approved CD-1, Approve Alternative Selection and Cost Range. Scientists and accelerator physicists from the Heavy Ion and the Medium Energy sub-programs are partnering to advance the EIC, both playing significant leadership roles in the development of the scientific agenda and implementation of the EIC.

Over the course of the acquisition of the EIC, RHIC operations funding will decrease as some scientific staff, engineers and technicians move from RHIC operations to the EIC project. This is a gradual movement to balance the need for the scientific and technical experts with RHIC while ramping up the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core

[a] Report: https://www.nap.edu/read/25171/chapter/1

competencies in collider operations that cannot easily be replaced; their support is embedded in the EIC total project cost and they represent the core facility operations force of RHIC and the EIC. Throughout the EIC project, the temporary reprioritization of funds from the collider facility operations budget to the construction budget will reduce the amount of "new funds" needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

BNL hosts one of the five National Quantum Information Sciences Research Centers (NQISRCs) and focuses on building the fundamental tools necessary for the United States to create quantum computers that provide a true advantage over their classical counterparts. Scientists working in Heavy Ion physics leverage discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS.

Core competencies exist at NP facilities in the areas of beam and collider physics, hadron beam cooling, high field superconducting magnets, SRF, and ion source technologies. AI/ML applications are pursued to optimize operation of the complex accelerators and detectors at user facilities in the NP program. This research is essential for maintaining accelerator technology core competencies at SC-supported laboratories. Accelerator scientists also pursue accelerator science aimed at improving the operations of existing facilities.

Collaboration in the Heavy Ion subprogram at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infancy of the universe. Data collected by the A Large Ion Collider Experiment (ALICE), Compact Muon Solenoid (CMS), and ATLAS detectors confirm that the QGP discovered at RHIC is also seen at the higher energy, and comparisons of results from LHC to those from RHIC have led to important new insights. U.S. researchers have been making important scientific contributions to the emerging results from all three LHC experiments. In ALICE and CMS, U.S. researchers have been participating in developing and upgrading instrumentation for future heavy ion campaigns at the LHC.

Research

This activity supports high priority research at universities and at BNL, LBNL, LANL, and Oak Ridge National Laboratory (ORNL) to participate in efforts at RHIC and the LHC. NP fully supports U.S. commitments to the LHC "common funds," fees based on the level of U.S. scientist participation in the LHC program and the use of LHC computing capabilities, enabling the participation of researchers in the complementary heavy ion program at CERN. U.S. scientists work with their international peers in developing and implementing upgrades to the LHC scientific instrumentation. One such proposed upgrade is the CMS minimum ionizing particle timing detector (MTD) to enhance particle identification for understanding jet quenching, improving heavy flavor hadron measurements, and exploring collectivity in small systems. Heavy Ion research also supports the NQISRCs in partnership with the other SC programs.

The university and national laboratory research groups support personnel and graduate students for taking data within the RHIC heavy ion program, analyzing data, publishing results, developing, and implementing scientific equipment, and planning for future experiments. BNL, LBNL, and ORNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. Scientists participate in the development of a world-leading scientific program for the future EIC.

Transformative accelerator R&D efforts are pursued, including advancements in ion source developments, SRF technology, and hadron beam cooling. Scientists and engineers also pursue accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics. Scientists develop cutting-edge techniques based on AI/ML of relevance to nuclear science research, accelerator facility operations and automated machine operations. NP has been supporting applications of artificial neural networks in the analysis of nuclear physics data for decades. Additionally, NP is supporting technical development at the intersections between real-time ML and control and the optimization of accelerator systems operations and detector design using AI/ML models.

The DOE Established Program to Stimulate Competitive Research (EPSCoR), that funds research in states and territories with historically lower levels of Federal academic research funding, is supported in the Heavy Ion subprogram. In FY 2024, the EPSCoR program will focus on EPSCoR State-National Laboratory Partnership awards to promote single principal investigators (PI) and small group interactions with the unique capabilities of the DOE national laboratory system and continued support of early career awards.

Operations

The Heavy Ion Operations activity supports the operations and power costs of the RHIC accelerator complex at BNL, which includes the Electron Beam Ion Source, Booster, and the Alternating Gradient Synchrotron accelerators that together serve as the injector for RHIC. Staff provides key experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. The Request will support high priority capital equipment and accelerator improvement projects at RHIC to promote enhanced and robust operations, such as upgrades to key accelerator infrastructure. The sPHENIX detector will be in full data-collection mode in FY 2024 and is the key instrument for the last RHIC data taking campaign. sPHENIX enables scientists to study how the near-perfect QGP liquid, which has the lowest shear viscosity ever observed, arises from the strongly interacting quarks and gluons from which it is formed.

RHIC operations have led to advances in accelerator physics which have, in turn, improved RHIC performance and enhanced NP capabilities. These core competencies provide collateral benefits to applications in industry, medicine, homeland security, and other scientific areas outside of NP. RHIC accelerator physicists are providing leadership and expertise to reduce technical risk of relevance to the EIC, including beam cooling techniques and energy recovery linacs. Accelerator physicists also play an important role in the training of next generation accelerator physicists, through support of graduate students and post-doctoral associates.

Funding for RHIC operations continues to be reprioritized to EIC as some scientific staff and experienced accelerator collider engineers and technicians move from RHIC operations to the EIC project. This is a gradual movement, to occur throughout the EIC project, to balance the need for the scientific experts with RHIC while ramping up the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced and represent a part of the core facility operations workforce of RHIC and the EIC. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will prioritize funding needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

RHIC operations allow for symbiotic, parallel, cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by the DOE Isotope Program to produce research and commercial isotopes critically needed by the Nation, and of the NASA Space Radiation Laboratory Program supported by NASA for the study of space radiation effects applicable to human space flight as well as electronics.

Projects

Other project costs (OPC) for the EIC support scientists and accelerator physicists to advance the conceptual design and conduct accelerator and detector R&D. Integration of laboratory core competencies and participation from across the national laboratory complex and universities continues. Accelerator and detector R&D focuses on reduction of technical risks and value engineering.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Heavy Ion Physics** | **$248,236** | **$226,499** | **-$21,737** |
| Research | $46,149 | $47,454 | +$1,305 |
| Funding supports scientists resident at RHIC, universities, and other national laboratories to develop, fabricate, implement, and maintain scientific instrumentation; participate in experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the EIC; and train students in nuclear science. U.S. scientists will participate in the high priority heavy ion efforts and instrumentation upgrades at the international ALICE, CMS, and ATLAS LHC experiments. Funding supports accelerator R&D relevant to NP programmatic needs. Research activities support the NQISRCs and AI/ML aimed at applications of artificial neural networks to nuclear physics research and the optimization of accelerator performance. | | The Request will support scientists resident at RHIC, universities, and other national laboratories to develop, fabricate, implement, and maintain scientific instrumentation; participate in experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the EIC; and train students in nuclear science. U.S. scientists will participate in the high priority heavy ion efforts and instrumentation upgrades at the international ALICE, CMS, and ATLAS LHC experiments. The Request will support accelerator R&D relevant to NP programmatic needs. Research activities support the NQISRCs and AI/ML aimed at applications of artificial neural networks to nuclear physics research and the optimization of accelerator performance. Funding supports EPSCoR State-National Laboratory Partnership awards and early career awards. | Funding will continue to support high priority core scientific workforce at universities and national laboratories to enhance high priority research at RHIC, the LHC, and for EIC science and detector development. Continued support for research in EPSCoR jurisdictions. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Operations $182,087 | $176,195 | -$5,892 |
| Funding supports RHIC operations at 2,400 hours (96 percent optimal funding) limited by installation of the new sPHENIX detector. Funding supports the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and computing capabilities for data taking and analysis. Support will provide critical core competencies and accelerator scientists, engineers, and technicians, for collider operations. Accelerator scientists conduct research aimed at improving the operations of the RHIC accelerator complex. | The Request will support RHIC operations at 2,580 hours (94 percent optimal funding). The Request will support the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and computing capabilities for data taking and analysis. Support will provide critical core competencies and accelerator scientists, engineers, and technicians, for collider operations. Accelerator scientists conduct research aimed at improving the operations of the RHIC accelerator complex. | The Request for RHIC operations will support operations to initiate the first full year of science with sPHENIX and continue the science program with STAR. Reprioritization of effort to support EIC continues. |
| Projects $20,000 | $2,850 | -$17,150 |
| The experienced scientists and engineers skilled in collider operations continue to transition from RHIC operations to support EIC activities. | OPC funds will support continued design efforts as well and research and development to increase technical readiness prior to the project's CD-2. | OPC support of EIC activities will continue at an anticipated lower rate as research and development activities wind down and preliminary design is advanced. |

*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, excluding facility operations.*

## Nuclear Physics
## Nuclear Theory

### Description

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. One major theme of theoretical research is the development of an understanding of the mechanisms and effects of quark confinement and deconfinement. A quantitative description of these phenomena through QCD is one of this subprogram's greatest intellectual challenges. New theoretical and computational tools are also being developed by the community to describe nuclear many-body phenomena; these approaches will likely also see important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements in the cosmos and what the nature of the neutrino may reveal about the evolution of the early universe.

This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington. It also supports topical collaborations within the university and national laboratory communities to address only the highest priority topics in nuclear theory that merit a concentrated, team-based theoretical effort.

The U.S. Nuclear Data Program (USNDP) aims to provide current, accurate, and authoritative data to workers in basic and applied areas of nuclear science and engineering. It addresses this goal primarily through maintaining and providing public access to extensive nuclear physics databases, which summarize and cross-correlate the results of over 100 years of research on nuclear science. These databases are an important national and international resource, and they currently serve approximately five million retrievals of nuclear data annually. The USNDP also addresses important gaps in nuclear data through targeted experiments and the development and use of theoretical models. The program involves the combined efforts of approximately 50 nuclear scientists at 10 national laboratories and universities and is managed by the National Nuclear Data Center (NNDC) at BNL. The NNDC is designated as an SC Public Reusable Research (PuRe) Data Resource, a designation commensurate with high standards of data management, resource operation, and scientific impact. The USNDP provides evaluated cross-section and decay data relevant to a broad suite of federal missions and topics. NP leads an interagency working group including the NNSA, NE, DOE IP, and other federal agencies to coordinate targeted experimental efforts.

Nuclear theorists also conduct research related to QIS and quantum computing (QC). This work is carried out in coordination with and support of other NP/SC efforts including R&D on quantum sensors to enable precision measurements, development of quantum sensors based on atomic-nuclear interactions, R&D on nuclear physics techniques to enhance qubit coherence times, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. In partnership with other SC programs, NP continues its role in jointly stewarding NQISRCs which focus on building the fundamental tools necessary for the United States to create quantum computers that provide a true advantage over their classical counterparts.

Scientists continue to develop cutting-edge techniques based on AI/ML to accelerate discovery in nuclear science research and optimize the efficiency of accelerator facility operations. NP applications of artificial neural networks in data analysis continue to be enhanced and made more powerful. Future "intelligent" experiments will seek to incorporate next generation AI advances into the optimization of detector design, detector hardware and electronics. The Request also supports technical development at the intersection between real-time ML and control and optimization of accelerator systems operations, with specific focus on improving the reliability and efficiency of accelerator operations.

The Nuclear Theory subprogram supports and leverages lattice quantum chromodynamics (LQCD) calculations that are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. NP supports LQCD computing needs for dedicated computational resources with investments at TJNAF.

The Nuclear Theory subprogram also supports SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities performing at current technological limits. The NP SciDAC program operates on a five-year cycle and supports computationally intensive research projects jointly with other SC and DOE offices in areas of mutual interest.

The Nuclear Theory subprogram supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. The Request includes funding for RENEW in the theory subprogram as well as the other NP subprograms with the distribution dependent on peer review results of topical proposals.

<u>Research</u>

This activity supports high priority research at ANL, BNL, LANL, LBNL, Lawrence Livermore National Laboratory (LLNL), ORNL, TJNAF, and universities. This research advances our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifies and explores compelling new areas of research. The Request continues support of topical collaborations within available funds to bring together theorists to address specific emerging and high-priority theoretical challenges. The activity supports high priority efforts on FRIB theory, which is critical to theory research associated with the planned FRIB scientific program to optimize the interpretation of the experimental results. NP will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes.

The Request supports research related to QIS and QC to provide technological and computational advances relevant to NP and other fields. Following exploratory QIS/QC workshops at the Institute for Nuclear Theory and at ANL, as well as a QC "test-bed" simulation to demonstrate proof-of-principle use of quantum computing for scientific applications. The Nuclear Science Advisory Committee published a report[b] in October 2019 to articulate further priority areas in QIS/QC where unique opportunities exist for nuclear physics contributions. For example, the report noted that the intersection of Quantum Field Theory and QC was an exciting opportunity for important advances achieved through nuclear physics research.

Support continues for the third year of SciDAC-5 awards initiated in FY 2022. In addition to addressing specific problems relevant for nuclear physics research, SciDAC projects continue to serve as critical research for highly trained scientists who can address national needs. A new round of topical collaborations awarded in FY 2023 is supported for a second year of these efforts.

Funding for AI/ML research continues in FY 2024. These activities help develop cutting-edge techniques based on AI of relevance to nuclear science research, accelerator facility operations, and automated machine operations.

The Request supports the activities of the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development, providing for world-leading acquisition and dissemination of high-quality data for public consumption. U.S. efforts focus on improving the completeness and reliability of data already archived that is used for industry and for a variety of Federal missions, and the USNDP expands the effort to conduct experiments needed to address gaps in the data archives deemed of high priority and urgency. Examples of targeted measurements include gamma ray spectroscopy of relevance for medical isotope science; nuclear beta decay data and reactor decay heat data of relevance for optimizing the emergency cooling systems of nuclear reactors and for the control of fast breeder reactors, anti-neutrino data relevant for basic research, and uranium-238 cross section data using neutron-gamma coincidences important for several Federal missions. NP will collaborate with other Federal Agencies that are members of the NP-led Inter-Agency Nuclear Data Working Group, to carry out experimental measurements.

This activity also supports the Funding for the FAIR initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice communities.

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[b] "*Nuclear Physics and Quantum Information Science*" Nuclear Science Advisory Committee, October 2015 (https://science.osti.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Nuclear Theory** | **$67,873** | **$77,142** | **+$9,269** |
| Research | $67,873 | $77,142 | +$9,269 |
| Funding supports high priority QIS efforts. LQCD computing investments continue at TJNAF. High priority theoretical research at universities and national laboratories is supported for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists focuses on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions continues to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the research program at FRIB, and ongoing and planned RHIC experiments. Funding supports the second year of SciDAC-5 grants and the first year of theory topical collaborations. Funding supports investments in an initiative to develop cutting-edge AI/ML techniques of relevance to nuclear science research, and accelerator facility operations. | | The Request will support high priority QIS efforts. LQCD computing investments continue at TJNAF. Funding will support high priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions will continue to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the research program at FRIB, and ongoing and planned RHIC experiments. The Request will support the third year of SciDAC-5 grants, as well as the second year of theory topical collaborations. Funding will target investments in an initiative to develop cutting-edge AI/ML techniques of relevance to nuclear science research, and accelerator facility operations. | Funding will support the highest priority research in nuclear theory, growth of the FAIR and RENEW initiatives, transition of ECP related activities to core, and DOE priority research areas. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| This activity also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. Funding also supports the FAIR initiative. | The RENEW initiative expands targeted efforts to increase participation and retention of individuals from underrepresented groups in SC research activities, including a RENEW graduate fellowship. The Request grows support for the FAIR initiative. Within available resources, NP will prioritize transitioning ECP researchers, software, and technologies into core research efforts and DOE priority research areas as ECP concludes. | |
| Funding continues the expanded USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development initiated in FY 2022. | The Request will continue the expanded USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. | Funding will support nuclear data efforts of the USNDP. |

*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, excluding facility operations.*

## Nuclear Physics
## Low Energy Physics

### Description

The Low Energy Physics subprogram includes two scientific activities that focus on using nuclear interactions and decays to answer overarching questions related to Nuclear Structure and Nuclear Astrophysics, and Fundamental Symmetries.

### Nuclear Structure and Nuclear Astrophysics

Questions associated with Nuclear Structure and Nuclear Astrophysics include:

- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?
- What is the origin of simple patterns in complex nuclei?
- What is the nature of neutron stars and dense nuclear matter?
- What are the origins of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

The Nuclear Structure and Nuclear Astrophysics activities address these questions through support of research to develop a comprehensive description of nuclei using beams of stable and rare isotopes to yield new insights and reveal new nuclear phenomena. The activities also measure the cross sections of the nuclear reactions that power stars and lead to spectacular stellar explosions, which are responsible for the synthesis of the elements.

ATLAS, at ANL, is an SC scientific user facility providing research opportunities in Nuclear Structure and Nuclear Astrophysics, serving approximately 300 domestic and international scientists per year. ATLAS is the world's premiere facility for stable beams and provides high-quality beams of all the stable elements up to uranium, as well as selected beams of short-lived (radioactive) nuclei to study nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics, using the Neutron-generator Upgrade to the Californium Rare Ion Breeder Upgrade (nuCARIBU) ion source. Technologically cutting-edge and unique instrumentation are a hallmark of ATLAS, and the facility continues to be significantly oversubscribed by the user community. ATLAS is also an essential training ground for scientists and students. The facility nurtures an expert core competency in accelerator science with SRF cavities for heavy ions that are relevant to next generation high-performance proton and heavy ion linacs. This competency is important to the SC mission and international stable and radioactive ion beam facilities. ATLAS stewards a target development laboratory, the Center for Accelerator Target Science (CATS), a national asset for the low energy community. Investments to increase ATLAS capabilities provide unique research opportunities including a cost-effective Multi-User Upgrade (MUU) to address a backlog of compelling experiments.

The FRIB at Michigan State University (MSU) became an SC scientific user facility in FY 2020, with FY 2023 planned as its first full year of operations. FRIB provides beams of rare isotopes with neutron and proton numbers far from those of stable nuclei to test the limits of nuclear existence and advance understanding of the atomic nucleus and the evolution of the cosmos. The GRETA MIE is one of the primary tools that the nuclear science community has identified as necessary to leverage the capabilities of FRIB. GRETA's unprecedented combination of full coverage with high efficiency, and excellent energy and position resolution, will extend the reach of FRIB to study the nuclear landscape, provide new opportunities to discover and characterize key nuclei for electric dipole moment searches, and open new areas of study in nuclear astrophysics. The High Rigidity Spectrometer (HRS) will exploit FRIB's fast beam capabilities, enabling the most sensitive experiments across the entire chart of nuclei with the most neutron-rich nuclei available.

Scientists participate in AI/ML research, conducting R&D targeting automated optimization of accelerator availability, performance, and operation, as well as software development enabling AI/ML-driven discovery.

Scientists participate in the international effort to discover and characterize new "super heavy" elements in the periodic table. U.S. researchers played a prominent role in the discovery of Elements 115, 117, and 118, and Element 117 was named Tennessine to acknowledge the leadership role of the U.S. in these efforts. Research is ongoing to characterize these new elements and to discover Element 120. Past and future experiments were/are made viable by the provision of rare isotopes produced at the High Flux Isotope Reactor (HFIR) through the DOE Isotope Program. NP also supports operations of the LBNL 88-Inch Cyclotron to provide beams for an in-house nuclear science program focused on studying the properties of newly discovered elements on the periodic table, as well as conducting independent searches for new super-heavy elements. DOD and NASA exploit materials irradiation capabilities at the 88-Inch Cyclotron to develop radiation-resistant electronics for their missions.

There are three university Centers of Excellence within the Low Energy subprogram, each with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU), the four facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University, and unique expertise and capabilities for instrumentation development at the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington.

**Fundamental Symmetries**

Questions related to Fundamental Symmetries of nature addressed in low energy nuclear physics experiments include:

- What is the nature of neutrinos, what are their masses, and what role have they played in creating the imbalance between matter and antimatter in our universe? Is there evidence from the electric-dipole moments of atomic nuclei and the neutron that indicate our current understanding of the fundamental laws governing nuclear physics is incomplete?
- Will precise measurements in electron scattering and the decay of nuclei indicate the existence of forces that were present at the dawn of the universe, and disappeared from view as the universe evolved?

The Fundamental Symmetries activities address these questions through precision studies using neutron and electron beams and decays of nuclei, including beta decay, double-beta decay, and neutrino-less double beta decay (NLDBD). U.S. scientists are world leaders in the global research effort aimed at neutrino science and owing to the importance of nuclear beta decay in understanding neutrino properties, NP is the SC steward of neutrino mass measurements and NLDBD. Often in partnership with NSF, NP has invested in neutrino experiments both domestically and overseas, playing critical roles in international experiments that depend on U.S. leadership for their ultimate success: e.g., the Cryogenic Underground Observatory for Rare Events (CUORE) and the Karlsruhe Tritium Neutrino Experiment (KATRIN). In partnership with NSF, NP also participates in the international LEGEND-200 experiment. The NSAC 2015 LRP recommended "the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment." NLDBD can only occur if neutrinos are their own anti-particles. The observation of such events would have profound, game changing consequences for present understanding of the physical universe. NP has invested in R&D on candidate technologies for next–generation ton-scale experiments, including crystals of enriched germanium (LEGEND-1000), liquid xenon (nEXO), and lithium molybdenate crystals (CUPID). The Request will provide support for ton-scale research based on one or more of these technologies to progress toward CD-1, Approve Alternative Selection and Cost Range. The NLDBD MIE received CD-0, Approval of Mission Need, in November 2018.

Very precise measurements in parity violating electron scattering, the decay of nuclei, and the properties of neutrons provide sensitivity to new forces and address questions about the matter/anti-matter imbalance rivaling, and even exceeding, the reach of high energy colliders. The MOLLER MIE will measure the parity-violating asymmetry in electron-electron scattering at CEBAF which is uniquely sensitive to the possible existence of new as-yet unforeseen particles. Evidence for electric dipole moments of the neutron and atoms violate time reversal invariance and would shed light on the matter/anti-matter imbalance in the universe. Beams of cold and ultracold neutrons with the dedicated Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source (SNS) are used to study fundamental properties of neutrons, including the flagship experiment to measure the electric dipole moment of the neutron.

Scientists engaged in Fundamental Symmetries research are particularly well positioned with their expertise in rare signal detection, to engage in research on QIS and QC. They contribute to R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems.

Nuclear Structure and Nuclear Astrophysics Research

This activity supports high priority research groups at ANL, LBNL, LLNL, and ORNL, and at universities. Scientists develop, fabricate, and use specialized instrumentation at ATLAS, and participate in the acquisition and analysis of data. Scientists design, fabricate, install, and commission instrumentation at FRIB for use in the scientific program. The Request supports leading researchers who worked at other facilities to help lead the FRIB scientific mission. Progress continues on the GRETA MIE, although the project received final funding in FY 2023 and no new funds are requested in FY 2024. It also continues implementation of the HRS. Scientists participate in research to characterize and discover new super-heavy elements at international facilities and the 88-Inch Cyclotron. The Request will provide support to the university Centers of Excellence at TUNL and TAMU for the conduct of nuclear structure and nuclear astrophysics experiments at these niche facilities. Accelerator scientists participate in transformative accelerator R&D, particularly in the development of next generation ion sources for accelerators. Scientists utilize AI/ML advances to improve machine performance and reliability.

Fundamental Symmetries Research

The activity supports high priority research at BNL, LANL, LBNL, LLNL, ORNL, Pacific Northwest National Laboratory, and SLAC National Accelerator Laboratory, and at universities. R&D continues for a challenging experiment to measure the electric dipole moment of the neutron, which is sensitive to a wide range of underlying new physics and is a test of charge-parity violation. Other experiments at the FNPB SNS continue, along with minor construction activities in support of this research. First-generation NLDBD experiments finalize analysis of data, such as the CUORE experiment at Gran Sasso Laboratory in Italy. Engineering and design efforts continue for international ton-scale NLDBD research, along with targeted R&D. Progress continues on the MOLLER MIE, although the project received final planned funding in FY 2023 and no new funds are requested in FY 2024. Scientists participate in the operations of the KATRIN experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany to provide a measurement of the neutrino mass. University Centers of Excellence at TUNL, CENPA, and TAMU with unique capabilities are exploited to advance research in Fundamental Symmetries. Researchers conduct NP research of relevance to QIS, with a focus on novel quantum sensors.

Nuclear Structure and Nuclear Astrophysics Operations

The activity supports facility and operations costs associated with ATLAS, FRIB, and the 88-Inch Cyclotron. ATLAS provides highly reliable and cost-effective stable and selected radioactive beams and specialized instrumentation. Funding provides support for the operations and power costs of the ATLAS, and targeted support for high priority accelerator and scientific instrumentation capital equipment, accelerator improvement projects, and experimental support. The ATLAS core competency in accelerator science is maintained that are important to the next generation of high-performance proton and heavy ion linacs. Critical efforts to address facility oversubscription and increase available beam time continue with the implementation of the cost-effective MUU Accelerator Improvement Project.

The Request supports FRIB operations to provide a reliable source of rare isotopes using in-flight production methods. The Request supports beam time for the highest priority experiments, improvements to scientific instrumentation and experimental capabilities, and accelerator enhancements to support progress towards reaching full power.

The Request also sustains operations of the 88-Inch Cyclotron for a focused in-house nuclear physics program which includes characterization and searches for new elements and nuclear data measurements.

## Nuclear Physics
## Low Energy Physics

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Low Energy Physics** | **$230,170** | **$215,292** | **-$14,878** |
| Research | $77,651 | $78,409 | +$758 |
| Funding supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and installation and commissioning of instrumentation for the FRIB scientific program. Funding targets research for critical FRIB scientific personnel to lead the scientific program at FRIB. Scientists continue to participate in the characterization of recently discovered elements and search for new ones. Research will continue at the university-based Centers of Excellence at TUNL, CENPA, and TAMU. Scientists utilize AI/ML that can promote automated platforms to improve machine performance and reliability and advance detector design and data processing. | | The Request will support high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and FRIB. Scientists will participate in the characterization of recently discovered elements and search for new ones. Research will continue at the university-based Centers of Excellence at TUNL, CENPA, and TAMU. Scientists utilize AI/ML that can promote automated platforms to improve machine performance and reliability and advance detector design and data processing. | The Request will support the highest priority research efforts and essential workforce at universities and national laboratories, with a focus on conducting experiments at ATLAS and FRIB. |
| High priority research in NLDBD will continue with a strategic mix of efforts for selection in FY 2023. Funding supports U.S. participation in the operations of the international KATRIN experiment. | | High priority research in NLDBD will continue with a strategic mix of efforts for selection in FY 2024. The Request will continue support for U.S. participation in the operations of the international KATRIN experiment. | The Request will support the highest priority research efforts and essential workforce at universities and national laboratories. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Operations $128,579 | $127,624 | -$955 |
| ATLAS operates for 5,950 hours (96 percent of optimal funding). Funding supports operations, staff, maintenance, and high priority accelerator improvement projects and capital equipment for the facility and scientific instrumentation, including the development of a multi-user capability. Funding also supports the second year of operations at FRIB for 3,600 hours (99 percent of optimal funding) to execute the first full year of the scientific program. Funding continues operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements. | ATLAS will operate for 5,800 hours (91 percent of optimal funding). The Request will fund operations, staff, maintenance, and high priority accelerator improvement projects and capital equipment for the facility and scientific instrumentation, including the development of a multi-user capability. The Request will also support the second year of operations at FRIB for 3,350 hours (94 percent of optimal funding) to execute the first full year of the scientific program. Funding will sustain operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements. | Funding will support FRIB, ATLAS, and 88-Inch Cyclotron. |
| Projects $23,940 | $9,259 | -$14,681 |
| Funding continues support for the GRETA MIE, MOLLER MIE, NLDBD MIE, and the HRS research project. The GRETA and MOLLER MIEs received their final funding allocation. | The Request will continue support for the NLDBD MIE and the HRS research project. | The GRETA and MOLLER MIEs complete their baselined and planned funding profiles with the FY 2023 Enacted Appropriations. |

*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, excluding facility operations.*

## Nuclear Physics
## Construction

**Description**

This subprogram supports all line-item construction for the entire NP program. All Total Estimated Costs (TEC) are funded in this subprogram, including engineering, design, and construction. OPC's are funded in the relevant subprograms. The FY 2024 Request continues the construction effort for the EIC, which is to be located at BNL. The estimated Total Project Cost (TPC) range for the EIC project is $1.7 billion to $2.8 billion. BNL has teamed with TJNAF to lead the development and implementation of the EIC. The EIC scope, cost, and schedule include an electron injector, rapid cycling synchrotron, an electron storage ring, modifications to one of the two RHIC ion rings, one interaction region with a detector, support buildings, and other infrastructure. Improvements will accommodate a second interaction region and its detector, although they are not part of the project scope. The project is expected to attract international collaboration and contributions.

EIC acquisition, will increasingly rely on RHIC scientists, engineers, and technicians as RHIC activities ramp down. This workforce with critical core competencies in collider operations remains essential to RHIC now and eventually EIC operations. They cannot easily be replaced. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will supplement funding needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

Since the release of the 2002 LRP for Nuclear Science, a high priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton, such as its mass and spin, are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how quantum chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points like quarks interacting via the exchange of gluons, acts to generate the "macroscopic" properties of protons and neutrons. The 2015 LRP for Nuclear Science concluded, "…a high energy, polarized electron ion collider is the highest priority for new facility construction…" A National Academies study, charged to independently assess the impact, uniqueness, and merit of the science that would be enabled by U.S. construction of an electron-ion collider, gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D. Scientists and accelerator physicists from both the Medium Energy and Heavy Ion subprograms are actively engaged in the development of the scientific agenda, design of the facility and development of scientific instrumentation related to a proposed EIC. Critical Decision-0 (CD-0), Approve Mission Need, was received on December 19, 2019, followed by CD-1, Approve Alternative Selection and Cost Range on June 29, 2021.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Construction** | **$50,000** | **$95,000** | **+$45,000** |
| 20-SC-52 Electron Ion Collider (EIC), BNL | $50,000 | $95,000 | +$45,000 |
| Funding continues TEC support for the EIC. The funds are for engineering and design to reduce technical risk after completion of the conceptual design. RHIC operations includes a “reprioritization” of expert workforce from the RHIC facilities operations budget to support both the EIC OPC and TEC request. | | The Request will continue TEC funding for the EIC. The funds will be used for engineering and design to reduce technical risk after completion of the conceptual design and limited long lead procurements. RHIC operations includes a “reprioritization” of expert workforce from the RHIC facilities operations budget to support the EIC OPC and TEC request. | The ramp-up of funding will support increased engineering and design efforts and limited long lead procurements as the project team advances towards establishing a performance baseline. |

## Nuclear Physics
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | | |
| Capital Equipment | N/A | N/A | 29,771 | 78,760 | 34,988 | 20,307 | -14,681 |
| Minor Construction Activities | | | | | | | |
| General Plant Projects | N/A | N/A | 1,626 | – | 2,642 | 2,642 | – |
| Accelerator Improvement Projects | N/A | N/A | 5,159 | – | 5,211 | 5,211 | – |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **36,556** | **78,760** | **42,841** | **28,160** | **-14,681** |

## Capital Equipment

| | (dollars in thousands) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
| **Capital Equipment** | | | | | | | |
| Major Items of Equipment | | | | | | | |
| Heavy Ion Physics | | | | | | | |
| Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX) | 20,577 | 20,364 | 213 | – | – | – | – |
| Low Energy Physics | | | | | | | |
| Gamma-Ray Energy Tracking Array (GRETA), LBNL | 57,700 | 25,500 | 9,000 | 7,700 | 15,500 | – | -15,500 |
| High Rigidity Spectrometer | 121,830 | 4,240 | 3,000 | 31,840 | 3,000 | 6,259 | +3,259 |
| MOLLER | 47,220 | 7,000 | 5,000 | 31,220 | 4,000 | – | -4,000 |
| Ton-Scale Neutrinoless Double Beta Decay (NLDBD) MIE | 626,700 | 2,400 | 400 | 8,000 | 1,440 | 3,000 | +1,560 |
| Total, MIEs | N/A | N/A | 17,613 | 78,760 | 23,940 | 9,259 | -14,681 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 12,158 | – | 11,048 | 11,048 | – |
| **Total, Capital Equipment** | **N/A** | **N/A** | **29,771** | **78,760** | **34,988** | **20,307** | **-14,681** |

*Notes:*
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*
- *The High Rigidity Spectrometer (HRS) is not an MIE, but a research project supported on a cooperative agreement with Michigan State University.*

## Minor Construction Activities

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| GPPs (greater than or equal to $5M and less than $30M) | | | | | | |
| nEDM Experimental Building 2 (EB-2) | 9,257 | – | – | 1,000 | 1,000 | – |
| Total GPPs (greater than or equal to $5M and less than $30M) | N/A | N/A | – | 1,000 | 1,000 | – |
| Total GPPs less than $5M | N/A | N/A | 1,626 | 1,642 | 1,642 | – |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **1,626** | **2,642** | **2,642** | **–** |
| **Accelerator Improvement Projects (AIP)** | | | | | | |
| Total AIPs less than $5M | N/A | N/A | 5,159 | 5,211 | 5,211 | – |
| **Total, Accelerator Improvement Projects (AIP)** | **N/A** | **N/A** | **5,159** | **5,211** | **5,211** | **–** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **6,785** | **7,853** | **7,853** | **–** |

*Note:*

- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*

## Nuclear Physics
## Major Items of Equipment Description(s)

Heavy Ion Physics MIE:

*Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)*

sPHENIX directly supports the NP mission by using precision, high rate jet measurements to further characterize the quark-gluon plasma (QGP) discovered at RHIC in order to understand the anomalous energy loss observed in the QGP. CD-0 was approved September 13, 2016, and Project Decision (PD)-2/3, which approves the performance baseline and start of construction, was approved on September 19, 2019, with a TPC $27,000,000. This MIE was funded within the existing funds for RHIC operations. Operating funds that are typically used to maintain and operate the PHENIX detector were used to upgrade the detector sPHENIX adds electron and hadron calorimeters to the existing silicon tracking capabilities and makes use of a recycled solenoid magnet for a cost effective upgrade. Final funding for sPHENIX was provided in the FY 2022 Enacted Appropriations. The project completed within cost and on schedule in FY 2023.

Low Energy Physics: Nuclear Structure and Nuclear Astrophysics MIE and Research Project:

*Gamma-Ray Energy Tracking Array (GRETA) MIE*

GRETA directly supports the NP mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. GRETA will provide unprecedented gains in detection sensitivity, addressing several high priority scientific topics, including how weak binding and extreme proton-to-neutron asymmetries affect nuclear properties and how the properties of nuclei evolve with changes in excitation energy and angular momentum. GRETA will provide transformational improvements in efficiency, peak-to-total ratio, and higher position resolution than the current generation of detector arrays. In particular, the capability of reconstructing the position of the interaction with millimeter resolution will fully exploit the physics opportunities of FRIB. Without GRETA, beam-times necessary for the proposed experiments will be expanded significantly, and some proposed experiments will not be feasible at all. CD-0 for GRETA was approved September 15, 2015 and CD-1 was obtained October 4, 2017. CD-3a, which approves long lead procurements, was obtained August 16, 2018. CD-2/3 was obtained October 7, 2020 with a TPC of $58,300,000. The FY 2023 Enacted appropriation represented the last year of planned funding for the GRETA MIE. CD-4 is scheduled for March 2028.

*High Rigidity Spectrometer (HRS) Research Project*

The HRS at FRIB will increase the scientific potential of state-of-the-art and community-priority devices, such as GRETA, and other ancillary detectors. FRIB is the world's premier rare-isotope beam facility capable of producing approximately 80 percent of the isotopes predicted to exist. The scientific impact of the FRIB fast beam science program will be enhanced by luminosity gain factors of between two and one hundred for neutron-rich isotopes, with the largest gains for the most neutron-rich species, by construction of the HRS. The HRS will allow experiments with beams of rare isotopes at the maximum production rates for fragmentation or in-flight fission. This enhancement in experimental sensitivity provides access to critical isotopes not available otherwise. The 2015 NSAC LRP recognized that the "HRS…will be essential to realize the scientific reach of FRIB." The HRS is being funded through a cooperative agreement with MSU and is not a capital asset (MIE). CD-0 was approved November 2018. CD-1 was approved in September 2020, with a TPC range of $85,000,000 to $111,400,000. The FY 2024 Request for the HRS of $6,259,000 will support the management team, coordination of collaboration activities and allow preliminary engineering and design work towards future critical decision points.

Low Energy Physics: Fundamental Symmetries MIEs:

*Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE*

The MOLLER experiment directly supports the NP mission by measuring the parity-violating asymmetry in polarized electron-electron (Møller) scattering. This extremely small asymmetry is predicted to be on the order of 35 parts per billion (ppb), which requires unprecedented experimental techniques employed for this experiment. CD-0 was approved December 2016. CD-1 was approved in December 2020 with a TPC range of $42,000,000 to $60,100,000. The project is working on preliminary engineering and design in advance of a combined CD-2/3 planned in Q2 of FY 2023. CD-4 is expected in Q4 of FY2027. The MOLLER experiment is an ultra-precise measurement of the weak mixing angle using Møller scattering which will improve on existing measurements by a factor of five, yielding the most precise measurement of the weak mixing angle at low or high energy anticipated over the next decade. This new result would be sensitive to the interference of the electromagnetic amplitude with new neutral current amplitudes as weak as approximately $10^{-3}$ $G_F$ (Fermi Factor) from as yet undiscovered dynamics beyond the Standard Model. The resulting reach for scientific discovery is far greater, for at least a decade, than any existing or proposed experiment which searches for new physics signaled by a departure from the expected before vs after conservation of flavor, charge and parity in fundamental particle interactions, and yields a unique window to new physics at MeV and multi-TeV scales, complementary to direct searches at high energy colliders such as the Large Hadron Collider (LHC). The FY 2023 Enacted appropriation represented the last year of planned funding for the MOLLER MIE.

*Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Program MIE*
The Ton-Scale NLDBD Program, implemented by deploying experiments instrumenting a large volume of a specially selected isotope to detect neutrino-less nuclear beta decays (where within a single nucleus, two neutrons decay into two protons and two electrons with no neutrinos emitted), directly supports NP's mission to explore all forms of nuclear matter. NLDBD can only occur if neutrinos are their own anti-particles and the observation of "lepton number violation" in such neutrino-less beta decay events would have profound consequences for present understanding of the physical universe. For example, one exciting prospect is that the observation of NLDBD would elucidate the mechanism, completely unknown at present, by which the mass of the neutrino is generated. The observation of lepton number violation would also have major implication for the present-day matter/anti-matter asymmetry which has perplexed modern physics for decades. Several demonstrator efforts using smaller volumes of isotopes and various technologies (bolometry in tellurium dioxide crystals, light collection in liquid xenon, charge collection in enriched germanium-76) have been in progress for several years, and all are in the process of delivering new state-of-the-art lifetime limits for neutrino-less double beta decay which are of order a few times $10^{25}$ years. The goal of the ton-scale program is to reach a lifetime limit of $10^{28}$ years with high confidence. For reference, the "lifetime limit" discussed is the time one might have to wait to observe neutrino-less double beta decay if observing a single nucleus only. Fortunately, in the ton of isotope planned for the ton-scale neutrino-less double beta decay experiments there are many trillions of nuclei. Thus, such decays, if they exist, should be observable on a much more reasonable timescale (five to ten years) similar to other large modern physics experiments. CD-0 was approved in November 2018 with a TPC range of $215,000,000 to $250,000,000. The FY 2024 Request of $3,000,000 will support the management teams and collaboration activities.

**General Plant Projects $5 Million to less than $30 Million**

| | |
|---|---|
| **Project Name:** | nEDM Experimental Building 2 (EB-2) |
| **Location/Site:** | Oak Ridge National Laboratory |
| **Type:** | GPP |
| **Total Estimated Cost:** | $9,257,032 |
| **Construction Design:** | $0 |
| **Project Description:** | Minor construction of an experimental building at Oak Ridge National Laboratory is needed to support neutron electric dipole moment research. This new experimental building will allow researchers to continue the challenging experiment to measure the electric dipole moment of the neutron, which is sensitive to a wide range of underlying new physics and is a test of charge-parity violation. |

## Nuclear Physics
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **20-SC-52, Electron Ion Collider** | | | | | | | |
| Total Estimated Cost (TEC) | 2,126,000 | 6,000 | 20,000 | 128,240 | 50,000 | 95,000 | +45,000 |
| Other Project Cost (OPC) | 292,450 | 34,650 | 24,800 | 10,000 | 20,000 | 2,850 | -17,150 |
| **Total Project Cost (TPC)** | **2,418,450** | **40,650** | **44,800** | **138,240** | **70,000** | **97,850** | **+27,850** |
| | | | | | | | |
| **Total, Construction** | | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **20,000** | **128,240** | **50,000** | **95,000** | **+45,000** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **24,800** | **10,000** | **20,000** | **2,850** | **-17,150** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **44,800** | **138,240** | **70,000** | **97,850** | **+27,850** |

## Nuclear Physics
## 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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Scientific User Facilities - Type A** | | | | | |
| **Relativistic Heavy Ion Collider** | **183,943** | **178,321** | **182,087** | **176,195** | **-5,892** |
| Number of Users | 1,010 | 954 | 1,010 | 1,010 | – |
| Achieved Operating Hours | – | 2,910 | – | – | – |
| Planned Operating Hours | 2,850 | 2,910 | 2,400 | 2,580 | +180 |
| **Continuous Electron Beam Accelerator Facility** | **142,709** | **138,335** | **149,834** | **141,930** | **-7,904** |
| Number of Users | 1,620 | 1,889 | 1,730 | 1,730 | – |
| Achieved Operating Hours | – | 4,154 | – | – | – |
| Planned Operating Hours | 3,790 | 4,154 | 4,100 | 3,350 | -750 |
| **Facility for Rare Isotope Beams** | **79,811** | **77,000** | **98,388** | **96,266** | **-2,122** |
| Number of Users | 605 | 600 | 650 | 755 | +105 |
| Achieved Operating Hours | – | 3,332 | – | – | – |
| Planned Operating Hours | 2,310 | 3,332 | 3,600 | 3,350 | -250 |

| | (dollars in thousands) | | | | |
|---|---|---|---|---|---|
| | FY 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
| **Argonne Tandem Linac Accelerator System** | **23,148** | **22,443** | **24,350** | **24,351** | **+1** |
| Number of Users | 305 | 348 | 340 | 340 | – |
| Achieved Operating Hours | – | 6,426 | – | – | – |
| Planned Operating Hours | 5,800 | 6,426 | 5,950 | 5,800 | -150 |
| **Total, Facilities** | **429,611** | **416,099** | **454,659** | **438,742** | **-15,917** |
| Number of Users | 3,540 | 3,791 | 3,730 | 3,835 | +105 |
| Achieved Operating Hours | – | 16,822 | – | – | – |
| Planned Operating Hours | 14,750 | 16,822 | 16,050 | 15,080 | -970 |

*Notes:*
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*
- *For FY 2022, FRIB planned operating hours and optimal hours include 800 hours of operations (commissioning) that are supported from FRIB construction funding that are part of the project TPC. FY 2022 is the first year of operations after project completion.*
- *For FY 2023, the dollar values for the facilities do not include research amounts.*

## Nuclear Physics
## Scientific Employment

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 864 | 856 | 860 | +4 |
| Number of Postdoctoral Associates (FTEs) | 362 | 366 | 372 | +6 |
| Number of Graduate Students (FTEs) | 543 | 524 | 529 | +5 |
| Number of Other Scientific Employment (FTEs) | 1,006 | 1,023 | 1,028 | +5 |
| **Total Scientific Employment (FTEs)** | **2,775** | **2,769** | **2,789** | **+20** |

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

**20-SC-52 Electron Ion Collider (EIC), BNL**
**Brookhaven National Laboratory, BNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the EIC is $95,000,000 of TEC funding and $2,850,000 of OPC funding. The current TPC range is $1,700,000,000 to $2,800,000,000. The preliminary TPC estimate for the project is $2,418,450,000.

**Significant Changes**

The EIC was initiated in FY 2020. The project most recently received Critical Decision (CD)-1, Approve Alternative Selection and Cost Range, on June 29, 2021. In this Project Data Sheet (PDS), the estimated completion date (CD-4) has shifted to Q3 FY 2034 that includes schedule contingency recommended by peer review. In addition, the preliminary TPC in this PDS reflects continued elaboration of the project scope and shows an increase over the point estimate in the FY 2022 PDS, however, the point estimate remains within the cost range. The project expects CD-2, Approve Performance Baseline, in Q2 FY 2024.

In March 2022, an expert panel issued a report recommending a path forward after reviewing three detector collaboration proposals. In FY 2022, the EIC team has focused on preliminary design of the infrastructure, collider machine, and detector instrumentation. The team is also developing a list of possible long-lead procurements and considering requesting a CD-3A, Approve Long Lead Procurement, in conjunction with CD-2. Through the Inflation Reduction Act the project received $10,000,000 OPC and $128,240,000 TEC at the end of FY 2022. The funds will support long lead procurements following a CD-3A while later reducing the peak requests for new funding. FY 2023 activities include planning and design for conventional infrastructure and technical systems, research and development to increase technical readiness for certain detector and technical scope, and fostering relations with potential in-kind contributors. FY 2024 funding will support the development and completion of the preliminary design and research and development to validate technical assumptions and to reduce project risk prior to start of construction.

A Federal Project Director (FPD) has been assigned to this project and has approved this project data sheet. The FPD is certified at Level 3, and the accrual of qualifications for Level 4 certification is in process.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 12/19/19 | 01/12/21 | 6/29/2021 | 2Q FY 2024 | 2Q FY 2025 | 2Q FY 2025 | 3Q FY 2034 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | TBD | 2Q FY 2024 |

**CD-3A** – Approve Long-Lead Procurements, for specialty materials procurement, including electrical infrastructure, magnets, refrigerators for the satellite cryogenics plant, and components for the injector, radio frequency power amplifier, and the detector.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 413,000 | 1,648,000 | 2,061,000 | 187,650 | 187,650 | 2,248,650 |
| FY 2024 | 256,000 | 1,870,000 | 2,126,000 | 292,450 | 292,450 | 2,418,450 |

*Note:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

**2. Project Scope and Justification**

**Scope**

The scope of this project is to design and build the EIC at BNL that will fulfill the scientific gap as identified in the 2015 NSAC LRP. BNL is partnering with TJNAF in the implementation of the EIC. The EIC will have performance parameters that include a high beam polarization of greater than 70 percent from both electrons and light ions, and the capability to accommodate ion beams from deuterons to the heaviest stable nuclei. The EIC will also have variable center of mass energies from 20 to 100 GeV and upgradable to 140 GeV, high collision luminosity from $10^{33}$ -$10^{34}$ $cm^{-2}s^{-1}$, one detector and one interaction region at project completion, and the capacity to accommodate a second interaction region and a second detector.

The scope also includes a new electron injection system and storage ring while taking full advantage of the existing infrastructure by modifying the existing hadron facility of the RHIC infrastructure at BNL.

The electron system will include a highly polarized room temperature photo-electron gun and a 400 MeV linac to be installed in an existing available straight section of the RHIC tunnel. It will include a transfer line that brings the electrons into the storage ring at the energy of 5 to 18 GeV that will be installed in the existing 2.4-mile circular RHIC tunnel.

Modifications to the existing hadron system include the injection, transfer line and storage ring to increase beam energy to 275 GeV. It will include a strong-hadron-cooling system to reduce and maintain the hadron beam emittance to the level needed to operate with the anticipated luminosity of $10^{33}$ -$10^{34}$ $cm^{-2}s^{-1}$.

The interaction region will have superconducting final focusing magnets, crab cavities, and spin rotators to provide longitudinally polarized beams for collisions, where the outgoing particles will be collected by one detector.

An enhanced 2 K liquid helium cryogenic plant is provided for the superconducting radiofrequency cavities, with enhanced water-cooling capacity and cooling towers and chillers to stabilize the environment in the existing tunnel. Civil construction will also include electrical systems, service buildings, and access roads.

It is anticipated that non-DOE funding sources such as international collaborators, the National Science Foundation, and the State of New York, will contribute to the EIC Project. The timeframe for commitments by non-DOE contributors will vary throughout the life of the project and become more certain as planning for the project progresses. All non-DOE funding sources will be closely coordinated with the Office of Nuclear Physics and will be incorporated into the project through the change control process once baselined.

**Justification**

The last three NSAC LRP reports have supported the EIC with recommendations ranging from investing in accelerator research and development (R&D) in the 2002 NSAC LRP, to reducing technical risks in the 2007 NSAC LRP, to the actual construction of a U.S.-based EIC in the 2015 NSAC LRP. Specifically, the 2015 NSAC LRP for Nuclear Science recommended a high-energy, high-luminosity polarized EIC as the highest priority for new facility construction following the completion of the Facility for Rare Isotope Beams. Consistent with that vision, in 2016 NP commissioned a National Academies of Sciences, Engineering, and Medicine study by an independent panel of experts to assess the uniqueness and scientific merit of such a facility. The report, released in July 2018, strongly supports the scientific case for building a U.S. based EIC, documenting that an EIC will advance the understanding of the origins of nucleon mass, the origin of the spin properties of nucleons, and the behavior of gluons.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change prior to setting the performance baseline at CD-2. The Threshold KPPs represent the minimum acceptable performance that the project must achieve for success. The Objective KPPs represent the project performance stretch goal. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Approve Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Center-of-Mass | Center-of-mass energy measured in the range of 20 GeV- 100 GeV. | Center-of-mass energy measured in the range of 20 GeV- 140 GeV. |
| Accelerator | Accelerator installed and capable of delivering beams of protons and a heavy nucleus such as Au. | Ability to deliver a versatile choice of beams from protons and light ions to heavy ions such as Au. |
| Detector | Detector installed and ready for beam operations. | Inelastic scattering events in the e-p and e-A collisions measured in Detector. |
| Polarization | Hadron beam polarization of > 50 percent and electron beam polarization of > 40 percent measured at $E_{cm}$ = 100 GeV. | Hadron beam polarization of > 60 percent and electron beam polarization of > 50 percent measured at $E_{cm}$ = 100 GeV. |
| Luminosity | Luminosity for e-p collisions measured up to $1.0x10^{32}$ $cm^{-2}$ $s^{-1}$. | Luminosity greater than $1.0x10^{33}$ $cm^{-2}$ $s^{-1}$. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 6,000 | 6,000 | 5,750 | – |
| FY 2022 | 20,000 | 20,000 | 19,750 | – |
| FY 2022 - IRA Supp. | 70,000 | 70,000 | – | – |
| FY 2023 | 50,000 | 50,000 | 49,500 | 50,000 |
| FY 2024 | 87,000 | 87,000 | 48,000 | 20,000 |
| Outyears | 23,000 | 23,000 | 63,000 | – |
| **Total, Design (TEC)** | **256,000** | **256,000** | **186,000** | **70,000** |
| Construction (TEC) | | | | |
| FY 2022 - IRA Supp. | 58,240 | 58,240 | – | – |
| FY 2024 | 8,000 | 8,000 | 2,000 | 58,240 |
| Outyears | 1,803,760 | 1,803,760 | 1,809,760 | – |
| **Total, Construction (TEC)** | **1,870,000** | **1,870,000** | **1,811,760** | **58,240** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 6,000 | 6,000 | 5,750 | – |
| FY 2022 | 20,000 | 20,000 | 19,750 | – |
| FY 2022 - IRA Supp. | 128,240 | 128,240 | – | – |
| FY 2023 | 50,000 | 50,000 | 49,500 | 50,000 |
| FY 2024 | 95,000 | 95,000 | 50,000 | 78,240 |
| Outyears | 1,826,760 | 1,826,760 | 1,872,760 | – |
| **Total, TEC** | **2,126,000** | **2,126,000** | **1,997,760** | **128,240** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 34,650 | 34,650 | 30,270 | – |
| FY 2022 | 24,800 | 24,800 | 26,230 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 20,000 | 20,000 | 21,500 | 10,000 |
| FY 2024 | 2,850 | 2,850 | 2,000 | – |
| Outyears | 200,150 | 200,150 | 202,450 | – |
| **Total, OPC** | **292,450** | **292,450** | **282,450** | **10,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 40,650 | 40,650 | 36,020 | – |
| FY 2022 | 44,800 | 44,800 | 45,980 | – |
| FY 2022 - IRA Supp. | 138,240 | 138,240 | – | – |
| FY 2023 | 70,000 | 70,000 | 71,000 | 60,000 |
| FY 2024 | 97,850 | 97,850 | 52,000 | 78,240 |
| Outyears | 2,026,910 | 2,026,910 | 2,075,210 | – |
| **Total, TPC** | **2,418,450** | **2,418,450** | **2,280,210** | **138,240** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 173,000 | 291,000 | **N/A** |
| Design - Contingency | 83,000 | 122,000 | **N/A** |
| **Total, Design (TEC)** | **256,000** | **413,000** | **N/A** |
| Construction | 1,262,000 | 1,127,000 | **N/A** |
| Construction - Contingency | 608,000 | 521,000 | **N/A** |
| **Total, Construction (TEC)** | **1,870,000** | **1,648,000** | **N/A** |
| **Total, TEC** | **2,126,000** | **2,061,000** | **N/A** |
| *Contingency, TEC* | *691,000* | *643,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | 97,450 | 46,650 | **N/A** |
| Conceptual Design | 11,000 | 11,000 | **N/A** |
| Other OPC Costs | 184,000 | 130,000 | **N/A** |
| **Total, Except D&D (OPC)** | **292,450** | **187,650** | **N/A** |
| **Total, OPC** | **292,450** | **187,650** | **N/A** |
| *Contingency, OPC* | ***N/A*** | *N/A* | ***N/A*** |
| **Total, TPC** | **2,418,450** | **2,248,650** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***691,000*** | ***643,000*** | ***N/A*** |

*Note:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

5. **Schedule of Appropriations Requests**

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 6,000 | 5,000 | — | 20,000 | — | 2,030,000 | 2,061,000 |
| | OPC | 34,650 | 24,650 | — | 10,000 | — | 118,350 | 187,650 |
| | TPC | 40,650 | 29,650 | — | 30,000 | — | 2,148,350 | 2,248,650 |
| FY 2024 | TEC | 6,000 | 20,000 | 128,240 | 50,000 | 95,000 | 1,826,760 | 2,126,000 |
| | OPC | 34,650 | 24,800 | 10,000 | 20,000 | 2,850 | 200,150 | 292,450 |
| | TPC | 40,650 | 44,800 | 138,240 | 70,000 | 97,850 | 2,026,910 | 2,418,450 |

6. **Related Operations and Maintenance Funding Requirements**

Over the course of the acquisition of the EIC, experienced RHIC scientists, engineers, and technicians will assume EIC project responsibilities. A gradual transition will balance the need for the scientific experts to continue to support RHIC while ramping up the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced, and they represent the core facility operations force of RHIC and the EIC. In the FY 2024 Request, RHIC Operations includes a "reprioritization" of the expert workforce from the RHIC facility operations budget to support the project under the EIC OPC and TEC request. The temporary reprioritization of funds from the facility operations budget to the construction budget will reduce the amount of "new funds" needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility. As the EIC nears CD-4 when the machine will be restarted, the scientists, engineers and technicians that are needed to operate the EIC will be transferred back to the facility operations budget.

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | Q3 FY 2034 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | Q3 FY 2084 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations, Maintenance and Repair | 167,000 | 167,000 | 13,500,000 | 13,500,000 |

## 7. D&D Information

As part of the upgrade and renovation of the existing accelerator facilities, up to 150,000 square feet of new industrial space will be built as service buildings to house mechanical and electrical equipment. The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at BNL | 150,000 |
| Area of D&D in this project at BNL | 0 |
| Area at BNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | N/A |
| Area of D&D in this project at other sites | N/A |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | N/A |
| Total area eliminated | 0 |

## 8. Acquisition Approach

SC selected Brookhaven National Laboratory (BNL) as the site for the EIC on January 9, 2020. NP approved the Acquisition Strategy in conjunction with CD-1. DOE will utilize the expertise of the Management and Operating contractors at BNL and TJNAF to manage the project including the design, fabrication, monitoring cost and schedule, and delivering the technical performance specified in the KPPs. A certified Earned Value Management System based on those that already exist at both laboratories and will evaluate project progress and ensure consistency with DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

## Isotope R&D and Production

### Overview

The mission of the DOE Isotope Program (DOE IP) is to:

- Produce and/or distribute stable isotopes and radioisotopes in short supply or unavailable in the U.S., including related isotope services;
- Maintain mission readiness of critical national infrastructure and core competencies needed to manufacture isotopes and ensure national preparedness to respond to supply chain gaps during a national crisis;
- Conduct R&D to develop transformative isotope production, separation, and enrichment technologies to enable federal, academic, and industrial innovation, research, and emerging technologies;
- Nurture a diverse and inclusive domestic workforce with unique and world-leading core competencies; and
- Mitigate U.S. dependence on foreign supplies of isotopes and promote robust domestic supply chains for U.S. economic resilience.

The DOE IP produces high priority radioactive and stable isotopes in short supply for the Nation that no domestic entity has the capability to meet market demand. The Program is typically the only, or one of few, global producers for these rare isotopes; however, the U.S. remains highly dependent on isotope supply chains from sensitive countries. Isotopes are high-priority and enabling commodities of strategic importance for the Nation and essential in medical diagnosis and treatment, discovery science, national security, advanced manufacturing, semiconductor manufacturing, space exploration, communications, biology, quantum information science, clean energy, and other fields. The DOE IP works closely with industry to ensure availability of needed isotopes for commercial stability and growth, and facilitates commercialization of isotope production to the domestic private sector. DOE IP is the only DOE "Mission Essential Function" in SC and continues operations during national emergencies to mitigate disruptions in isotope supply chains. DOE IP stepped in during the COVID-19 pandemic and Russian invasion of Ukraine to mitigate disruptions in supply chains critical to federal agencies, industry, and research.

The DOE IP utilizes particle accelerators and research nuclear reactors at national laboratories and universities to irradiate targets which are then processed in radiochemical infrastructure to extract radioisotopes of interest; DOE IP also extracts radioisotopes from legacy waste or inventories to reduce waste disposition while providing a valuable product. DOE IP manages federal inventories of isotopes for the Nation, such as helium-3 (He-3) which is essential for cryogenics, quantum information science (QIS), fusion energy, and national security; Russia is the other major producer of He-3. The DOE IP is responsible for the national repository of all stable isotopes that were created by the calutrons (electromagnetic ion separation) developed as part of the Manhattan Project. The calutrons ceased operations in 1998, leaving the U.S. with no broad isotope enrichment capability. Russia has the largest stable isotope enrichment capability worldwide and China has recently started operation of a new facility with significant capabilities. The U.S. inventory of stable isotopes is limited, causing the U.S. to rely on foreign countries for critical stable isotopes. The DOE IP is developing modern stable isotope enrichment capabilities to rebuild domestic manufacturing capabilities, replenish inventories, and promote U.S. economic resilience, prosperity, and competitiveness.

The DOE IP supports a world-leading R&D program in innovative isotope production, enrichment, and chemical separations. Isotope manufacturing and R&D activities provide collateral benefits for training and workforce development, and promotion of a future U.S.-based expertise relevant to clean energy, accelerator science, nuclear engineering, nuclear physics, isotope enrichment, and radiochemistry. These disciplines are foundational, not only to isotope production and processing, but underpin many essential aspects of basic and applied nuclear and radiochemical science. Research and production activities develop and employ techniques and platform technologies in artificial intelligence (AI), machine learning (ML), robotics, and advanced manufacturing.

Funds in this Request support mission readiness of infrastructure, staff, and facilities; research; and new capabilities to meet the Nation's growing demand for isotopes. Customer collections from sales pay for the actual production of the isotope, distribution, and related services. Isotopes sold to commercial customers and foreign entities are priced at full-cost recovery or market price (whichever is higher). Isotope pricing for domestic research is reduced to promote innovation and scientific advances. DOE IP funding is executed through the Isotope Production and Distribution Program revolving fund, where both appropriated funding and customer revenues are deposited and executed for Program viability.

**Highlights of the FY 2024 Request**

In FY 2024, the DOE IP expects increasing demand in both radio and stable isotopes. The Russian invasion of Ukraine and subsequent impacts to isotope supply chains have highlighted the need for domestic supplies of critical isotopes. Demand of radioisotopes increases for high priority national applications and technologies such as nuclear batteries, power sources, clean energy technologies, semiconductor and microelectronics manufacturing, quantum computing, next generation molten salt and fusion reactors, and medical treatment and diagnosis of cancer and infectious disease.

In FY 2024, support for operations of production facilities increases to 92 percent optimal and supports additional workforce to respond more efficiently as a DOE Mission Essential Function and fill gaps in supply chains. Funding for mission readiness is also provided for the first time to the Pacific Northwest National Laboratory (PNNL), the Y-12 Security Complex, Idaho National Laboratory (INL), and the Los Alamos National Laboratory (LANL) Plutonium facility to improve stable operations. Funding enables the Linear Electron Accelerator Facility (LEAF) at Argonne National Laboratory (ANL) to transition from NNSA to DOE IP for increased production of medical isotopes. A newly refurbished low energy medical cyclotron at Brookhaven National Laboratory (BNL) ramps up to produce actinium-225. Support is provided to address deferred maintenance and single point failures to ensure safe, robust and reliable operations across production sites. Funding supports the receipt and testing of the first heavy curium product stream (for critical radioisotope production) coming from the processing of Mark 18-A legacy reactor targets.

FY 2024 funding enables the standup of a new group in stable isotope enrichment operations to prepare for the start of operations of the Stable Isotope Production Facility (SIPF) Major Item of Equipment and eventually the Stable Isotope Production and Research Center (SIPRC). SIPF will operate the Nation's first full-scale and modern gas centrifuge cascade to produce Xe-129 for polarized lung imaging. Staff assemble and commission new electromagnetic ion separation (EMIS) devices to produce high priority enriched stable isotopes. The Program develops a heavy water inventory, enabled with Inflation Reduction Act (IRA) funding. FY 2024 funding also increases staffing at the National Isotope Development Center (NIDC), the business arm of the DOE IP, to address the increased interfaces with stakeholder community.

The DOE Isotope Initiative will support the conduct of research to proactively address current or looming high-impact isotope shortages. In FY 2024, this initiative focuses on three high priority isotopes that are currently in short supply and otherwise only available from Russia. Krypton-85 is utilized in semiconductor manufacturing and research efforts establish a domestic supply chain to meet federal and U.S. industrial demand. Research develops new chemical separations to restore and increase the Sr-90 inventory to better meet the rising demand for nuclear batteries and medical applications. New techniques are researched and developed to explore unique sources of He-3 and increase the national inventory.

The Reaching a New Energy Sciences Workforce (RENEW) and Funding for the Accelerated, Inclusive Research (FAIR) initiatives expand DOE IP efforts to advance justice, equity, diversity, and inclusion in SC-sponsored research. The DOE IP involvement in the Biopreparedness Research Virtual Environment (BRaVE) initiative increases to enhance national preparedness with investment of equipment and research to produce isotopes at the Radioisotope Science Center (RSC) at the University of Missouri (MURR), creating jobs in an underserved community. New investments in microelectronics supports research to produce isotopes needed for microelectronics fabrication and development. DOE IP continues as part of the Accelerate Innovations in Emerging Technologies initiative. DOE IP will increase support of translational research, in coordination with the NIH, for novel medical isotopes used in medical trials. The DOE IP maintains efforts in the Advanced Manufacturing initiative and QIS to advance the production of isotopes of interest for QIS.

Support increases for the University Isotope Network, providing support for Texas A&M University and the University of Wisconsin-Madison to participate in the network. The Facility for Rare Isotope Beams (FRIB) Isotope Harvesting effort approaches completion, adding capabilities to extract and process rare isotopes from the beam dump of the FRIB.

The FY 2024 Request includes $20.9 million in Total Estimated Cost (TEC) funding to continue SIPRC, which in combination with the funding provided by the Inflation Reduction Act, positions the project closer to its optimal profile. SIPRC restores large scale stable isotope enrichment capacity for the Nation to remove U.S. dependency on foreign countries. The Request initiates construction for the Radioisotope Processing Facility (RPF) to address a lack of available radiochemical processing infrastructure to mitigate U.S. dependency on foreign supply chains of radioisotopes. Funding supports engineering design and long lead procurements for the Clinical Alpha Radionuclide Producer (CARP) facility to increase availability of high demand medical isotopes and address disruptions in global isotope supply chains.

**Isotope R&D and Production**
**Funding**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Isotope R&D and Production** | | | | |
| Isotopes, Research | 32,133 | 38,827 | 63,827 | +25,000 |
| Isotopes, Operations | 37,867 | 46,624 | 78,824 | +32,200 |
| **Subtotal, Isotope R&D and Production** | **70,000** | **85,451** | **142,651** | **+57,200** |
| **Construction** | | | | |
| 20-SC-51 U.S. Stable Isotope Production and Research Center (SIPRC), ORNL | 12,000 | 24,000 | 20,900 | -3,100 |
| 24-SC-92 Clinical Alpha Radionuclide Producer (CARP), BNL | – | – | 1,000 | +1,000 |
| 24-SC-91 Radioisotope Processing Facility, ORNL | – | – | 8,500 | +8,500 |
| **Subtotal, Construction** | **12,000** | **24,000** | **30,400** | **+6,400** |
| **Total, Isotope R&D and Production** | **82,000** | **109,451** | **173,051** | **+63,600** |

**Basic and Applied R&D Coordination**

R&D coordination and integration are deeply rooted in all activities of the DOE IP as a goal of the Program is to ensure that critical isotopes are available to achieve federal missions, industrial applications, and support R&D. Isotopes are vital to federal agencies, including the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Department of Defense (DoD), Office of the Director of National Intelligence (ODNI), National Institute of Standards and Technology (NIST), Federal Bureau of Investigations (FBI), Department of Agriculture, Department of Homeland Security (DHS), National Science Foundation (NSF), and DOE. DOE IP conducts the biennial Workshop on Federal Isotope Supply and Demand to collect 5-year projections from all federal agencies to ensure adequate supply and evidence-based Program priorities. DOE IP participates in Federal Working Groups and Interagency groups to promote communication, including the White House Office of Science and Technology Policy (OSTP) National Science and Technology Council (NSTC) Subcommittee on Critical and Strategic Mineral Supply Chains, the Interagency Group on He-3, which it leads, and the OSTP NSTC Subcommittee on Fusion Energy. The DOE IP participates in the Nuclear Sub-Inter Policy Committee (Sub-IPC), Fusion Sub-IPC, Russian Sanctions IPC, White House Small Group on Sterilization and Medical Isotopes, QIS Working Group, and the Certified Reference Material Working Group, which ensures material availability for nuclear forensics applications to support national security missions. Other groups include the NNSA GARS II Working Group and the NRC Radiation Source Protection and Security Task Force. DOE IP interacts closely and partners frequently with other DOE Offices on domestic supply chains of valuable isotopes; a few examples are the extraction of americium-241 for batteries from plutonium waste streams (NNSA); the provision of He-3 for cryogenics from tritium beds (NNSA); the detritiation of heavy water from legacy stockpiles and the provision of strontium-90 from legacy inventories from Environmental Management (EM); the extraction of promethium-147 for nuclear batteries from plutonium-238 waste streams (NE); and the recovery of krypton-85 for semi-conductor manufacturing during spent fuel reprocessing (NE). In all these examples, the only other producer of these isotopes is Russia.

The DOE IP, along with the NIDC, meets throughout the year with industrial stakeholders to gauge the health of global supply chains, including two multiple-day sessions of dedicated meetings. The Program also attends industry-organized meetings and roundtables to report on supply chain stability and sets up a Program booth at expositions at professional society meetings to promote communication and conduct outreach. The DOE IP is in the process of establishing a new Federal Advisory Committee, the Isotope R&D and Production Advisory Committee (IRDPAC), to provide guidance to the Program and aid in the development of priorities and long-range plans. Membership diversity will be balanced for demographics, disciplines, and stakeholder interests.

While the DOE IP is not responsible for the production of molybdenum-99, the widely used isotope in diagnostic medical imaging in the Nation, it works closely with NNSA, the lead entity responsible for domestic molybdenum-99 production, offering technical and management support. SIPRC will produce molybdenum-98 and molybdenum-100, precursors to certain molybdenum-99 production routes to ensure domestic supply chain resilience.

**Program Accomplishments**

*Promoting the Commercialization of a Promising Medical Isotope World-wide*

Astatine-211 (At-211) has shown great promise in preclinical and clinical trials as a radioisotope for the treatment of multiple forms of cancer including leukemia, lymphoma, glioblastoma, and ovarian cancers. Because of its short half-life, effective distribution of At-211 is achieved with regional production sites. The DOE IP has been establishing a production network for At-211 across the Nation. The University of Washington Medical Cyclotron Facility (UWMCF) is currently one of five sites within the U.S., and one of a handful globally, with such a capability. To increase the domestic availability of At-211 for research and clinical use, UWMCF engineers designed and fabricated a new target station that could be retrofitted to existing small-medical cyclotrons and a target optimized for At-211 production. The newly fabricated and patented target station is fully automated, significantly improving the efficiency and safety of isotope production, and adaptable for production of other isotopes. The DOE IP is making this technology available world-wide to researchers and industry to promote commercialization of At-211.

*Gold-199 (Au-199) Domestic Supply Chain Established for Environmental and Biomedical Research*

Gold-199 (Au-199) has drawn interest from the biomedical research community due to its theragnostic potential for targeted radioimmunotherapy, as nanoparticles for biomedical imaging applications, and in radiolabeling for detection of environmental compounds; a theragnostic isotope can be used for both diagnosis and treatment, reducing patient dose.

DOE IP supported the University of Missouri Research Reactor (MURR), a production site within the DOE IP University Isotope Network, to develop a production capability for Au-199. MURR is now being utilized to support nationwide availability of this short-lived radioisotope, establishing a new domestic supply chain for this novel product.

*Improving Predictive Power of Modeling Codes for Isotope Production (and spacecraft design)*
Researchers from LANL, BNL, and Lawrence Berkeley National Laboratory (LBNL) have formed the Tri-Lab Effort in Nuclear Data, an ongoing DOE IP funded effort to measure the nuclear data needed to inform and optimize production of emerging radionuclides. In FY 2022, the teams measured the production of Lead-202, a rare radionuclide used in geochronology as an environmental tracer and calibration standard for mass spectrometry. The team performed a series of experiments at the BNL Brookhaven Linac Isotope Producer, the LANL Isotope Production Facility, and the LBNL 88-Inch Cyclotron. Production rates for 78 isotopes were measured using proton bombardment of lead, niobium, and arsenic targets with energies up to 200 MeV, including two radionuclides used for Positron Emission Tomography (PET). Comparison of this data to predictions by state-of-the-art nuclear reaction models enabled the study of how quickly the energy from an incoming proton is spread over the entire nucleus. The results show that energy gets distributed in the nucleus more slowly than expected leading to an increase in higher energy particles getting released; this influences the relative production of isotopes with different proton-to-neutron ratios. Using state-of-the-art nuclear reaction modeling codes, the data also allows to better tune the performance of these codes for reactions which have not yet been measured. These results can improve the accuracy of the codes from within a factor of 10-20 to within 5 percent, minimizing the production of contaminants in radiopharmaceuticals for human use, e.g., for PET, and influencing the design of shielding for new generations of spacecraft.

*Robotics and Automation Advances Isotope Manufacturing*
The radiochemistry team at LANL has deployed the "LANL Super Separator," enabling automation of radiochemical separation R&D and reducing the time needed to bring crucial radioisotopes to market for the DOE IP. This capability brings robotics to the radiochemistry toolset, which has so far been manual, enabling rapid development and optimization of radioisotope processing and separation methods. This instrument has been used to develop optimized chemical separation methods for new radioisotopes and to optimize existing production lines—through automation and rapid screening of different chemical separation options. The LANL Super Separator has demonstrated significant acceleration of separation optimization. Applied to existing product lines, the instrument enabled quick characterization of the impact from radiolysis versus chemical degradation on resin performance for over 20 potential contaminants and six resins within the confines of current production restrictions. The results are supporting the DOE IP's efforts to bring new radioisotopes into production this calendar year and the need to maintain and improve the Program's processing capability.

*Creative Partnerships to Optimize Isotope Productivity*
Strontium-89 (Sr-89) has demonstrated a significant palliative benefit in the treatment of painful bone cancer metastases, due to the affinity of strontium in the bones. ORNL has historically performed the domestic production of this important radioisotope. With domestic radioisotope production hampered by the lack of radiochemical infrastructure, DOE IP examined whether radiochemical processing facilities were available that could process irradiated Sr-89 targets to free up processing space at ORNL to tackle emerging isotope shortages. ORNL and LANL subsequently partnered to develop and implement Sr-89 radiochemical processing capabilities at LANL. The material is irradiated in HFIR at ORNL and then shipped to LANL. At LANL, the material is chemically purified before being shipped to a customer. This successful partnership is a step forward for increasing the overall supply of Sr-89 and enabled ORNL to ramp up production of barium-133, an isotope used in QIS and industrial radiography, otherwise only produced in Russia.

*New Partnership with a University Increases Domestic Supplies of Isotopes*
The DOE IP introduced four domestic isotope supply chains to the Nation with the recent entrance of the University of Alabama Birmingham (UAB) into its University Isotope Network (UIN). The UAB cyclotron facility has joined the UIN and will produce a reliable supply of isotopes focused on advancing scientific research, including cobalt-55, manganese-52, vanadium-48, and lead-203. Cobalt-55 shows promising use in PET imaging of cancer and other diseases, lung and oncology imaging, and targeted radiolabeled antibodies for ablation therapy. Manganese-52 is an isotope of interest as a long-lived positron emitter for investigating the biodistribution of intact antibodies or nanoparticles, and as a potential PET analog. Vanadium-48 is of interest as a long-lived positron emitter for the study of vanadium chemistry and biochemistry, nutrition, and as a target isotope for cross-sections of interest for stockpile stewardship. Lead-203 is a diagnostic partner to the therapeutic lead-212 radioisotope, forming a theragnostic radioisotope pair for targeted cancer treatments.

## Isotope R&D and Production

### Description

Research

Research funding supports core research groups at national laboratories and universities for both stable and radioisotopes, competitive research opportunities, SC research initiatives, operations mission readiness of the university facilities (a core competency of staff and maintained equipment for isotope production), university research projects, Other Project Costs (OPC) of construction projects, and workforce development. The DOE IP supports core research groups at ANL, BNL, INL, LANL, ORNL, and PNNL to conduct advanced research for novel or advanced production and separation techniques for high priority isotopes in short supply. A priority is to develop a broad national stable isotope enrichment core competency. A stable isotope enrichment core competency is essential for the U.S. as enriched stable isotopes are foundational to so many applications, including the production of all radioisotopes. The production of each enriched stable isotope requires an intense research campaign. Machines are designed and optimized for isotopes of interest for quantum computing as part of the SC QIS Initiative. This technology is dual-use and the Program exploits synergies with NNSA. Stable isotope research to promote clean energy considers isotopically tailored low activation materials for fusion and fast fission nuclear reactors and transformative technology development to enrich isotopes that can yield fuel cycle cost savings and reduced nuclear waste.

Core research support is provided to the UIN institutions; these universities provide domestic supply chains primarily to strengthen the Nation's research competitiveness and play an important role in workforce development. The UIN is currently comprised of the University of Washington (UW) Cyclotron, MURR, FRIB Isotope Harvesting at MSU, University of Alabama-Birmingham (UAB) and University of Wisconsin-Madison (UWM). Texas A&M University is expected to join in the near future. These universities have unique capabilities, such as the UW multi-particle cyclotron, where full-scale production of the alpha-emitter astatine-211 was developed for cancer therapy. The MURR boasts the highest flux university research reactor in the U.S., and DOE IP uses MURR to produce multiple isotopes, including lutetium-177 for cancer therapy research. The UAB cyclotron includes four beamlines and associated target stations to produce a wide variety of radioisotopes, and has hot cells designated for the preparation of human use and preclinical radiopharmaceuticals. Harvesting of isotopes from the beam dump of the nuclear physics facility, FRIB, is an innovative research project to repurpose unwanted waste into valuable assets for U.S. research and approaches completion. The UWM cyclotron distributes a variety of isotopes as well as providing target fabrication services for the UIN. The research staff at both national labs and universities support the development of new production and chemical separations for rare isotopes or isotopes in short supply, specific to the facility at their site, and collaborate to tackle mutual challenges and focus on urgently needed isotopes.

Competitive research funds to universities and national laboratories support targeted high priority activities, including research to develop novel isotopes of interest to U.S. stakeholders and establish domestic isotope supply chains. An example is heavy water (hydrogen replaced with deuterium), last produced in the U.S. in 1981; the U.S. now depends on foreign supplies. Deuterium is disassociated from heavy water and is used in deuterated drugs products, biomedical research, fusion energy research, and semi-conductor manufacturing. Foreign supply has been fragile and the DOE IP is developing technology to detritiate legacy heavy water at Savannah River National Laboratory (SRNL). Other examples of competitive research topics include the production of isotopes for next-generation molten salt and fusion reactors, innovative medical isotopes, new sources of helium-3 for cryogenics, rare isotopes for nuclear forensics, critical nuclear data measurements, radioisotope enrichment technology, targetry, modular automated systems, robotics, and the application of machine learning and artificial intelligence to isotope production.

A high priority of both core and competitive research is the development of transformative medical isotopes to diagnose disease and reduce cancer mortality. Globally, there is escalating interest in alpha and beta emitters for revolutionary cancer and infectious disease therapy and diagnostics. The DOE IP has established itself as the world leader in this arena, typically being the sole global source for many of these isotopes or leading the way in innovative research and manufacturing to make them available. DOE IP remains committed to ramping up production capabilities of alpha-emitters, including actinium-225 (Ac-225), a high-priority isotope that has shown stunning success in the treatment of diffuse cancers and infections. To meet U.S. demand will require expansion of radiochemical processing infrastructure. Support for OPC for the Clinical Alpha Radionuclide Producer facility (CARP) advances new chemical processing capabilities at BNL, so that additional life-saving isotopes can be provided to U.S. patients, reducing cancer mortality. In coordination with the NIH, the DOE IP supports the basic science research that facilitates the transition of novel radioisotopes and targeted delivery agents from the laboratory to use in clinical trials for both diagnosis and treatment of disease, to bridge the "valley of death" that lies at the intersection of these two federal programs.

The DOE Isotope Initiative, proposed in the FY 2024 Budget, enables a proactive and robust targeted research effort aimed at establishing a domestic supply chain for high-priority, high-impact isotopes, whose progress has been funding-limited; the targeted isotopes are required for the success of federal missions and Administration priorities. As part of the SC BRaVE Initiative, national preparedness is enhanced with equipment and research to produce medical isotopes at the Radioisotope Science Center (RSC) at MURR, mitigating single point failures in the Program and increasing performance and response times during times of national crisis. The RSC is planned to be located in the Discovery Ridge Research Park near the University of Missouri, providing the surrounding underserved rural area with job opportunities in isotope science. Support through the SC Advanced Manufacturing initiative focuses on revolutionary and innovative approaches to isotope production with broader applications in commercial isotope production. Participation in the microelectronics initiative enables a close examination of the isotopes that are needed for semiconductor manufacturing and subsequent research to consider the technology and radiochemistry needed for their production. As part of the Accelerate initiative, the DOE IP supports research of multi-scale/multi-physics simulations of targets to improve isotope production efficiencies, research to advance the production of industrially relevant quantities of isotopes for a clean energy economy, and approaches that combine advanced manufacturing, AI/ML and novel chemical processes.

Training and development opportunities for students and post-docs are a priority for DOE IP to promote a vibrant, diverse, and inclusive workforce essential for isotope production. DOE IP participates in the RENEW initiative to expand targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance justice, equity, diversity, and inclusion in SC-sponsored research. Participation in the SC FAIR initiative provides opportunities for research, bolstered with investments in equipment and infrastructure at minority serving institutions, including attention to underserved and environmental justice regions. DOE IP sponsors workshops at professional society meetings to promote communication of advances in isotope availability, research & development, and production, and invests in the Nation's future nuclear chemistry and biomedical researchers through support for the Nuclear Chemistry Summer School (NCSS) program. The NCSS, jointly supported with SC's Basic Energy Sciences (BES) and Nuclear Physics (NP) programs, consists of an intensive six-week program of formal accredited lectures on the fundamentals of nuclear science, radiochemistry, and their applications in related fields, as well as laboratory practicums focusing on state-of-the-art instrumentation and technology used routinely in basic and applied nuclear science.

<u>Facility Operations</u>
Facility operations supports activities at national labs: mission readiness at reactor, accelerator, and enrichment facilities; equipment and infrastructure for chemical processing (such as hot cells and glove boxes); pre-operations of stable isotope equipment; inventory management and dispensing activities; management and maintenance of advanced manufacturing capabilities; operations support and assembly; and support of the NIDC, the business arm of the DOE IP.

The DOE IP is the steward of several facilities for isotope production and chemical processing and leverages facilities and capabilities across the U.S. government that are owned by other Federal entities for cost effective operations. The DOE IP stewards the Isotope Production Facility (IPF) at LANL and the Brookhaven Linac Isotope Producer (BLIP) facility at BNL; both are proton accelerators that provide year-round continuous availability of critical radioisotopes. The IPF operates concurrently with the NNSA Los Alamos Neutron Science Center facility and BLIP operates concurrently with the Relativistic Heavy Ion Collider, and soon the Electron Ion Collider. The LEAF at ANL is the only electron accelerator in the Program and provides unique pathways for producing medical radioisotopes. The DOE IP utilizes the capabilities of two research reactors, the High Flux Isotope Reactor (HFIR) at ORNL stewarded by the SC Office of Basic Energy Sciences and the Advanced Test Reactor at INL, stewarded by the Office of Nuclear Energy. Related chemical processing and handling infrastructure is supported at these sites. In addition, processing capabilities are supported at PNNL for targeted isotopes such as strontium-90 for batteries, radium-226 to produce Ac-225 and lead-212 isotope generators for cancer treatments. At the Y-12 National Security Complex, DOE IP supports the preparation and packaging of lithium isotopes for industry and research, and americium-241 for nuclear sources and batteries is recovered from NNSA plutonium processes at the LANL Plutonium Facility. Helium-3 for cryogenics is extracted from NNSA-owned tritium beds at the Savannah River Site, and the radioisotope separator at INL enriches radioisotopes for nuclear forensics. Individual electromagnetic ion separators are assembled and operated at ORNL as the country awaits SIPRC to provide substantial capability.

The NIDC is located at ORNL and is responsible for the day-to-day business operations for the DOE IP, including sales, contract negotiation, marketing assessments, public outreach, quality control, packaging, and transportation. The NIDC arranges for regular and frequent interfaces between DOE IP and industrial, academic, and medical communities to ensure that strategies are evidence-based and informed by stakeholder interactions. Furthermore, the DOE IP formally canvasses the broad federal community for isotope demands every other year to align priorities with evidence-based program evaluations.

The DOE IP provides over 220 stable isotopes from inventory, produces a few stable isotopes, and produces over 81 radioisotopes in short supply for the Nation. The Program is often the only source of these isotopes globally. Some examples of produced isotopes by the DOE IP are:

- actinium-225, actinium-227, astatine-211, cerium-134, scandium-47, scandium-44, holmium-166m, tungsten-188, lutetium-177, strontium-89, strontium-90, tin-117m, vanadium-48, manganese-52, manganese-54, gold-199, cobalt-55, and cobalt-60 for cancer therapy and imaging diagnostics
- californium-252 for nuclear reactor start-up, oil and gas exploration and production well logging
- arsenic-73, iron-52, iron-59, and zinc-65 as tracers in metabolic studies
- barium-133 for quantum computing research, medical standards, and industrial sources
- berkelium-249, americium-243, uranium-238, plutonium-242, plutonium-244, californium-249, californium-251, einsteinium-254, and curium-248 for use as targets for discovery of new super heavy elements
- bismuth-213, lead-212, lead-203, astatine-211, copper-67, thorium-227, thorium-228, radium-223, and radium-224 for cancer and infectious disease therapy and research
- cadmium-109 for X-ray fluorescence imaging and environmental research
- fermium-257 for heavy element chemistry research
- helium-3 for cryogenics
- lithium-6 neutron detectors for homeland security applications
- selenium-75 for industrial radiography
- silicon-32 for oceanography and climate modeling
- ytterbium-171 for quantum memory
- ytterbium-176 as feedstock for isotopes that treat prostate cancer
- nickel-63 for explosives detection
- strontium-90, promethium-147, americium-241, and thulium-170 for nuclear batteries and power sources

It can take decades for an economically and technically viable commercial market to be developed for any novel isotope. The DOE IP works closely with industry to commercialize technology and promote domestic independent producers in a smooth transition that does not disrupt supply and/or prohibit research. At that point, the DOE IP stops production to not compete with the domestic industry. Examples in which domestic commercial production now exists include strontium-82 for cardiac heart imaging and germanium-68 for medical diagnostics.

Projects

The prototype capabilities of the Enriched Stable Isotope Prototype Plant (ESIPP), developed through DOE IP-supported research, demonstrated the feasibility of new EMIS and gas centrifuge (GC) technologies and re-established a small general enriched stable isotope production capability in the U.S. The subsequent SIPF Major Item of Equipment (MIE) at ORNL establishes the first full-scale GC cascade to enrich stable isotopes. The implementation of SIPF nears its planned completion in FY 2025 to produce enriched xenon-129. Xenon-129 has demonstrated effectiveness in polarized lung imaging and there is currently no U.S. production capability. This isotope has also garnered the interest of the medical community in monitoring lung function and damage from infectious disease such as COVID-19.

The SIPRC line-item construction project further expands gas centrifuge isotope separation and EMIS production capability to meet the Nation's growing demand for stable isotopes. CD-1, Approve Alternative Selection and Cost Range, and Subproject-1 CD-3A, Approve Long Lead Procurement, was received on November 4, 2021. The Total Project Cost (TPC) point estimate is $325,000,000 with a preliminary TPC range of $187,000,000 to $338,000,000, approved at CD-1. Across the Nation, rising construction costs and supply chain issues are impacting project costs, and SIPRC is no exception; these impacts will be assessed at an evidence-based peer review planned in 4Q FY 2023. SIPRC is required to mitigate U.S. dependence for enriched stable isotopes on sensitive countries.

The RPF at ORNL is required to expand chemical processing capacity in the U.S. to mitigate dependence for radioisotopes on sensitive countries. Currently, the lack of radioisotope processing capacity is inhibiting the DOE IP from meeting U.S. demand for critical isotopes and establishing domestic supply chains. The RPF is planned as a Hazard Category 2 nuclear facility, able to process the higher specific activity targets that are irradiated in a reactor, such as HFIR. CD-0, Approve Mission Need, was received on April 29, 2021. The current Total Project Cost (TPC) point estimate is $425,000,000 with a CD-0 approved TPC range of $310,000,000 to $615,000,000.

The CARP facility provides chemical processing infrastructure at BNL for the processing of accelerator-irradiated targets. CARP repurposes an existing nuclear Hazard Category 3 Building and outfits it cost-effectively with hot-cells and infrastructure. Not only will CARP allow the domestic establishment of new accelerator-produced isotopes currently only produced outside of the United States, but it will enable an increase in the availability of highly sought-after alpha-emitting isotopes to decrease cancer mortality. CD-0, Approve Mission Need, was received on December 5, 2022. The CD-0 TPC range is $60,000,000 to $80,000,000.

## Isotope R&D and Production

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Isotope R&D and Production** | **$109,451** | **$173,051** | **+$63,600** |
| Isotopes, Research | $38,827 | $63,827 | +$25,000 |
| Funding supports high impact R&D activities at universities and national laboratories leading to advanced, innovative, and novel isotope production and processing technologies, increasing the availability of isotopes in short supply and promote U.S. economic resilience. The priority R&D remains on the development of full-scale processing and technology capabilities for the production of alpha- and beta-emitters for cancer therapy, of which the DOE IP is a global leader, and to promote their transition to medical applications. Funding maintains the University Isotope Network to perform the R&D necessary to enable routine production. Research to develop enrichment capability for new stable isotopes of importance, including isotopes for clean energy and quantum computing is maintained. Participation in the Advanced Manufacturing initiative continues with innovative isotope production technology that can facilitate commercial engagement and the promotion of domestic supply chains, such as “desktop” inkjet printing of production targets. Support for the DOE IP Traineeship Program with a goal to increase the diversity of the workforce as part of RENEW increases in FY 2023. | | Core research supports the highest impact R&D activities at universities and national laboratories. Advanced, innovative, and novel isotope production and processing technologies will increase the availability of the highest priority isotopes in short supply to promote U.S. independence in isotope supply chains. Competitive research supports the most compelling research to address urgent needs in the development of isotope production or processing techniques. Funding increases for the University Isotope Network, adding niche capabilities. Activities continue implementing the Isotope Harvesting at FRIB, which is nearing completion. Advances in other stable isotope enrichments technologies will be explored. Funding supports research translation research to advance novel medical isotopes to clinical trials. Efforts to promote isotopes for clean energy applications is held flat. Efforts continue to develop isotope production for QIS, as does participation in the SC Advanced Manufacturing, FAIR, and Accelerate initiatives. Participation in RENEW and BRaVE initiatives increases. Funding supports new investments in the microelectronics and DOE Isotope initiatives. Increased research funding enables direct support of the Nuclear Chemistry Summer School and participation in the SC Early Career Awards Program. Support for OPC activities of the CARP facility, to increase availability of medical isotopes, is provided. | Evidence-based research activities will improve or develop innovative isotope production, enrichment, and processing technology with the goal of increasing domestic supplies of critical isotopes for medicine, energy, national security, and other fields. The increase initiates the DOE Isotope Initiative. The increase will support modest funding to support conceptual design of the CARP at BNL, increased support for the University Isotope Network, and increases to the RENEW and BRaVE initiatives. Funding supports new participation in the microelectronics initiative. Increased funding enables direct support of the Nuclear Chemistry Summary School and participation in the SC Early Career Awards Program. Funding provides OPC funding for CARP to start conceptual design activities. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Research increases for the BRaVE initiative in partnership with the University of Missouri to address a single point failure in reactor isotope processing and create tech-savvy jobs in an underserved rural area of Missouri with the implementation of the Radioisotope Science Center at MURR. Design for the ORNL RPF project continues to advance needed chemical processing infrastructure at ORNL. Research to advance isotope harvesting capabilities and expertise at FRIB are roughly maintained.<br><br>Funding supports participation in the Accelerate initiative which supports scientific research to accelerate the transition of isotope science advances to clinical trials. Also, funding supports the FAIR initiative which provides focused investment on enhancing isotope research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions. | | |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Isotopes, Operations | $46,624 | $78,824 | +$32,200 |
| Funding supports mission readiness (~80 percent optimum) of the growing portfolio of isotope production and processing sites and nurtures critical core competencies in isotope production and development, promoting robust domestic supply chains for cancer therapy and other applications. Support maintains NIDC activities to interface with the growing stakeholder community and rapidly expanding isotope portfolio. Funding continues to support electromagnetic separation technology optimized to heavy elements, enriched radioisotope separation technology, extraction of valuable isotopes from legacy Mark 18-A targets. | | The Request will support increased mission readiness at all production and processing sites to ~92 percent enabling the Program to better respond as a DOE Mission Essential Function, fill gaps in isotope supply chains and develop new domestic sources of critical isotopes. The Request will provide increased support to NIDC, the business arm of the DOE IP. Funding will continue to support EMIS and development of other enrichment core competencies. Isotopes extracted from legacy reactor target processing, including krypton-85 for semiconductor manufacturing and curium-246/248 to produce Cf-252, will continue. Inventories of isotopes are managed, including He-3 and the stable isotope inventory. Investments target single point failures at the production sites as well as deferred maintenance to ensure safe and reliable operations. | Mission readiness of radioisotope production sites increases to 92 percent. Evidence-based activities will support increased readiness to produce stable isotopes and build up a core competence in stable isotope operations; additional staff commission and operate new enrichment machines. NIDC will add staff to respond to growing inquiries. HFIR remains a workhorse in developing new supply chains for Russian-sourced isotopes, and additional staff continue these efforts. Increased support for the LEAF accelerator at ANL will allow its transition from NNSA to DOE IP. Support will increase for the inventory management and unique dispensing of stable isotopes in special forms. Support will increase for the extraction of isotopes from the Mark 18-A legacy targets, as the first shipments from SRNL reach ORNL for testing. Increased readiness enables the first-time provision of mission readiness support to INL, PNNL, Y-12 and the LANL Plutonium Facility for their efforts in isotope production. Increased funding addresses the highest priority efforts in a backlog of deferred maintenance and performance improvements to increase robust and efficient operations. |
| Construction | $24,000 | $30,400 | +$6,400 |
| *U.S. Stable Isotope Production and Research Center (SIPRC)* | *$24,000* | *$20,900* | *-$3,100* |
| Funding supports the continuation of engineering design and approved long lead procurements of the U.S. SIPRC. | | Funding will continue design and construction of the U.S. SIPRC at ORNL, to provide large scale stable isotope production capacity for the Nation and mitigate U.S. dependence on Russia and Chinese capabilities. | Activities focus on design of gas centrifuges, site preparations, facility construction and EMIS fabrication. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| *Radioisotope Processing Facility (RPF)* *$ —* | *$8,500* | *+$8,500* |
| No funding requested. | The Request will initiate TEC of the RPF at ORNL. RPF will address a lack of available radiochemical processing infrastructure within the DOE IP complex for reactor target processing which is currently inhibiting production of critical isotopes. RPF is required to mitigate U.S. independence on foreign radioisotope supply chains. | TEC will be initiated for RPF, including engineering design and long lead procurements. RPF proposes to be constructed at ORNL as a greenfield site. |
| *Clinical Alpha Radionuclide Producer (CARP)* *$ —* | *$1,000* | *+$1,000* |
| No funding requested. | The Request will initiate TEC of the CARP at BNL. CARP enables the domestic establishment of new accelerator-produced isotopes currently only produced outside of the United States and allows an increase in the availability of highly sought after alpha-emitting isotopes to decrease cancer mortality and meet U.S. demand. | TEC will be initiated for CARP, including engineering design and long lead procurements. CARP repurposes an existing facility at BNL and adds chemical processing infrastructure. |

**Isotope R&D and Production**
**Capital Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | – | 2,000 | 9,100 | +7,100 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **–** | **2,000** | **9,100** | **+7,100** |

**Isotope R&D and Production**
**Construction Projects Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **24-SC-91, Radioisotope Processing Facility (RPF), ORNL** | | | | | | | |
| Total Estimated Cost (TEC) | 585,000 | – | – | – | – | 8,500 | +8,500 |
| Other Project Cost (OPC) | 29,406 | – | 3,000 | 10,600 | 1,000 | – | -1,000 |
| **Total Project Cost (TPC)** | **614,406** | **–** | **3,000** | **10,600** | **1,000** | **8,500** | **+7,500** |
| **24-SC-92, Clinical Alpha Radionuclide Producer (CARP), BNL** | | | | | | | |
| Total Estimated Cost (TEC) | 70,000 | – | – | – | – | 1,000 | +1,000 |
| Other Project Cost (OPC) | 10,000 | – | – | – | – | 1,500 | +1,500 |
| **Total Project Cost (TPC)** | **80,000** | **–** | **–** | **–** | **–** | **2,500** | **+2,500** |
| **20-SC-51, SIPRC** | | | | | | | |
| Total Estimated Cost (TEC) | 288,800 | – | 12,000 | 75,000 | 24,000 | 20,900 | -3,100 |
| Other Project Cost (OPC) | 6,600 | – | 3,200 | – | – | – | – |
| **Total Project Cost (TPC)** | **295,400** | **–** | **15,200** | **75,000** | **24,000** | **20,900** | **-3,100** |
| | | | | | | | |
| **Total, Construction** | | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **12,000** | **75,000** | **24,000** | **30,400** | **+6,400** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **6,200** | **10,600** | **1,000** | **1,500** | **+500** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **18,200** | **85,600** | **25,000** | **31,900** | **+6,900** |

*Notes:*

- *The total preliminary TPC for the U.S. Stable Isotope Production and Research Center (SIPRC) of $295,400,000 does not include $29,600,000 ($24,000,000 TEC and $5,600,000 OPC) included in the Nuclear Physics program for prior years. The full preliminary total for SIPRC, combining the Nuclear Physics and Isotope R&D and Production funding, is $325,000,000. This project is not baselined.*
- *The total preliminary TPC for the Radioisotope Processing Facility (RPF) of $614,406,000 does not include $594,000 in OPC funding included in the Nuclear Physics program for prior years. The full CD-0 approved total for RPF, combining the Nuclear Physics and Isotope R&D and Production funding, is $615,000,000. This project is not baselined.*

**Isotope R&D and Production**
**Scientific Employment**

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 33 | 41 | 57 | +16 |
| Number of Postdoctoral Associates (FTEs) | 19 | 30 | 34 | +4 |
| Number of Graduate Students (FTEs) | 17 | 33 | 45 | +12 |
| Number of Other Scientific Employment (FTEs) | 89 | 103 | 140 | +37 |
| **Total Scientific Employment (FTEs)** | **158** | **207** | **276** | **+69** |

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

**24-SC-91, Radioisotope Processing Facility**
**Oak Ridge National Laboratory, ORNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Radioisotope Processing Facility (RPF) is $8,500,000 of Total Estimated Cost (TEC) funding. The current Total Project Cost (TPC) point estimate is $425,000,000 with a CD-0 approved TPC range of $310,000,000 to $615,000,000.

**Significant Changes**

This project data sheet (PDS) is a new start in FY 2024. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on April 29, 2021. The project is working to achieve CD-1/3A, Approve Alternative Selection and Cost Range, planned for FY 2024.

Other Project Cost (OPC) activities related to conceptual design and research and development come to completion in FY 2024; the Inflation Reduction Act (IRA) and FY 2023 Enacted Appropriation fully funds activities which finalize the conceptual design of the facility, modular hot cell units, and radiochemical equipment in preparation for CD-1/3A. The IRA support avoids projected reductions-in-force, reduces project risks, and enables early value engineering. TEC funding in FY 2024 will support engineering design activities and initiate long-lead procurements for the design-build modular hot cell units; funding will also support early site preparation activities such as geotechnical sampling, tree clearing, and cut and fill operations to prepare the site.

A Federal Project Director (FPD) is in the process of being assigned to the ORNL RPF and will be in place by CD-1.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 4/29/21 | 2Q FY 2024 | 3Q FY 2024 | 1Q FY 2027 | TBD | 1Q FY 2027 | 4Q FY 2033 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 1Q FY 2027 | 3Q FY 2024 |

**Project Cost History**

This project has a pre-CD-1 preliminary point estimate of $425,000,000 and a CD-0 approved Total Project Cost (TPC) range of $310,000,000 to $615,000,000. The table below reflects the upper cost of the TPC range as there is not yet a baseline. No construction, excluding for approved long-lead procurement, will be performed until the project performance baseline has been validated and CD-3 has been approved.

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 48,500 | 536,500 | 585,000 | 30,000 | 30,000 | 615,000 |

*Notes:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Since project is at CD-0, the funding estimates correlate to the upper end of the estimated TPC range.*

## 2. Project Scope and Justification

**Scope**

The scope of this project includes design and construction of a new Hazard Category 2 radioisotope processing facility, approximately 45,000 square feet, and the associated equipment for production of priority radioisotopes, with particular focus on irradiated reactor targets. RPF will be a purely technical facility (i.e., minimal office and staff amenities), and located on the Oak Ridge National Laboratory (ORNL) main campus. The design should support up to eight new radioisotope production lines and be equipped with sufficient hot cells grouped to support these new product lines and research. Facility design concepts will include separate bays needed to support reconfigurable heavy shielding for transloading of irradiated targets and waste handling and storage of radioactive materials. The facility will be designed to incorporate other operations required to successfully produce isotopes such as staging and repair of manipulators and other equipment as well as the supporting infrastructure necessary for efficient operations such as cranes to assist in moving casks within the facility. The facility design will address how current Good Manufacturing Practices (cGMP) compliance will be assured. Construction of the proposed facility will also integrate “safety by design”, “quality by design”, and “safeguards by design” standards to ensure safe and efficient future operations.

**Justification**

RPF is critical to the Nation and to the DOE Isotope Program (DOE IP) within SC’s Office of Isotope R&D and Production. Radioisotopes are high-priority commodities essential for energy, medical, space, environmental, and national security applications and for basic research. Currently, radioisotope processing facility capacity, including required elements such as hot cells, glove boxes and supporting laboratories, is the limiting factor for increasing domestic radioisotope production and establishing U.S. independence from foreign supplies of reactor produced isotopes. There is a shortage of radioisotope processing capabilities to process irradiated reactor targets, such as from the High Flux Isotope Reactor (HFIR) at Oak Ridge National Lab, a pivotal facility in the DOE IP which produces a suite of high priority radioisotopes for the Nation. The facility will enable radioisotope processing infrastructure to meet the near-and long-term needs of the DOE IP, therefore promoting U.S. economic growth and resilience, as well as reducing dependence on foreign supply.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements will be met.

Key Performance Parameters (KPPs)

Preliminary Key Performance Parameters (KPPs) are defined at CD-1 and may change as each subproject continues towards CD-2, Approve Performance Baseline. CD-1 approval is expected later in 2024. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Design/construct building | TBD | TBD |
| Instrumentation design/development | TBD | TBD |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| FY 2024 | 8,500 | 8,500 | 8,500 | – |
| Outyears | 40,000 | 40,000 | 40,000 | – |
| **Total, Design (TEC)** | **48,500** | **48,500** | **48,500** | **–** |
| Construction (TEC) | | | | |
| Outyears | 536,500 | 536,500 | 536,500 | – |
| **Total, Construction (TEC)** | **536,500** | **536,500** | **536,500** | **–** |
| Total Estimated Cost (TEC) | | | | |
| FY 2024 | 8,500 | 8,500 | 8,500 | – |
| Outyears | 576,500 | 576,500 | 576,500 | – |
| **Total, TEC** | **585,000** | **585,000** | **585,000** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 594 | 594 | – | – |
| FY 2022 | 3,000 | 3,000 | 3,594 | – |
| FY 2022 - IRA Supp. | 10,600 | 10,600 | – | – |
| FY 2023 | 1,000 | 1,000 | 1,000 | 10,600 |
| Outyears | 14,806 | 14,806 | 14,806 | – |
| **Total, OPC** | **30,000** | **30,000** | **19,400** | **10,600** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 594 | 594 | – | – |
| FY 2022 | 3,000 | 3,000 | 3,594 | – |
| FY 2022 - IRA Supp. | 10,600 | 10,600 | – | – |
| FY 2023 | 1,000 | 1,000 | 1,000 | 10,600 |
| FY 2024 | 8,500 | 8,500 | 8,500 | – |
| Outyears | 591,306 | 591,306 | 591,306 | – |
| **Total, TPC** | **615,000** | **615,000** | **604,400** | **10,600** |

*Note:*
- *Since project is still at CD-0, the funding estimates in the tables above correlate to the upper end of the estimated TPC range.*

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 35,000 | N/A | **N/A** |
| Design - Contingency | 13,500 | N/A | **N/A** |
| **Total, Design (TEC)** | **48,500** | **N/A** | **N/A** |
| Construction | 360,000 | N/A | **N/A** |
| Construction - Contingency | 176,500 | N/A | **N/A** |
| **Total, Construction (TEC)** | **536,500** | **N/A** | **N/A** |
| **Total, TEC** | **585,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *190,000* | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Design | 12,194 | N/A | **N/A** |
| Start-up | 9,306 | N/A | **N/A** |
| OPC - Contingency | 8,500 | N/A | **N/A** |
| **Total, Except D&D (OPC)** | **30,000** | **N/A** | **N/A** |
| **Total, OPC** | **30,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *8,500* | *N/A* | ***N/A*** |
| **Total, TPC** | **615,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***198,500*** | ***N/A*** | ***N/A*** |

*Note:*
- *Since project is at CD-0, the funding estimates correlate to the upper end of the estimated TPC range.*

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | — | — | — | — | 8,500 | 576,500 | 585,000 |
| | OPC | 594 | 3,000 | 10,600 | 1,000 | — | 14,806 | 30,000 |
| | TPC | 594 | 3,000 | 10,600 | 1,000 | 8,500 | 591,306 | 615,000 |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2033 |
| Expected Useful Life | — |
| Expected Future Start of D&D of this capital asset | — |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | — | N/A | — |
| Utilities | N/A | — | N/A | — |
| Maintenance and Repair | N/A | — | N/A | — |
| Total, Operations and Maintenance | N/A | — | N/A | — |

## 7. D&D Information

| | Square Feet |
|---|---|
| New area being constructed by this project at ORNL................................................................................ | ~45,000 |
| Area of existing facility(ies) being replaced ................................................................................... | 0 |
| Area of any additional D&D space to meet the "one-for-one" requirement........................................ | 0 |

## 8. Acquisition Approach

The ORNL Management and Operating (M&O) contractor, UT Battelle, will perform the acquisition for this project, overseen by the DOE Oak Ridge National Laboratory Site Office. The M&O contractor will consider various acquisition approaches and project delivery methods prior to achieving CD-1 and will be responsible for awarding and administering all subcontracts related to this project. Its annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

**24-SC-92, Clinical Alpha Radionuclide Producer (CARP)**
**Brookhaven National Laboratory, BNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the 24-SC-92, Clinical Alpha Radionuclide Producer (CARP) facility is $2,500,000, including $1,000,000 of Total Estimated Cost (TEC) funding and $1,500,000 of Other Project Costs (OPC) funding. The current Total Project Cost (TPC) pre-conceptual point estimate is $74,000,000 with CD-0 approved TPC range of $60,000,000 to $80,000,000.

**Significant Changes**

This project data sheet (PDS) is a new start in FY 2024. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on December 5, 2022. In FY 2024, OPC funding will continue conceptual design activities for both the facility modification as well as the hot cell and radiochemical equipment conceptual design. In FY 2024, TEC funding will initiate preliminary design activities.

A Federal Project Director (FPD) has not yet been assigned to the BNL CARP, but one will be assigned by CD-1.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 12/5/22 | TBD | 4Q FY 2024 | 4Q FY 2025 | TBD | 4Q FY 2025 | 4Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 4Q FY 2025 | 4Q FY 2024 |

**Project Cost History**

The table below reflects the upper cost of the TPC range as there is not yet a baseline. No construction, excluding for approved long-lead procurement, will be performed until the project performance baseline has been validated and CD-3 has been approved.

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 6,500 | 63,500 | 70,000 | 10,000 | 10,000 | 80,000 |

## 2. Project Scope and Justification

### Scope

The scope of this project includes design and construction activities to retrofit an already existing 6,000 square feet uncontaminated building at Brookhaven National Lab (BNL), that was designed and once operated as a Hazard Category 3 facility as well as the associated instrumentation and equipment. The proposed facility will be equipped with hot cells, glove boxes, and equipment sufficient in number, space, and capability to support processing of the irradiated thorium targets, as well as Quality Assurance/Quality Control (QA/QC) and shipping and distribution activities. The facility design will address how current Good Manufacturing Practices (cGMP) compliance will be assured. The proposed modifications will also integrate "safety by design", "quality by design", and "safeguards by design" standards to ensure safe and efficient future operations.

### Justification

CARP is critical to the Nation and to the DOE Isotope Program (DOE IP) within SC's Office of Isotope R&D and Production. Radioisotope processing needs to be performed in facilities that carry a Hazard Category designation. The nuclear facility hazard category (i.e., Hazard Category 1, 2, 3, or below 3—"radiological facility") defines the maximum quantity and type of radioactive material that can be present within a facility. This facility will enable DOE IP to better meet U.S. demand for isotopes and mitigate supply chain interruptions for critical radioisotopes. Without this facility, DOE IP will limit radioisotope processing operations to the sub-Hazard Category 3 level, resulting in significant constraints on the amount of material that can be processed, smaller batch sizes, and fewer concurrent processing activities. Isotope production and processing at one of the DOE IP radioisotope production flagship facilities, the Brookhaven Linac Isotope Producer (BLIP), will be significantly impacted. The CARP facility will enable DOE IP to continue its mission of isotope production at BLIP as a DOE Mission Essential Function to meet the anticipated demand for radioisotopes for research, medical therapy and diagnosis, commercial applications, and national security, therefore promoting U.S. economic growth and stability. The ability of BLIP to continue to process its irradiated targets will also help decrease U.S. dependence for radioisotopes on other countries, such as Russia.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements will be met.

<u>Key Performance Parameters (KPPs)</u>

Preliminary Key Performance Parameters (KPPs) are defined at CD-1 and may change as the project continues towards CD-2, Approve Performance Baseline. CD-1 approval is expected later in 2024. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Design/construct building | TBD | TBD |
| Instrumentation design/development | TBD | TBD |

3. **Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| FY 2024 | 1,000 | 1,000 | 1,000 |
| Outyears | 5,500 | 5,500 | 5,500 |
| **Total, Design (TEC)** | **6,500** | **6,500** | **6,500** |
| Construction (TEC) | | | |
| Outyears | 63,500 | 63,500 | 63,500 |
| **Total, Construction (TEC)** | **63,500** | **63,500** | **63,500** |
| Total Estimated Cost (TEC) | | | |
| FY 2024 | 1,000 | 1,000 | 1,000 |
| Outyears | 69,000 | 69,000 | 69,000 |
| **Total, TEC** | **70,000** | **70,000** | **70,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2024 | 1,500 | 1,500 | 1,500 |
| Outyears | 8,500 | 8,500 | 8,500 |
| **Total, OPC** | **10,000** | **10,000** | **10,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2024 | 2,500 | 2,500 | 2,500 |
| Outyears | 77,500 | 77,500 | 77,500 |
| **Total, TPC** | **80,000** | **80,000** | **80,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 4,500 | N/A | **N/A** |
| Design - Contingency | 2,000 | N/A | **N/A** |
| **Total, Design (TEC)** | **6,500** | **N/A** | **N/A** |
| Construction | 42,500 | N/A | **N/A** |
| Construction - Contingency | 21,000 | N/A | **N/A** |
| **Total, Construction (TEC)** | **63,500** | **N/A** | **N/A** |
| **Total, TEC** | **70,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *23,000* | ***N/A*** | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Design | 4,000 | N/A | **N/A** |
| Start-up | 3,000 | N/A | **N/A** |
| OPC - Contingency | 3,000 | N/A | **N/A** |
| **Total, Except D&D (OPC)** | **10,000** | **N/A** | **N/A** |
| **Total, OPC** | **10,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *3,000* | *N/A* | ***N/A*** |
| **Total, TPC** | **80,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***26,000*** | ***N/A*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | — | — | — | 1,000 | 69,000 | 70,000 |
| | OPC | — | — | — | 1,500 | 8,500 | 10,000 |
| | TPC | — | — | — | 2,500 | 77,500 | 80,000 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | — |
| Expected Future Start of D&D of this capital asset | — |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

### 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at BNL | N/A |
| Area of D&D in this project at BNL | N/A |
| Area at BNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | N/A |
| Area of D&D in this project at other sites | N/A |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | N/A |
| Total area eliminated | N/A |

### 8. Acquisition Approach

The BNL Management and Operating (M&O) contractor, Brookhaven Science Associates, will perform the acquisition for this project, overseen by the DOE Brookhaven National Laboratory Site Office. The M&O contractor will consider various acquisition approaches and project delivery methods prior to achieving CD-1 and will be responsible for awarding and administering all subcontracts related to this project. Its annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

**20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC)**
**Oak Ridge National Laboratory, ORNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History


**<u>Summary</u>**

The FY 2024 Request for the U.S. Stable Isotope Production and Research Center (SIPRC) is $20,900,000 of Total Estimated Cost (TEC) funding. The current Total Project Cost (TPC) point estimate is $325,000,000 with a preliminary TPC range of $187,000,000 to $338,000,000.


**<u>Significant Changes</u>**

This project data sheet (PDS) is an update of the FY 2023 PDS; the project is not a new start in FY 2024. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range and Subproject 1 CD-3A, Approve Long-Lead Procurement, which was approved on November 4, 2021; the project is not baselined. The TPC point estimate increased from $250,000,000 to $325,000,000, remaining within the CD-1 approved TPC range of $187,000,000 to $338,000,000. The increase is primarily driven by COVID-19 supply chain impacts which have created an environment of long-lived increasing costs especially for facility construction and materials. The point estimate also reflects the result of advancing project maturity with the progression of the preliminary engineering design. The increase and the TPC point estimate will be thoroughly assessed through an evidence-based peer-review in late FY 2023. The current TPC point estimate is anticipated to remain within the TPC range established at CD-1. In early FY 2023, driven by an extraordinary increase in lead times for critical EMIS magnet components, the project pursued Subproject 1 CD-3B, Approve Long-Lead Procurement, as a risk mitigation strategy. Approval of CD-3B is anticipated for mid-FY 2023.

The project received Inflation Reduction Act (IRA) funding in FY 2022, supporting the SIPRC facility construction award contract planned for early FY 2024 and maintains optimal project progress throughout that year; IRA funding also pulls forward the CD-4 from FY 2032 to FY 2031. The FY 2024 Request will continue support for Project Engineering and Design (PED) activities and approved long-lead procurements, which are based on known designs of technologies developed under previous efforts. Due to an anticipated CD-2/3, Approve Performance Baseline and Approve Start of Construction, approval of SIPRC Subproject 1 (SP-1) in early FY 2024. The FY 2024 Request will also support activities such as the facility construction and EMIS machine component procurements.

A Federal Project Director (FPD) with certification Level III has been assigned to the SIPRC.

**Critical Milestone History**

| | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| SIPRC Project | 1/4/19 | 2/26/21 | 11/4/21 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY2031 |
| SIPRC SP-1 - Facility and EMIS | 1/4/19 | 2/26/21 | 11/4/21 | 1Q FY 2024 | 1Q FY 2024 | 1Q FY 2024 | 1Q FY 2030 |
| SIPRC SP-2 - Mo-100 Cascade | 1/4/19 | 2/26/21 | 11/4/21 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2031 |
| SIPRC SP-3 - Si-28 Test Cascade Infrastructure | 1/4/19 | 2/26/21 | 11/4/21 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2031 |

*Notes:*

- *Dates shown in the SIPRC Project row in table above correspond to the latest subproject date (broken out by subproject in rows below).*
- *The estimated schedules shown are preliminary.*

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| SIPRC Project | 4Q FY 2025 | 4Q FY 2025 | 2Q FY 2023 |
| SIPRC SP-1 - Facility and EMIS | 1Q FY 2024 | 11/4/21 | 2Q FY 2023 |
| SIPRC SP-2 - Mo-100 Cascade | 4Q FY 2025 | 4Q FY 2025 | – |
| SIPRC SP-3 - Si-28 Test Cascade Infrastructure | 4Q FY 2025 | 4Q FY 2025 | – |

*Note:*

- *Dates shown in the SIPRC Project row in table above correspond to the latest subproject date (broken out by subproject below). Dates shown for CD-3B are anticipated.*

**CD-3A for Subproject 1** – Approve Long-Lead Procurements (EMIS components and Facility Site Preparation)
**CD-3B for Subproject 1 –** Approve Long-Lead Procurements (Additional EMIS components).

**Project Cost History**

This project is at CD-1/3A with a preliminary point estimate of $325,000,000 and Total Project Cost (TPC) range of $187,000,000 to $338,000,000. No construction, excluding for approved long-lead procurement, will be performed until the project performance baseline has been validated and CD-3 has been approved.

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 36,000 | 201,800 | 237,800 | 12,200 | 12,200 | 250,000 |
| FY 2024 | 36,000 | 276,800 | 312,800 | 12,200 | 12,200 | 325,000 |

**2. Project Scope and Justification**

**Scope**

The scope of this project includes design and construction of a building, approximately 64,000 square feet, and associated instrumentation and equipment for enriching isotopes. Electromagnetic isotope separator systems and gas centrifuge cascades will be designed and installed in this new facility to promote operational, cost and security effectiveness, with space for future growth. The planned facility will include adequate space for test stands and prototype systems development and will be a purely technical facility (i.e., minimal office and staff amenities), and located on the Oak Ridge National Laboratory (ORNL) main campus. Gas centrifuges and electromagnetic separators are based on existing designs leveraging prior projects and R&D supported by the DOE Isotope Program (DOE IP). The laboratory considered the optimal number of production systems for each type of technology as part of the alternatives analysis for CD-1.

**Justification**

SIPRC is critical to the Nation and to the DOE Isotope Program (DOE IP) within SC's Office of Isotope R&D and Production. The facility will expand the only broad U.S. stable isotope production capability to enable multiple production campaigns of enriched stable isotopes. SIPRC will use innovative technology to establish domestic supply chains of critical stable isotopes and nurtures domestic core competencies in enrichment technologies using centrifuges and electromagnetic ion separators. This will provide domestic supply chains of critical isotopes for industry, medicine, and national security and mitigate U.S. dependencies on foreign suppliers, a critical need which has been magnified by the Russian invasion of Ukraine and the development of a stable isotope production facility in China. The current capacity within the U.S. is insufficient to meet the Nation's growing demands and the current inventory of stable isotopes is being depleted. The SIPRC project will provide an adequately sized building and transformative technology to address our Nation's stable isotope needs in a more economical and operationally efficient manner.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements will be met.

Key Performance Parameters (KPPs)

Preliminary Key Performance Parameters (KPPs) are defined at CD-1 and may change as each subproject continues towards CD-2, Approve Performance Baseline. CD-1 approval was received November 4, 2021. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

Summary of preliminary KPPs is indicated below.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Design/construct building | SP-1 – Facility and EMIS:<br>Beneficial occupancy of the facility obtained. | SP-1 – Facility and EMIS:<br>Beneficial occupancy of the facility obtained. |
| Instrumentation design/development | SP-1 – Facility and EMIS:<br>Ninety percent (90 percent) of the EMIS machines complete the operability demonstration by running simultaneously with gas for 4 hours. | SP-1 – Facility and EMIS:<br>One hundred percent (100 percent) of the EMIS machines complete the operability demonstration by running simultaneously with gas for 4 hours. |
| | SP-2 – Mo-100 Cascade:<br>a. The SIPRC project will complete the validation and verification (V&V) of the controls system with the completed documentation of the process.<br>b. The SIPRC project will complete documented system leak tests with results meeting the requirements laid out in the systems requirements documents.<br>c. The SIPRC project will complete a mechanical operability test of the completed production GCIS cascade. | SP-2 – Mo-100 Cascade:<br>The SIPRC project will complete a 100Mo gas test of the constructed cascade using molybdenum hexafluoride gas. Evidence of completion will be the report on the results of the gas test. |
| | SP-3 – Si-28 Test Cascade Infrastructure:<br>a. The SIPRC project will complete the V&V of the controls system with the completed documentation of the process.<br>b. The SIPRC project will complete documented system leak tests with results meeting the requirements laid out in the systems requirements documents. | SP-3 – Si-28 Test Cascade Infrastructure:<br>The SIPRC project will successfully complete an operability test of the TCI's feed and withdrawal system using a defined gas, either surrogate or actual planned $SiF_4$ gas. The system must be able to flow gas at the planned flow rate range per the systems requirements document and withdraw the gas from the system piping into cold traps. Evidence of completion will be a report on the results of this test. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 12,000 | 12,000 | – | – |
| FY 2022 | 9,000 | 9,000 | 11,500 | – |
| FY 2023 | 6,000 | 6,000 | 11,500 | – |
| FY 2024 | 6,000 | 6,000 | 9,500 | – |
| Outyears | 3,000 | 3,000 | 3,500 | – |
| **Total, Design (TEC)** | **36,000** | **36,000** | **36,000** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 12,000 | 12,000 | – | – |
| FY 2022 | 3,000 | 3,000 | 13,800 | – |
| FY 2022 - IRA Supp. | 75,000 | 75,000 | – | – |
| FY 2023 | 18,000 | 18,000 | – | 35,000 |
| FY 2024 | 14,900 | 14,900 | 30,000 | 40,000 |
| Outyears | 153,900 | 153,900 | 158,000 | – |
| **Total, Construction (TEC)** | **276,800** | **276,800** | **201,800** | **75,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 24,000 | 24,000 | – | – |
| FY 2022 | 12,000 | 12,000 | 25,300 | – |
| FY 2022 - IRA Supp. | 75,000 | 75,000 | – | – |
| FY 2023 | 24,000 | 24,000 | 11,500 | 35,000 |
| FY 2024 | 20,900 | 20,900 | 39,500 | 40,000 |
| Outyears | 156,900 | 156,900 | 161,500 | – |
| **Total, TEC** | **312,800** | **312,800** | **237,800** | **75,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 5,600 | 5,600 | 5,600 | – |
| FY 2022 | 3,200 | 3,200 | 3,200 | – |
| Outyears | 3,400 | 3,400 | 3,400 | – |
| **Total, OPC** | **12,200** | **12,200** | **12,200** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 29,600 | 29,600 | 5,600 | – |
| FY 2022 | 15,200 | 15,200 | 28,500 | – |
| FY 2022 - IRA Supp. | 75,000 | 75,000 | – | – |
| FY 2023 | 24,000 | 24,000 | 11,500 | 35,000 |
| FY 2024 | 20,900 | 20,900 | 39,500 | 40,000 |
| Outyears | 160,300 | 160,300 | 164,900 | – |
| **Total, TPC** | **325,000** | **325,000** | **250,000** | **75,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 30,000 | 27,000 | **N/A** |
| Design - Contingency | 6,000 | 9,000 | **N/A** |
| **Total, Design (TEC)** | **36,000** | **36,000** | **N/A** |
| Construction | 200,000 | 150,000 | **N/A** |
| Construction - Contingency | 76,800 | 51,800 | **N/A** |
| **Total, Construction (TEC)** | **276,800** | **201,800** | **N/A** |
| **Total, TEC** | **312,800** | **237,800** | **N/A** |
| *Contingency, TEC* | *82,800* | *60,800* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| R&D | N/A | 2,600 | **N/A** |
| Conceptual Design | 8,000 | 4,100 | **N/A** |
| Start-up | 2,500 | 2,100 | **N/A** |
| OPC - Contingency | 1,700 | 3,400 | **N/A** |
| **Total, Except D&D (OPC)** | **12,200** | **12,200** | **N/A** |
| **Total, OPC** | **12,200** | **12,200** | **N/A** |
| *Contingency, OPC* | *1,700* | *3,400* | ***N/A*** |
| **Total, TPC** | **325,000** | **250,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***84,500*** | ***64,200*** | ***N/A*** |

**5. Schedule of Appropriations Requests**[a]

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 24,000 | 12,000 | — | 12,000 | — | 189,800 | 237,800 |
| | OPC | 5,600 | 3,200 | — | — | — | 3,400 | 12,200 |
| | TPC | 29,600 | 15,200 | — | 12,000 | — | 193,200 | 250,000 |
| FY 2024 | TEC | 24,000 | 12,000 | 75,000 | 24,000 | 20,900 | 156,900 | 312,800 |
| | OPC | 5,600 | 3,200 | — | — | — | 3,400 | 12,200 |
| | TPC | 29,600 | 15,200 | 75,000 | 24,000 | 20,900 | 160,300 | 325,000 |

**6. Related Operations and Maintenance Funding Requirements**

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2030 |
| Expected Useful Life | 30 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2060 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 33,295 | 33,295 | 1,106,807 | 1,106,807 |
| Utilities | 4,053 | 4,053 | 133,735 | 133,735 |
| Maintenance and Repair | 2,992 | 2,992 | 90,458 | 90,458 |
| Total, Operations and Maintenance | $40,340 | $40,340 | $1,331,000 | $1,331,000 |

**7. D&D Information**

| | Square Feet |
|---|---|
| New area being constructed by this project at ORNL | 64,000 |
| Area of existing facility(ies) being replaced | 0 |
| Area of any additional D&D space to meet the "one-for-one" requirement | 0 |

The new area being constructed in this project is not replacing existing facilities. Any existing space that is freed up from consolidating activities into SIPRC will likely be repurposed.

**8. Acquisition Approach**

The ORNL Management and Operating (M&O) contractor, UT Battelle, will perform the acquisition for this project, overseen by the DOE Oak Ridge National Laboratory Site Office. The M&O contractor will be responsible for awarding and administering all subcontracts related to this project. Its annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

[a] The project does not have CD-2 approval; FY 2024 schedules and costs are estimates consistent with the updated preliminary point estimate.

# Isotope Production and Distribution Program Fund

## Overview

The Department of Energy's (DOE) Isotope Production and Distribution Program Fund, more commonly called the DOE Isotope Program (DOE IP), provides critical isotopes in short supply to the Nation and develops robust domestic supply chains to meet federal missions, facilitates emerging technology, and promotes the Nation's economic prosperity and technical competitiveness. The DOE IP produces and sells radioactive and stable isotopes, byproducts, surplus materials, and related isotope services worldwide to federal agencies, universities, and industry. Isotopes are foundational to essential applications that benefit society every day, such as revolutionary cancer therapy, diagnostic medical imaging, clean energy, explosives detection, quantum computing, advanced manufacturing, nuclear batteries, space exploration, national security, and biological tracers. In some cases, the DOE IP is the Nation's sole supplier of radioisotopes used in human clinical trials and/or in FDA-approved radiopharmaceuticals. A priority of the DOE IP is to mitigate the Nation's dependency on foreign supply chains of isotopes, particularly those from sensitive countries.

The Department supplies isotopes and related services to the Nation under the authority of the Atomic Energy Act of 1954, which specifies the role of the U.S. Government in isotope distribution. The Isotope Production and Distribution Program Fund was established by the 1990 Energy and Water Development Appropriations Act (Public Law 101-101) and amended by the 1995 Energy and Water Development Appropriations Act (Public Law 103-316). Funding for this revolving fund is provided by the annual appropriations from the Science appropriation account (from the Office of Isotope R&D and Production Program [IRP or DOE IP]) and collections from isotope sales; both are needed to maintain the Isotope Program's viability. Isotopes sold to commercial customers are priced to recover the full cost of production or the market price (whichever is higher). Research isotopes are sold at a reduced price to ensure that the high priority research requiring them does not become cost prohibitive. The revolving fund allows continuous and smooth operations of isotope production, sales, and distribution independent of the federal budget cycle and fluctuating sales revenue. It also enables the DOE IP to operate as a DOE Mission Essential Function during times of national crisis. During COVID-19 and the Russian invasion of Ukraine, the program has mitigated disruptions in isotope supply chains. An independent cost review of the fund's revenues and expenses is conducted annually by an external contractor.

The DOE IP produces radioisotopes by irradiating targets in accelerators or reactors at national laboratories and universities, and from extraction of materials from legacy waste, and strategic inventories. Accelerator facilities include the Brookhaven Linac Isotope Producer at Brookhaven National Laboratory, the Isotope Production Facility at Los Alamos National Laboratory, the Low Energy Accelerator Facility at Argonne National Laboratory, the University of Washington cyclotron, the University of Alabama-Birmingham cyclotron, and the University of Wisconsin-Madison cyclotron. Reactor facilities include the High Flux Isotope Reactor at Oak Ridge National Laboratory (ORNL), the University of Missouri Research Reactor, and the Advanced Test Reactor at Idaho National Laboratory. Irradiated targets are processed in associated hot cells and gloveboxes at these facilities. Isotopes are also extracted and purified at the Y-12 National Security Complex, the Pacific Northwest National Laboratory, and the Savannah River Site. Enriched stable isotopes are distributed from inventory and produced in modest amounts at ORNL with modern electromagnetic ion separating devices. The DOE IP can produce over 81 radioisotopes in short supply and distribute over 220 stables to the Nation. More details on these isotopes can be found in the DOE IP budget request in the Office of Science.

The National Isotope Development Center (NIDC) is the business arm of the DOE IP and manages contractual obligations with customers, marketing, and isotope production coordination. Given the myriad of supply chain disruptions from the Russian invasion of Ukraine, an immense amount of time was spent with stakeholders in FY 2022 and FY 2023 to understand the health of supply chains, ease customer concerns, and develop alternate sourcing of supplies. The NIDC organized stakeholder meetings throughout each year, including multiple several day sessions of dedicated meetings with industrial representatives. User group meetings of four promising medical isotopes to combat cancer were organized by the NIDC to promote information exchange between industry and research institutions. A DOE IP booth was presented at two international conferences in FY 2022 to conduct outreach and meet with stakeholders.

Annual appropriations in the DOE IP program support a payment into the revolving fund to maintain mission-readiness of facilities, including the support of core scientists and engineers needed to produce and process isotopes, and the maintenance and enhancement of isotope facilities and capabilities to assure reliable production and provide novel isotopes in high demand and short supply. In addition, appropriated funds provide support for R&D activities associated with development of new production and processing techniques for isotopes and workforce development in isotope production and chemical processing. Appropriated funding also supports infrastructure refurbishment and enhancements in capabilities to quickly respond to isotope supply chain disruptions, as well as construction funds for ongoing line-item projects. Revenues are collected from customers to offset the costs of producing, dispensing, packaging, and shipping isotopes; these revenues are also deposited into the revolving fund. About 80 percent of the total resources in the revolving fund are used for operations, maintenance, isotope production, and R&D for new isotope production techniques, with approximately 20 percent available for process improvements, unanticipated changes in revenue, manufacturing equipment, capability and infrastructure upgrades, and capital equipment such as assay equipment, glove boxes, and shipping containers needed to ensure on-time deliveries.

In FY 2023, a total of $148.5 million is estimated to be deposited into the revolving fund for isotope sales and technical services. This consists of the FY 2023 appropriation of $97.5 million paid into the revolving fund from the Isotope R&D and Production program, plus anticipated collections by NIDC of $51.0 million to recover costs related to isotope production and isotope services. In FY 2023, the DOE IP expects to sell over 125 different radioactive and stable isotopes to a broad range of research and commercial customers, including major pharmaceutical companies, industrial stakeholders, and researchers at hospitals, national laboratories, other federal agencies, universities, and private companies.

**Highlights of the FY 2024 Request**

For FY 2024, the Department foresees continued strong growth in isotope demand, including alpha and beta emitters for novel cancer therapy and medical diagnostics; stable isotopes to enable high-discovery science, emerging technologies in medicine and national security; isotopes for quantum information science; isotopes to promote clean energy, including fusion energy; and isotopes for nuclear batteries, semiconductor manufacturing, and power supplies. With the new DOE Isotope Initiative in FY 2024, the Program is focused on developing U.S. independence from Russian isotope supply chains; the Isotope Initiative will enable the DOE IP to be proactive and target high-risk supply chains effectively to ensure that the U.S. has access to isotopes for discovery science, essential industrial applications, Administration priorities, and to combat cancer. The FY 2024 Request of the DOE IP Budget is $173.1 million. Revolving fund resources will be used to address the following priorities in the program:

- Promote world-leading core competencies for isotope production to address gaps in supply chains and the provision of innovative, rare isotopes for high priority applications.
- Operate as a Departmental Mission Essential Function, supporting facilities with a high degree of Mission Readiness so that they can operate safely, reliably and efficiently to respond to crisis situations and fill gaps in isotope supply chains.
- Through cutting-edge research and advanced manufacturing, introduce novel and critical isotopes to the Nation to facilitate emerging technology and applications (medicine, quantum computing, clean energy, nuclear batteries…), promoting U.S. economic prosperity and technical strengths.
- Mitigate U.S. dependence on foreign supply chains and promote domestic production capabilities with technology transfer.
- Advance and expand transformative, domestic stable isotope enrichment capabilities.
- Enhance isotope processing capabilities to address a lack of infrastructure limiting the availability of new isotopes, mitigating single point failures to increase the Nation’s preparedness for reacting to global supply chain disruptions. Address targeted, high priority critical infrastructure needs.

**Program Accomplishments**

*Rare Isotope Made Available to Promote Commercialization and Advance R&D*

Radium-226 (Ra-226) was made famous through Marie Curie’s research. Decades ago, it was used in various medical treatments, including in small needles, tubes, and plaques. Once those treatments were proven ineffective and some of the hazards of handling radium were better understood, those small needles, tubes, and plaques were collected and stored in various waste drums throughout the world. In the modern era, scientists have discovered how to use Ra-226 as a source material for producing the new generation of alpha-emitting radioisotopes, including actinium-225 (Ac-225). Over the past decade, DOE has acquired some of this "waste" Ra-226 and subsequently developed the means to recycle and purify it into the needed starting material/feedstock for production of radioisotopes. In FY 2022, DOE announced the availability of R&D quantities of Ra-226 so that other organizations can also develop supply chains for these new alpha-emitters to develop a robust U.S. supply. DOE is currently the only supplier of this limited Ra-226 starting material, other than Russia.

*Record Breaking number of Shipments of New Cancer-Fighting Isotope*

Transporting radioisotopes is a non-trivial task requiring specialized shipping containers and stringent packaging steps to ensure worker and public safety. These critical steps become all the more challenging when delivering isotopes with a short half-life, such as actinium-225 (Ac-225). Ac-225 is showing tremendous advances in the fight against cancer such as Acute Myeloid Leukemia, Colorectal Cancer, Prostate Cancer, Multiple Myeloma, and others. But with a drug shelf-life of some 3-days and the underlying Ac-225 half-life of ~10-days, reliable and safe weekly shipments of Ac-225 are required for patient care. The DOE IP is the world leader in the production of Ac-225, followed by Russia and Germany. In FY 2022, the DOE achieved record levels of distribution by making over 500 shipments totaling over 1 million micro-curies of Ac-225 to support patient treatments and clinical trials.

*U.S. Production Demonstration of Ytterbium Isotopes Using Newly Developed Stable Isotope Enrichment Equipment Leads to Cutting-edge Cancer Therapies and Quantum Science Applications*

ORNL is routinely enriching the stable isotopes of ytterbium using the latest generation of electromagnetic isotope separation (EMIS) technology developed and deployed at ORNL. Ytterbium-176 (Yb-176) has been enriched at or above the isotopic purity required for production of the radioisotope lutetium-177, which is the active ingredient in an FDA-approved radiopharmaceutical used to treat pancreatic cancer. The DOE IP entered the market for Yb-176 sales in FY 2022. Prior to the success of the ORNL EMIS technology, Russia was the sole supplier of Yb-176 and was limiting U.S. availability. Other isotopes of ytterbium are simultaneously enriched with the same EMIS device, including Yb-171 and Yb-172, which have application in quantum information science.

## Accelerator R&D and Production

### Overview

The mission of the Accelerator R&D and Production (ARDAP) program is to coordinate Office of Science (SC) accelerator R&D; advance accelerator science and technology relevant to the Department, other Federal Agencies, and U.S. industry; foster public-private partnerships and other collaborative R&D activities to develop, demonstrate, and enable the commercial deployment of accelerator technology; support the development of a skilled, diverse, and inclusive workforce; and provide access to accelerator design and engineering resources. The overarching goal is to ensure a robust pipeline of innovative accelerator technology, train an expert and diverse workforce, and reduce significant supply chain risks by reshoring critical accelerator technology. By ensuring the supply of leading accelerator technology and facilities, ARDAP supports physical science research that provides the foundations for innovative technologies for green energy, medicine, security, and new tools to help clean up the environment and safeguard the water supply.

As the lead Office in the Accelerator Science and Technology Initiative, ARDAP coordinates accelerator R&D across SC and initiates new partnerships to move technologies from basic R&D into use at U.S. science facilities and into commercial products that benefit all Americans. These activities allow the U.S. to continue to provide the world's most comprehensive and advanced scientific research facilities and stimulate high technology sectors of the U.S. economy.

The ARDAP program is organized into two subprograms: Accelerator Stewardship and Accelerator Production.

#### Accelerator Stewardship

The Accelerator Stewardship subprogram supports cross-cutting basic R&D; facilitates access to unique state-of-the-art SC accelerator R&D infrastructure for the private sector and other users; operates a dedicated user facility for accelerator R&D and training new generations of scientists; and supports use-inspired accelerator technology R&D aimed at discovery science, medical, industrial, security, and environmental applications. The Accelerator Stewardship subprogram also supports curation of software and material properties databases commonly used for accelerator design.

Research activities in cross-cutting accelerator technologies include superconducting magnets and accelerators, beam physics, data science-based accelerator controls, simulation software, new particle sources, advanced laser technology, and other transformative research. Early-stage collaboration among academia, Department of Energy national laboratories, and U.S. industry will be fostered, reducing the time to commercialization. Research activities are informed by the requirements of both future SC facilities and the requirements for other applications.

#### Accelerator Production

The Accelerator Production subprogram supports public-private partnerships and other collaborative arrangements among academia, industry, and the DOE national laboratories to develop and mature accelerator technologies to address targeted supply chain risk areas for SC scientific facilities and to strengthen the domestic accelerator technology industry with new commercial products. Increasing the capabilities of domestic accelerator technology suppliers to both produce components and innovate will strengthen the SC mission to conduct world-leading scientific research.

Development activities will support partnerships in advanced superconducting wire and cable, superconducting radiofrequency (RF) cavities, and high efficiency RF power sources for accelerators, among other areas.

**Highlights of the FY 2024 Request**

The FY 2024 Request for $34.3 million will focus resources on fundamental research, operation and maintenance of a scientific user facility, and production of accelerator technologies in domestic industry. The FY 2024 Request will support:

- Innovative research, development, and deployment of accelerator technology, the implementation of the first consortium-based approach to accelerator R&D, and workforce development;
- Public-private partnerships to develop technologies that include advanced superconducting wire and cable, superconducting accelerators, and advanced radiofrequency power sources for accelerators;
- An increase in the Funding for Accelerated, Inclusive Research (FAIR) initiative will provide focused investment on enhancing research on clean energy, climate, and related topics at Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs), including attention to underserved and environmental justice regions;
- ARDAP's participation in the Reaching a New Energy Sciences Workforce (RENEW) initiative will expand targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research.

The FY 2024 Request also will support operations of the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF) for 2,100 hours and will provide funding to address significant remedial maintenance and deferred maintenance items, resulting in increased facility reliability and availability.

## Accelerator R&D and Production
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Accelerator R&D and Production** | | | | |
| Accelerator Stewardship, Research | 11,117 | 15,554 | 19,754 | +4,200 |
| Accelerator Stewardship, Facility Operations and Experimental Support | 5,137 | 6,000 | 8,434 | +2,434 |
| **Total, Accelerator Stewardship** | **16,254** | **21,554** | **28,188** | **+6,634** |
| Accelerator Production, Research | 1,746 | 5,882 | 6,082 | +200 |
| **Total, Accelerator Production** | **1,746** | **5,882** | **6,082** | **+200** |
| **Total, Accelerator R&D and Production** | **18,000** | **27,436** | **34,270** | **+6,834** |

SBIR/STTR funding:
- FY 2022 Enacted: SBIR $576,000 and STTR $81,000
- FY 2023 Enacted: SBIR $686,000 and STTR $96,000
- FY 2024 Request: SBIR $686,000 and STTR $97,000

**Basic and Applied R&D Coordination**
The ARDAP program advances cross-cutting accelerator technology R&D and supply chain risk reduction efforts that support the mission of multiple SC programs and other federal agencies. The ARDAP program was developed based on input from accelerator R&D experts from DOE, other federal agencies, universities, national laboratories, and the private sector to help identify specific research areas and supply chain gaps where investments would have sizable impacts beyond the SC research mission[a]. This program is closely coordinated with Basic Energy Sciences, Fusion Energy Sciences, High Energy Physics, Nuclear Physics, the Isotope R&D and Production program, and partner agencies to ensure federal stakeholders have input in crafting funding opportunity announcements, reviewing applications, and evaluating the efficacy and impact of funded activities.

Use-inspired accelerator R&D for medical applications has been closely coordinated with the National Institutes of Health/National Cancer Institute (NIH/NCI); ultrafast laser technology R&D with the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA); and microwave and high power accelerator R&D coordinated with the National Nuclear Security Administration (NNSA) and DOD, the Department of Homeland Security's Domestic Nuclear Detection Office in the Countering Weapons of Mass Destruction Office (DHS/CWMD), and the National Science Foundation/Mathematical and Physical Sciences (NSF/MPS) Division.

Discussions with the NCI, DOD, DHS, and NNSA on mission needs and R&D coordination in medical accelerators, laser technology, radioactive source replacement, and particle detector technologies led to a Basic Research Needs Workshop on Compact Accelerators for Security and Medicine[b] that was held in May 2019 to establish research priorities for accelerator R&D in this critical area. This workshop was co-sponsored by NNSA, DOD, DHS, and NIH, and has inspired follow-on funding opportunities at those agencies in addition to informing use-inspired basic R&D investments by the Accelerator Stewardship subprogram. These R&D and facility investments are guided through the participation of applied agencies in merit and facility operations reviews. In addition, to ensure R&D is aimed at a commercially viable product, accelerator R&D collaborations are expected to involve a U.S. company to guide the early-stage R&D.

**Program Accomplishments**
In FY 2022, the Accelerator Stewardship and Accelerator Development subprograms funded 45 institutions, including 19 private companies, and 9 DOE national laboratories. The funded R&D efforts resulted in 3 patents, more than 40 publications, and more than 85 conference papers.

Technology translation activities have included collaborative R&D on proton therapy delivery systems (joint with Varian Medical Systems), advanced proton sources for therapy (joint with ProNova Solutions), advanced detectors for cancer therapy (joint with Best Medical International), advanced microwave source development (joint with Communications & Power Industries, L3Harris, and General Atomics), advanced laser technology development (with IPG Photonics and General Atomics), and technical design studies for high power accelerators for wastewater treatment (joint with Metropolitan Water Reclamation District of Greater Chicago, the Air Force Research Laboratory, and General Atomics). Public-private partnerships have begun with U.S. companies Radiation Monitoring Devices and Communications & Power Industries to strengthen key domestic suppliers of accelerator technology.

The BNL-ATF user facility provided a total of 1,972 user hours in FY 2022, supporting a range of basic R&D and commercial technology development, and providing a training ground for the next generation of scientists. The facility supported 25 active experiments, which produced 13 publications. Since 2014, BNL-ATF has provided more than 21,428 user beamtime hours.

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[a] https://www.osti.gov/servlets/purl/1863553
[b] https://science.osti.gov/-/media/hep/pdf/Reports/2020/CASM_WorkshopReport.pdf

## Accelerator R&D and Production

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Accelerator R&D and Production** | **$27,436** | **$34,270** | **+$6,834** |
| Accelerator Stewardship | $21,554 | $28,188 | +$6,634 |
| *Research* | *$15,554* | *$19,754* | *+$4,200* |
| Funding supports new research activities at laboratories, universities, and in the private sector on cross-cutting accelerator technologies such as superconducting magnets and accelerators, beam physics, data analytics-based accelerator controls, new particle sources, advanced laser technology R&D, and transformative R&D. Funding also supports the FAIR initiative to provide focused investment on enhancing research and workforce development at HBCUs, MSIs and Emerging Research Institutions. | | The Request will support new research activities at laboratories, universities, and in the private sector on cross-cutting accelerator technologies such as superconducting magnets and accelerators, beam physics, data analytics-based accelerator controls, new particle sources, advanced laser technology R&D, and transformative R&D. The Request will continue support for the FAIR initiative and ramps up support for the RENEW initiative, providing focused investment on enhancing research capabilities and workforce development at HBCUs, MSIs, and Emerging Research Institutions. | The Accelerator Stewardship program will fund a modest increase in FAIR initiative activities and increase support for critical R&D on ultrafast laser technology. The RENEW initiative will increase support of workforce development in accelerator science and engineering that focuses resources on HBCUs, MSIs, and Emerging Research Institutions to diversify the workforce. |
| *Facility Operations and Experimental Support* | *$6,000* | *$8,434* | *+$2,434* |
| Funding supports the BNL-ATF operations at optimal levels. | | The Request will support the BNL-ATF operations for the maximum number of user hours and permit significant progress addressing deferred maintenance issues that adversely impact facility availability. | Funding will support increased operating costs, and critical deferred maintenance to enable significant improvements in facility reliability and availability. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Accelerator Production | $5,882 | $6,082 | +$200 |
| *Research* | *$5,882* | *$6,082* | *+$200* |
| Funding supports increase for partnerships and collaborative R&D efforts to develop additional suppliers for critical accelerator technologies for SC scientific facilities. Increased investments allow technology transfer to proceed faster and across a broader range of component and subsystem technologies. Critical areas include advanced superconducting wire and cable, superconducting RF cavities and associated components, and high efficiency radiofrequency power sources for accelerators. Research partnerships to industrialize technologies for water purification, groundwater decontamination, and wastewater treatment begin. | | The Request will increase the number of partnerships and collaborative R&D efforts to work with and strengthen domestic suppliers for critical accelerator technologies for SC scientific facilities. Increased investments will allow more of the identified supply chain risks to be addressed. Critical areas include advanced superconducting wire and cable, superconducting RF cavities and associated components, and high efficiency RF power sources for accelerators. | The number and breadth of supply chain risk reduction activities will continue to ramp up, addressing more of the high-risk accelerator technologies needed for SC facilities. |

*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, excluding facility operations.*

**Accelerator R&D and Production**
**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 2022 Enacted | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Scientific User Facilities - Type A** | | | | | |
| **Accelerator Test Facility** | **5,797** | **7,239** | **6,410** | **8,844** | **+2,434** |
| Number of Users | 80 | 87 | 87 | 112 | +25 |
| Achieved Operating Hours | – | 1,972 | – | – | – |
| Planned Operating Hours | 1,800 | 1,800 | 1,900 | 2,100 | +200 |
| Unscheduled Down Time Hours | – | 398 | – | – | – |
| **Total, Facilities** | **5,797** | **7,239** | **6,410** | **8,844** | **+2,434** |
| Number of Users | 80 | 87 | 87 | 112 | +25 |
| Achieved Operating Hours | – | 1,972 | – | – | – |
| Planned Operating Hours | 1,800 | 1,800 | 1,900 | 2,100 | +200 |
| Unscheduled Down Time Hours | – | 398 | – | – | – |

*Notes:*
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*
- *The Accelerator Test Facility will undergo an Accelerator Readiness Review in FY 2023, necessitating a reduction in planned operating hours as extensive preparation and review activities take place.*

**Accelerator R&D and Production**
**Scientific Employment**

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Number of Permanent Ph.Ds (FTEs) | 9 | 14 | 17 | +3 |
| Number of Postdoctoral Associates (FTEs) | 3 | 4 | 6 | +2 |
| Number of Graduate Students (FTEs) | 15 | 23 | 28 | +5 |
| Number of Other Scientific Employment (FTEs) | 15 | 23 | 28 | +5 |
| **Total Scientific Employment (FTEs)** | **42** | **64** | **79** | **+15** |

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

## Workforce Development for Teachers and Scientists

### Overview

The mission of the Workforce Development for Teachers and Scientists (WDTS) program is to ensure that Department of Energy (DOE) has a sustained pipeline for the science, technology, engineering, and mathematics (STEM) workforce. Accomplishing this mission depends on continued support for undergraduate internships, graduate thesis research opportunities, and visiting faculty research appointments; administration of the Albert Einstein Distinguished Educator Fellowship for K–12 STEM teachers for the federal government; and annual, nationwide, middle, and high school science competitions culminating in the National Science Bowl® finals in Washington, D.C. These activities support the development of the next generation of scientists and engineers to address the DOE mission, administer programs, and conduct research.

WDTS activities rely significantly on DOE's 17 national laboratories and scientific user facilities, which employ more than 30,000 individuals with STEM backgrounds. The DOE laboratory system provides access to leading scientists, world-class scientific user facilities and instrumentation, and large-scale, multidisciplinary research programs unavailable in universities or industry. WDTS leverages these assets to develop and train post-secondary students and educators in support of the DOE mission. The WDTS discovery learning-based STEM training programs enable highly qualified applicants to conduct research at DOE laboratories and facilities in support of the DOE workforce development mission.

### Highlights of the FY 2024 Request

The FY 2024 Request for $46.1 million prioritizes funding for programs that place highly qualified applicants in STEM learning and authentic research experiences at DOE laboratories and expands training opportunities to students and faculty from Minority Serving Institutions (MSIs) and individuals from underrepresented, underserved groups. The Request increases support for the Reaching a New Energy Sciences Workforce (RENEW) initiative, which will significantly increase outreach to and workforce training opportunities for underrepresented and underserved groups, described further below. The Request continues strong support for undergraduate internships, graduate thesis research, and visiting faculty program to help sustain a skilled workforce pipeline. The Request increases support for the technology infrastructure modernization and evaluation activity, which is critically important for evidence-based management and evaluation practice to sustain the workforce training programs at DOE laboratories. It also prioritizes support for the DOE National Science Bowl®, a signature STEM competition testing middle and high school students' knowledge in science and mathematics. By encouraging and preparing students to pursue STEM careers, these programs address the DOE's STEM mission critical workforce pipeline needs required to advance science innovation and energy, environment, and national security.

## Workforce Development for Teachers and Scientists
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Workforce Development for Teachers and Scientists** | | | | |
| Science Undergraduate Laboratory Internship (SULI) | 14,000 | 15,700 | 16,000 | +300 |
| Community College Internship Program (CCI) | 2,000 | 2,200 | 2,300 | +100 |
| Visiting Faculty Program (VFP) | 2,100 | 2,100 | 2,100 | – |
| Office of Science Graduate Student Research (SCGSR) Program | 5,000 | 5,000 | 6,100 | +1,100 |
| Reaching a New Energy Sciences Workforce (RENEW) | 5,000 | 10,000 | 12,000 | +2,000 |
| **Internships and Visiting Faculty Activities at DOE Labs** | **28,100** | **35,000** | **38,500** | **+3,500** |
| **Albert Einstein Distinguished Educator Fellowship** | **1,200** | **1,200** | **1,200** | **–** |
| **National Science Bowl** | **2,900** | **3,000** | **3,100** | **+100** |
| **Technology Development and On-Line Application** | **700** | **700** | **1,000** | **+300** |
| **Evaluation** | **600** | **600** | **800** | **+200** |
| **Outreach** | **1,500** | **1,500** | **1,500** | **–** |
| **Total, Workforce Development for Teachers and Scientists** | **35,000** | **42,000** | **46,100** | **+4,100** |

**Program Accomplishments**

***Science Undergraduate Laboratory Internship (SULI)*** — In FY 2022, approximately 1,059 placements were supported, of which 20.4 percent were from MSIs and approximately 27 percent were women. Among the participants, more than 98 percent reported positive impacts to their educational and career goals, and 99.6 percent would recommend SULI to their peers. As in prior years, participants continue to make notable contributions to research projects as evidenced by co-authorship in peer reviewed journals, patents, and/or presentations at scientific meetings. In the Summer 2022 Term application period, the SULI program opened to freshman undergraduate students from 4-year institutions and community colleges. DOE national laboratories recommended the change, noting that other Federal undergraduate research programs are open to freshmen.

***Community College Internship Program (CCI)*** — In FY 2022, 105 placements were supported, with 57.1 percent from MSIs. Among the participants, about 99 percent would recommend CCI to their peers and more than 98 percent reported positive impacts to their educational and career goals. Nearly 95 percent of participants reported that they would consider a job or career at their host DOE laboratory or facility.

***Visiting Faculty Program (VFP)*** — In FY 2022, 63 faculty and 24 student placements were supported, and of these participants, 46.0 percent of the faculty were from MSIs and 23.8 percent from historically black colleges and universities (HBCUs). Among the faculty participants, 17.5 percent were Black or African American and 23.8 percent were women. All VFP Faculty participants reported a positive impact on their careers, and all expressed interest in continuing their research collaboration. All would recommend VFP to their peers.

***Office of Science Graduate Student Research (SCGSR) Program*** — During FY 2022, the second solicitation of FY 2021 resulted in 80 new awards with nearly 40 percent going to female graduate students; the first of the two annual solicitations of FY 2022 was released, currently going through review and selection process, and the second solicitation is on schedule for release in August. In late FY 2022, the SCGSR program implemented an increase of the current monthly stipend of active awardees due to increasing housing and other general living costs. The increased stipend level will enable the SCGSR program to attract more diverse applicants, particularly those from underserved communities, and advance SC's diversity, equity, inclusion, and accessibility objectives for the energy sciences workforce.

***Reaching a New Energy Sciences Workforce (RENEW)*** — In FY 2022, WDTS, in collaboration with DOE national laboratories, organized a total of 10 listening sessions with MSIs, community colleges, and underrepresented groups for understanding barriers that prevent underrepresented and underserved groups from participating in WDTS workforce development programs. In addition, WDTS, in collaboration with SC research programs, organized two webinars focused on HBCUs and Tribal Colleges respectively. Based on the feedback received, WDTS developed new activities to address major barriers in three areas: (i) coordinating the evaluation and assessment of the RENEW initiative with all SC research programs and DOE national laboratories; (ii) developing WDTS RENEW Pathway summer schools for high school and early undergraduate students at DOE national laboratories; and (iii) developing WDTS RENEW Pathway for faculty from higher education institutions underrepresented in research and STEM (including all HBCUs). The above efforts are ongoing and will inform the further development and implementation of the RENEW initiative.

***Albert Einstein Distinguished Educator Fellowship (AEF)*** — In FY 2022, one of the six WDTS-sponsored AEF participants held a WDTS office appointment. The hosting Federal agencies included DOE, Library of Congress, Department of Defense, Department of Homeland Security, U.S. Geological Survey, National Air and Space Museum, and National Aeronautics and Space Administration. Upon the establishment of a Memorandum of Understanding (MOU), the Department of Homeland Security hosted their first Fellow in FY 2022. During the pandemic, the AEF participants of the 2021-2022 cohort engaged with their host federal agencies or Congressional offices remotely and actively participated in the program's professional development activities.

***National Science Bowl®(NSB)*** — In FY 2022, more than 2,700 middle school students (from 504 schools) and 5,200 high school students (from 941 schools) participated in 108 regional competitions, with 46 middle school teams and 62 high school teams advancing to the virtual National Semi-Finals in May 2021. Forty-nine U.S. States, the District of Columbia, and Puerto Rico were represented at regionals. More than 2,000 volunteers also participated in the local and national competitions. In early July 2022, the National Science Bowl® Championship Finals were successfully held at William F. Bolger Center in Potomac, Maryland, and feature a live web-streaming broadcast of the event to a broad public audience. The top 9 middle school teams and the top 8 high school teams from the semi-finals competed in 2022 NSB finals, which was the first in-person event since the COVID-19 pandemic. Despite the challenging circumstances, the NSB continued to inspire young students nationwide to continue striving for their high levels of academic success and encourage them to follow their passions in STEM, and hopefully, to consider a career to support the DOE mission.

***Technology Development and On-Line Application*** — In FY 2022, the upgrade of the online platform was started and the transition of the existing online application system is expected to continue through FY 2023. The upgrade is long overdue and once completed, will significantly increase the cybersecurity and modernization of the online technology supporting all WDTS programs. New modules using the Data Analysis and Visualization (DAV) capability have been developed and have demonstrated their usefulness in providing annual program data summary reports to all host DOE national laboratories, compiling data for WDTS evaluation projects, and producing information to address inquiries from internal and external stakeholders. In FY 2022, the technical development for an improved NSB online registration system to better support regional and national participants was completed.

***Evaluation*** — In FY 2022, WDTS, in collaboration with the evaluation experts at the Oak Ridge Institute for Science and Education (ORISE), continued its work plan for building and sustaining a comprehensive evaluation portfolio to support evidence-based management and evaluation of workforce development programs and initiatives in WDTS and SC. A set of evaluation projects based on pre- and post-survey were completed, including assessing how undergraduate internships affected participants on their STEM skills/knowledge, career goals, and diversity and inclusion, and outcome analysis of where they are. In FY 2022, WDTS completed the internal review of a proposed longitudinal evaluation study plan of the impacts of WDTS-sponsored undergraduate internship programs at DOE national laboratories and the external peer review is ongoing. An important evaluation activity is to coordinate with SC research programs on the assessment and evaluation for the RENEW initiative, leveraging the knowledge, infrastructure, and capabilities built through the evaluation activity and plan for the current WDTS programs.

***Outreach*** — In FY 2022, in collaboration with ORISE, DOE laboratories, and higher education institutions, WDTS supported and co-hosted a series of virtual events (IGNITE Off, Virtual Internship Fair, Virtual Intern Panel and Networking, and Virtual Graduate Student Recruitment Fair) to actively engage MSIs and individuals from underrepresented groups, and to enable equitable access to workforce training opportunities by all. WDTS completed the update of a comprehensive MSI database that compiled the MSI designations, Carnegie Classification, institutional information from the Department of Education's Integrated Post-Secondary Data System, and the contact information of key STEM leaders at all MSIs. The MSI database has been shared as a resource with all other SC programs and DOE national laboratories to support the engagement efforts with MSIs and to promote diversity, equity, inclusiveness, and accessibility to SC research and STEM workforce training opportunities. The outcome of the WDTS annual proposal call has resulted in a comprehensive set of outreach activities led by DOE host laboratories. They focus on: expanding model outreach practices "mini-semester" over winter break and training past participants to serve as WDTS program "ambassadors" on social media and at in-person events at their home institutions; introducing faculty from institutions historically underrepresented in the research enterprise to unique lab capabilities and facilities; creating pipeline programs for high school students to remain engaged with lab programming and receive support in applying for a SULI or CCI internship and raising awareness of SC and WDTS opportunities among the professional societies with a strong focus on underrepresented and underserved students, faculty, and institutions, including *The National Diversity in STEM* of 2022 SACNAS (Society for Advancement of Chicanos/Hispanics & Native Americans in Science)/*The 2022 National Conference* of AISES (Advancing Indigenous People in STEM), *The 49th Annual Meeting of NOBCChE (the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers) and The 2022 National Convention* of the NSBE (National Society of Black Engineers).

## Workforce Development for Teachers and Scientists

### Description

**Activities at the DOE Laboratories**

WDTS supports activities such as the SULI program, the CCI program, the VFP, the SCGSR program, and RENEW. One of the primary goals of these programs is to prepare students to enter STEM careers that are especially relevant to the DOE mission. By providing research experiences at DOE laboratories under the direction of scientific and technical laboratory staff who serve as research advisors and mentors, these activities provide opportunities for participants to engage in research requiring specialized instrumentation; large-scale, multidisciplinary efforts; and/or scientific user facilities. WDTS activities are aligned with the STEM workforce training recommendations of the Federal Advisory Committees of SC's research program offices, the strategic objectives of the National Science and Technology Council's Committee on STEM Education (CoSTEM) Federal STEM Education 5-Year Strategic Plan, and the Administration's goals for educating and training a diverse and skilled U.S. workforce for the 21st century economy.

SULI places students from two- and four-year undergraduate institutions as paid interns in science and engineering research activities at DOE laboratories, working with laboratory staff scientist and engineer mentors on projects related to ongoing research programs. Appointments are for ten weeks during the summer term and 16 weeks during the fall and spring terms.

CCI places community college students as paid interns in technological activities at DOE laboratories, working under the supervision of a laboratory technician or researcher mentor. CCI provides dedicated technical training for community college students who are interested in technical careers and provides a pathway for those who plan to pursue further educational objectives beyond community college.

The VFP goal is to increase the research competitiveness of faculty members and students at U.S. institutions of higher education historically underrepresented in the research community, including MSIs. Through direct collaboration with research staff at DOE host laboratories, VFP appointments provide an opportunity for faculty and their students to develop skills applicable to programs at their home institutions. VFP helps increase the STEM workforce in DOE science mission areas at institutions historically underrepresented within the DOE enterprise. Appointments are in the summer term for ten weeks, and faculty may participate in the program for up to three terms.

SCGSR's goal is to prepare graduate students for STEM careers critically important to the SC mission by providing graduate thesis research opportunities at DOE laboratories. The SCGSR program provides supplemental awards for graduate students to pursue part of their graduate thesis research at a DOE laboratory or facility in areas that address scientific challenges central to the SC mission. U.S. graduate students pursuing Ph.D. degrees in physics, chemistry, materials sciences, non-medical biology, mathematics, computer or computational sciences, or specific areas of environmental sciences aligned with the SC mission, are eligible for research awards to conduct part of their graduate thesis research at a DOE laboratory or facility in collaboration with a DOE laboratory scientist. Research award terms range from three months to one year. SCGSR continues support of graduate research opportunities at DOE national laboratories in high-need SC mission areas for workforce development, such as basic research for clean energy, climate science, artificial intelligence/machine learning, quantum information science as well as convergence research areas to address workforce needs for SC's long-range vision on emerging frontiers in science discovery and innovation that increasingly require transdisciplinary approaches.

As an active participant in the SC-wide RENEW initiative, WDTS coordinates with SC research programs and DOE national laboratories to develop SC mission research focused training opportunities for undergraduate and graduate students from population groups and academic institutions not currently well represented in the U.S. S&T ecosystem. WDTS has a unique role to play by significantly expanding SC outreach to students and educators from underrepresented and underserved groups and enabling additional pathways to help them advance along the STEM workforce development pipeline. Additionally, WDTS will, in collaboration with DOE laboratories and SC research programs, continue to develop and implement strategies and mechanisms to remove barriers and facilitate increased application/participation by underrepresented and underserved groups, including experimenting with new training models or elements to enable application/participation. Funding will also support DOE National Laboratory-based research or technical training experiences for preparing future scientists, technicians, and professionals to support DOE mission needs.

**Albert Einstein Distinguished Educator Fellowship**

The Albert Einstein Distinguished Educator Fellowship Act of 1994 charges DOE with administering a fellowship program for elementary and secondary school mathematics and science teachers that focuses on bringing teachers' real-world expertise to government to help inform federal STEM education programs. Selected teachers spend 11 months in a Federal agency or a Congressional office. WDTS manages the Albert Einstein Distinguished Educator Fellowship Program for the Federal government. DOE and other Federal agencies support these Fellows. SC sponsors placement opportunities in WDTS and in Congressional offices. Other Federal agencies sponsor placement opportunities in their own offices. Participating agencies include the National Science Foundation (NSF), National Aeronautics and Space Administration, the Library of Congress, the Department of Defense, the Smithsonian, the U.S. Geological Survey, and the Department of Homeland Security. The Fellows provide educational expertise, years of teaching experience, and personal insights to these offices to advance Federal science, mathematics, and technology education programs.

**National Science Bowl®**

The DOE National Science Bowl® is a nationwide academic competition testing students' knowledge in all areas of mathematics and science, including energy. High school and middle school students are quizzed in a fast-paced, question-and-answer format. Approximately 320,000 students have participated in the National Science Bowl® throughout its 32-year history, and it is one of the Nation's largest science competitions. WDTS manages the National Science Bowl® and sponsors the National Science Bowl® finals competition. Regional competitions rely upon volunteers and are supported by numerous local organizations, both public and private.

The National Science Bowl® regional winning teams receive expenses-paid trips to Washington, D.C. to compete at the National Finals in late April. Competing teams are composed of four or five students and a teacher who serves as an advisor and coach. WDTS provides central management of its regional events.

**Technology Development and On-Line Application**

This activity modernizes on-line systems used to manage application solicitations, review applications, and facilitate data collection, curation, and compilation to support evaluation for WDTS programs. A project to develop, build, and launch new online application and program support systems continues, with evolving new elements that improve accessibility to applicants, advance program oversight and assessment by WDTS program staff, and allow more efficient management and execution of programs by DOE laboratory staff. An important feature of the systems is the integration of a data analysis and visualization capability to support evidence-based management and evaluation of programs.

**Evaluation**

The evaluation activity supports work to assess whether WDTS programs meet established goals. This is accomplished through triennial reviews of its program performers, of WDTS itself, and of program performance. These reviews involve peer reviews and Federal Advisory Committee-commissioned Committee of Visitors reviews. In addition, as an important part of assessing STEM workforce training programs, activities are supported to measure short-term program outcomes and assess longer-term program impact. The supported activities include the compilation and analysis of data and other materials, including pre- and post-participation surveys, participant deliverables, notable outcomes (publications, presentations, patents, etc.), and longitudinal participant tracking/outcome analysis. WDTS is also tracking and reporting how its programs, and activities at DOE labs and SC scientific user facilities, fulfill program goals and objectives.

The evaluation activity is aligned with the Government Performance and Results Act Modernization Act of 2010, which emphasizes the need for federal programs (including STEM education programs) to demonstrate their effectiveness through rigorous evidence-based evaluation. WDTS works cooperatively with SC programs, other DOE programs, and other federal agencies through CoSTEM to share best practices for STEM program evaluation to ensure the implementation of evaluation processes appropriate to the nature and scale of the program effort.

In support of the RENEW initiative, the knowledge, infrastructure, and capabilities built through the evaluation activity for the current WDTS programs will be leveraged to help set the goals and craft strategies for assessing the new activities, in coordination with SC research programs and offices.

**Outreach**

WDTS engages in outreach activities, some in cooperation with other DOE program offices and select federal agencies, to widely publicize its opportunities. The WDTS website (https://science.osti.gov/wdts) is the most widely used tool for prospective program participants to obtain information about WDTS, and it provides a gateway to accessing the online applications for the WDTS programs. To help diversify the applicant pool and provide equitable access, outreach is conducted via multiple venues, with intentional brand messaging, such as hosting panels for and giving presentations to targeted stakeholder groups, sharing information with professional societies, and using virtual platforms to host internship and career fairs. WDTS leverages SC's social media resources to amplify the program opportunities to a broad range of stakeholders, including SC research grantees, scientific professional societies, HBCUs and other MSIs, and community colleges with a focus on underrepresented and underserved groups.

WDTS also annually solicits proposals from DOE host laboratories and facilities to develop and execute outreach activities aimed at recruiting more diverse, equitable, and inclusive applicant and participant pools for WDTS laboratory-based programs, and to encourage WDTS program participants to pursue careers supporting the SC and DOE mission, including staffing needs at DOE national laboratories. Emphasis of laboratory outreach activities is on reaching potential applicants who are underrepresented in STEM fields, including building partnerships and targeted outreach to MSIs. Eligible DOE laboratories and facilities are those that host participants in the SULI, CCI, VFP, and/or SCGSR programs. Based upon reported outcomes of annually completed activities, a portfolio of model practices is evolving to help ensure that WDTS activities are fully open and accessible to all eligible students and faculty.

The Laboratory Equipment Donation Program (LEDP) is operated under Outreach and provides excess laboratory equipment to STEM faculty at accredited post-secondary educational institutions. Through the General Services Administration Energy Asset Disposal System, DOE sites identify excess equipment and colleges, and universities can then search for equipment of interest and apply via the website. The equipment is free, but the receiving institutions pay for shipping costs.

## Workforce Development for Teachers and Scientists

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Workforce Development for Teachers and Scientists** | **$42,000** | **$46,100** | **+$4,100** |
| Activities at the DOE Laboratories | $35,000 | $38,500 | +$3,500 |
| *Science Undergraduate Laboratory Internship (SULI)* | *$15,700* | *$16,000* | *+$300* |
| Funding for SULI supports approximately 1,035 students with an increased allocation per participant. Over the years, the cost of supporting interns at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support (stipend and allowance for housing/travel) to individual interns in comparison to other internships programs (such as those supported by NSF and other agencies). | | The Request for SULI will support approximately 1,054 students. | Funding will support 19 more students. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| *Community College Internship Program (CCI)* | *$2,200* | *$2,300* | *+$100* |
| Funding for CCI supports approximately 167 students with an increased allocation per participant. Over the years, the cost of supporting interns at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support to individual interns in comparison to other internships programs (such as those supported by NSF and other agencies). | | The Request for CCI will support approximately 174 students. | Funding will support 7 more students. |
| *Visiting Faculty Program (VFP)* | *$2,100* | *$2,100* | *$ —* |
| Funding for the VFP supports approximately 66 faculty and 32 students with an increased allocation per participant. Over the years, the cost of supporting visiting faculty members at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support to individual faculty members in comparison to similar programs. | | The Request for the VFP will support approximately 66 faculty and 32 students. | No change. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| *Office of Science Graduate Student Research (SCGSR) Program* *$5,000* | *$6,100* | *+$1,100* |
| Funding for the SCGSR program supports approximately 190 graduate students. Targeted priority research areas will be informed by SC's workforce training needs studies. | The Request for the SCGSR program will support approximately 190 graduate students with an increased allocation per participant. Over the years, the cost of living to conduct graduate thesis research at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support to individual graduate awardees in comparison to similar programs. Targeted priority research areas will be informed by SC's workforce training needs studies. | Funding will support the same number of SCGSR participants due to the increased allocation per participant. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| *Reaching a New Energy Sciences Workforce (RENEW)* *$10,000* | *$12,000* | *+$2,000* |
| Funding supports continued implementation of the FY 2022 RENEW initiative and a planned growth of the existing workforce training programs/activities. Building upon the core science and technology capabilities at DOE national laboratories, the RENEW Pathway Summer Schools will enable equitable access to the best expertise and tools for discovery science driven learning in STEM. WDTS RENEW Pathways for faculty from underrepresented institutions will include 1) the expansion of the existing VFP program to non-summer terms for extended engagement for faculty capacity building in research and 2) the addition of a new parallel track for VFP with the goal of helping faculty enhance and innovate their STEM teaching at home institution for better STEM learning and preparedness in STEM. WDTS' RENEW pathways will build and strengthen partnerships between DOE national laboratories and MSIs, two-year colleges, and other colleges and universities nationwide. | The Request will support continued implementation of the RENEW initiative and a planned growth of the existing workforce training programs/activities. WDTS will continue support for the RENEW Pathway Summer Schools for High School and Early Undergraduate Students at DOE National Laboratories as well as the RENEW Pathways for faculty programs. | Funding will increase to support an increase in the number of awards at MSIs and for individuals from underrepresented communities. |
| Albert Einstein Distinguished Educator Fellowship $1,200 | $1,200 | $ — |
| Funding supports 6 Fellows. | The Request will support 6 Fellows. | No change. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| National Science Bowl® | $3,000 | $3,100 | +$100 |
| Funding provides support to sponsor the National Finals and provide central management of over 110 virtual and in-person regional events, involving more than 14,000 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. | | The Request will provide support to sponsor the National Finals and provide central management of over 110 virtual and in-person regional events, involving more than 14,000 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. | The new venue for the National Finals in Potomac, Maryland, will have increased costs for additional lodging, and transportation. |
| Technology Development and On-Line Application | $700 | $1,000 | +$300 |
| Funding continues development and operation of the on-line systems and support new development to meet the evolving needs of the programs. | | The Request will continue development and operation of the on-line systems and support new development to meet the evolving needs of the programs. The online application and review system is the backbone infrastructure for the application, review, laboratory placement, award/participation management, outreach, and evaluation of WDTS workforce training programs at DOE national laboratories. | An increase of funding is necessary to sustain WDTS programs and activities. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Evaluation $600 | $800 | +$200 |
| Funding supports a comprehensive evaluation portfolio with short- and longer-term projects for assessing WDTS program performance and producing knowledge to inform evidence-based management and evaluation practice. | The Request will support a comprehensive evaluation portfolio with short- and longer-term projects for assessing WDTS program performance and producing knowledge to inform evidence-based management and evaluation practice. The evaluation activities are a key element directly in support of the Administration's priority for evidence-based management practice. A combination of program management assessments, regular short-term outcome measures, and longer-term program impact studies will provide vital knowledge on how well WDTS workforce training programs achieve their goals and guidance for working with DOE national laboratories to deliver better quality results. | An increase of funding is necessary to establish and execute a comprehensive evaluation portfolio in support of workforce development programs and activities. |
| Outreach $1,500 | $1,500 | $ — |
| Funding supports outreach activity proposal solicitations from DOE host labs and facilities. WDTS will maintain support of activities such as those that promote diversity, equity, and inclusion; and/or prioritize recruitment of STEM students to DOE research and development workforce mission-relevant fields of study, and particularly to fields related to SC research programs. Support continues for the LEDP program. | The Request will support outreach activity proposal solicitations from DOE host labs and facilities. WDTS will maintain support of activities such as those that promote diversity, equity, and inclusion; and/or prioritize recruitment of STEM students to DOE research and development workforce mission-relevant fields of study, and particularly to fields related to SC research programs. Support continues for the LEDP program. | No change. |

# Science Laboratories Infrastructure

## Overview

The Science Laboratories Infrastructure (SLI) program mission is to support scientific and technological innovation at the Office of Science (SC) laboratories by funding and sustaining general purpose infrastructure and fostering safe, efficient, reliable, and environmentally responsible operations. The main priorities of the SLI program are improving SC's existing physical assets (including major utility systems) and funding new cutting-edge facilities that enable emerging science opportunities. The SLI program funds line-item construction projects; General Plant Projects (GPP) (minor construction less than $30 million); Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories (ANL, BNL, and ORNL); Nuclear Operations at ORNL; landlord responsibilities across the Oak Ridge Reservation; and will support a new Laboratory Operations Apprenticeship program to begin in FY 2024.

SC manages an infrastructure portfolio worth nearly $31.8 billion, which is composed of 13 sites, including 10 national laboratories, with nearly 24 million gross square feet (gsf) in over 1,600 government-owned buildings and trailers. SC assets at the national laboratories include major research and user facilities, laboratory and office buildings, support facilities, and a vast network of utilities and other support facilities that form the backbone of each site. Delivering SC mission requires significant stewardship of research facilities, the renovation and replacement of general-purpose infrastructure, including buildings and support infrastructure.

SC laboratories conduct an annual assessment of the condition, utilization, and mission readiness, of their buildings and support infrastructure. The assessments show that 43 percent of the buildings are rated substandard or inadequate to meet mission needs. In addition, 71 percent of the utility systems are rated as substandard or inadequate while 35 percent of the remaining support infrastructure is rated as substandard or inadequate. The substandard and inadequate condition of facilities results in operational inefficiencies, reduced resiliency and reliability, unplanned outages, costly repairs, and elevated safety risks. In collaboration with SC programs and the laboratories, the SLI program plans and executes modernization projects to reduce the impacts of these deficiencies on the SC mission.

SC and the laboratories use the assessments to help develop comprehensive Campus Strategies required in the bi-annual laboratory planning process. To support the core capabilities and achieve the scientific vision, each laboratory's Campus Strategy identifies activities and infrastructure investments such as line-item construction and GPPs. SC leadership uses these Campus Strategies to inform the SLI budget requests.

To sustain and enhance its general-purpose infrastructure, SC invested nearly $801 million in maintenance, repair, and construction in FY 2022. These investments came from a variety of funding sources, including Federal appropriations for line-item construction, GPPs, laboratory overhead funding of Institutional GPP projects, and maintenance and repair. The SLI investments in line-item construction and GPPs are key elements of this overall investment strategy.

## Highlights of the FY 2024 Request

The SLI program Request continues to focus on improving infrastructure across the SC national laboratory complex. The FY 2024 Request supports ten ongoing construction projects:

1. Princeton Plasma Innovation Center at Princeton Plasma Physics Laboratory (PPPL);
2. Critical Infrastructure Recovery & Renewal at Princeton Plasma Physics Laboratory (PPPL);
3. Ames Infrastructure Modernization at Ames National Laboratory (AMES);
4. Seismic and Safety Modernization project at Lawrence Berkeley National Laboratory (LBNL);
5. CEBAF Renovation and Expansion project at Thomas Jefferson National Accelerator Facility (TJNAF);
6. Argonne Utilities Upgrade project at Argonne National Laboratory (ANL);
7. Linear Assets Modernization Project at Lawrence Berkeley National Laboratory (LBNL);
8. Critical Utilities Infrastructure Revitalization Project at SLAC National Accelerator Laboratory (SLAC);
9. Utilities Infrastructure Project at Fermi National Accelerator Laboratory (FNAL); and
10. Biological and Environmental Program Integration Center at Lawrence Berkeley National Laboratory (LBNL).

These ongoing line-item projects will upgrade and improve utility systems and facilities and provide new laboratory space with the necessary performance capabilities to enhance SC's mission.

The FY 2024 Request also includes funding for GPPs which are an essential component of our infrastructure modernization portfolio to address targeted and emerging, high priority core infrastructure and utility needs across SC laboratories and facilities. Infrastructure needs for all laboratories are evaluated annually by SLI. GPP projects are evaluated and prioritized through data analysis of criteria including mission readiness, cost savings (including energy and water), environment safety and health issues, sustainability (including net zero initiatives), resilience, and reliability.

## Science Laboratories Infrastructure
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Science Laboratories Infrastructure** | | | | |
| Payment In Lieu of Taxes (PILT) | 4,820 | 4,891 | 5,004 | +113 |
| OR Landlord | 6,430 | 6,559 | 6,910 | +351 |
| Facilities and Infrastructure | 14,450 | 13,900 | 32,104 | +18,204 |
| Laboratory Operations Apprenticeship | – | – | 3,000 | +3,000 |
| Oak Ridge Nuclear Operations | 26,000 | 26,000 | 46,000 | +20,000 |
| **Subtotal, Science Laboratories Infrastructure** | **51,700** | **51,350** | **93,018** | **+41,668** |
| **Construction** | | | | |
| 22-SC-71 Critical Infrastructure Modernization Project (CIMP) - ORNL | 1,000 | 1,000 | – | -1,000 |
| 22-SC-72 Thomas Jefferson Infrastructure Improvements (TJII) - TJNAF | 1,000 | 1,000 | – | -1,000 |
| 21-SC-71 Princeton Plasma Innovation Center (PPIC), PPPL | 7,750 | 10,000 | 15,000 | +5,000 |
| 21-SC-72 Critical Infrastructure Recovery & Renewal (CIRR), PPPL | 2,000 | 4,000 | 10,000 | +6,000 |
| 21-SC-73 Ames Infrastructure Modernization (AIM) | 2,000 | 2,000 | 8,000 | +6,000 |
| 20-SC-71 Critical Utilities Rehabilitation Project (CURP), BNL | 26,000 | 26,000 | – | -26,000 |
| 20-SC-72 Seismic and Safety Modernization (SSM), LBNL | 18,000 | 27,500 | 40,000 | +12,500 |
| 20-SC-73 CEBAF Renovation and Expansion (CEBAF), TJNAF | 10,000 | 15,000 | 11,000 | -4,000 |
| 20-SC-75 Large Scale Collaboration Center (LSCC), SLAC | 21,000 | 21,000 | – | -21,000 |
| 20-SC-76 Tritium System Demolition and Disposal (TSDD), PPPL | 6,400 | – | – | – |

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
| 20-SC-77 Argonne Utilities Upgrade (AU2), ANL | 10,000 | 8,000 | 8,007 | +7 |
| 20-SC-78 Linear Assets Modernization Project (LAMP), LBNL | 10,400 | 23,425 | 18,900 | -4,525 |
| 20-SC-79 Critical Utilities Infrastructure Revitalization (CUIR), SLAC | 8,500 | 25,425 | 35,075 | +9,650 |
| 20-SC-80 Utilities Infrastructure Project (UIP), FNAL | 10,500 | 20,000 | 45,000 | +25,000 |
| 19-SC-71 Science User Support Center (SUSC), BNL | 38,000 | – | – | – |
| 19-SC-73 Translational Research Capability (TRC), ORNL | 21,500 | – | – | – |
| 19-SC-74 - BioEPIC, LBNL | 35,000 | 45,000 | 38,000 | -7,000 |
| 17-SC-71 Integrated Engineering Research Center (IERC), FNAL | 10,250 | – | – | – |
| **Subtotal, Construction** | **239,300** | **229,350** | **228,982** | **-368** |
| **Total, Science Laboratories Infrastructure** | **291,000** | **280,700** | **322,000** | **+41,300** |

**Science Laboratories Infrastructure**
**Explanation of Major Changes**

| | (dollars in thousands) FY 2024 Request vs FY 2023 Enacted |
|---|---|
| **Infrastructure Support** | **+41,668** |
| The Request fully funds Oak Ridge nuclear operations through the Office of Science, increases funding for GPPs to address targeted and emerging high-priority infrastructure needs across the SC complex, and begins a Laboratory Operations Apprenticeship to support trade and craft employee development. | |
| **Construction** | **-368** |
| Funding supports 10 ongoing line-item projects at Ames, ANL, FNAL, LBNL, PPPL, SLAC, and TJNAF. | |
| **Total, Science Laboratories Infrastructure** | **+41,300** |

**Program Accomplishments**

Since FY 2006, the SLI program has invested nearly $1.95 billion in general purpose infrastructure, excluding GPPs, across the SC-stewarded laboratory complex. These investments have provided state-of-the-art science user support facilities, renovated, and repurposed aged facilities, upgraded inadequate core infrastructure and systems, and removed excess.

**Line-Item Construction Projects**

Since FY 2006, the SLI program has successfully completed 16 line-item construction projects and was honored with 13 DOE Secretary's Achievement Awards. These investments began following an FY 2006 SC decision to modernize infrastructure across the SC-stewarded laboratory complex. With these investments, the SLI program constructed approximately more than 1.8 million gsf of new and modernized existing space. As a result, an estimated 2,900 laboratory users and researchers now occupy newly constructed and/or modernized buildings that better support scientific and technological innovation in a collaborative environment.

**GPP upgrades across SC Laboratories**

Since FY 2016, SLI has funded nearly $215 million in 37 laboratory core infrastructure improvement projects including $137 million in electrical and utility improvements, $35 million in building renovations, $29 million in safety and environmental projects and $14 million in sustainability/resilience projects. Examples of recent SLI investments in core infrastructure include building heating, ventilation, and air conditioning (HVAC) upgrades at BNL; access control upgrades at Ames and Fermi and steam to hydronics conversion project at PNNL. SLI also funded an emergency generator upgrade project and building HVAC system improvements at LBNL and a cooling tower water reuse project at TJNAF.

## Science Laboratories Infrastructure
## Infrastructure Support

**Description**
This subprogram supports investments that focus on laboratory core infrastructure and operations. Continuing investments in core infrastructure (e.g., utility systems, site-wide services, and general-purpose facilities) ensure that facilities and utilities are either upgraded or replaced as they approach end-of-life. Upgraded facilities have improved reliability, resilience, efficiency, and performance. This subprogram also supports nuclear operations at ORNL, funds stewardship-type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation, begins a Laboratory Operations Apprenticeship program in FY 2024, and funds Payments In Lieu of Taxes (PILT).

Facilities and Infrastructure
This activity supports minor construction investments (general plant projects of less than $30 million) that address urgent and emerging core infrastructure needs. SC laboratories conduct rigorous condition assessments of their core infrastructure, which determine the need for investments in these basic systems that form the backbone of their campuses. The Science Laboratories Infrastructure program maintains an active list of critical core infrastructure investment needs. Projects are evaluated on mission readiness; cost savings (including energy and water); environment, safety, and health issues; sustainability (including net zero initiatives); resilience; and reliability. Projects are evaluated continuously, and the highest priority projects are selected for funding upon entry into the corresponding execution year.

Oak Ridge Nuclear Operations
To support critical DOE nuclear operations, this Request includes the full funding required to operate ORNL's non-reactor nuclear facilities (i.e., Buildings 7920, 7930, 3525, and 3025E) and the associated support facilities (i.e., Buildings 3502 and 7935). These facilities support a variety of users including SC programs, the National Nuclear Security Administration, the Office of Nuclear Energy, and other federal agencies. This funding supports maintenance and repair of hot cells and supporting systems and ensuring compliance with safety standards and procedures.

OR Landlord
This funding supports landlord responsibilities, including infrastructure for the 24,000-acre Oak Ridge Reservation and DOE facilities in the city of Oak Ridge, Tennessee. Activities include maintenance of roads, grounds, other infrastructure, and support and improvement of environmental protection, safety, and health.

Payment In Lieu of Taxes (PILT)
Funding within this activity supports SC stewardship responsibilities for PILT. The Department is authorized to provide discretionary payments to state and local government authorities for real property that is not subject to taxation because it is owned by the United States Federal Government and operated by the Department. Under this authorization, PILT is provided to communities around ANL, BNL, and ORNL to compensate for lost tax revenues for land removed from local tax rolls. PILT payments are negotiated between the Department and local governments based on land values and tax rates.

Laboratory Operations Apprenticeship
Funding will support the initiation of a Laboratory Operations Apprenticeship program to ensure the next generation of critical, highly skilled trade and craft employees is in place to replace the aging and retiring workforce throughout the SC laboratory complex.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Infrastructure Support** | **$51,350** | **$93,018** | **+$41,668** |
| Facilities and Infrastructure | $13,900 | $32,104 | +$18,204 |
| Funding supports the replacement of the emergency generator at the LBNL Hazardous Waste Building, the Steam to Hot Water Conversion project in the Physical Sciences Laboratory at PNNL and the Storm Water Reuse project at TJNAF. | | The Request will continue to support the highest priority core infrastructure needs across the SC complex. Projects being considered are: HVAC Upgrade Life Sciences Laboratory (Bldg. 331) (PNNL); Power Quality Compensation Equipment Installation (SLAC); Chiller Replacement (Bldg. 450) (ANL); Electrical Component Replacement 88 Inch Cyclotron User Facility (Bldg. B88) (LBNL). | Increased funding will support at least four general plant projects at multiple labs. |
| Oak Ridge Nuclear Operations | $26,000 | $46,000 | +$20,000 |
| Funding supports critical nuclear operations and provides funding to manage ORNL's nuclear facilities. | | The Request will provide full funding for ORNL's nuclear facilities from the Office of Science. | Funding will provide the full amount needed to support the most critical nuclear operations and facilities at ORNL. |
| OR Landlord | $6,559 | $6,910 | +$351 |
| Funding continues support of landlord responsibilities across the Oak Ridge Reservation. Activities include maintenance of roads, grounds, and other infrastructure; and support and improvement of environmental protection, safety, and health. | | The Request will continue to support of landlord responsibilities across the Oak Ridge Reservation and in Oak Ridge. Activities include maintenance of roads, grounds, other infrastructure, and support and improvement of environmental protection, safety, and health. | Funding will support OR landlord requirements. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| Payment In Lieu of Taxes (PILT) | $4,891 | $5,004 | +$113 |
| Funding supports PILT payments to communities around ANL, BNL, and ORNL. | | The Request will provide funding for PILT payments to communities around ANL, BNL, and ORNL. | Funding will support anticipated PILT requirements. |
| Laboratory Operations Apprenticeship | $ — | $3,000 | +$3,000 |
| No funding requested or appropriated in FY 2023. | | The Request will begin a new program to support technician- and craft-level apprenticeships in the SC complex. | FY 2024 will be the first year of funding to initiate the Laboratory Operations Apprenticeship program. |

**Description**
The SLI program funds line-item projects to maintain and enhance the general-purpose infrastructure at SC laboratories. SLI's infrastructure modernization construction projects are focused on the accomplishment of long-term science goals and strategies at each SC laboratory. The main objectives of the SLI program are improvement of SC's physical assets and funding of new cutting-edge facilities to enable emerging science opportunities. Modernizing infrastructure supporting the SC national laboratories will ensure the critical needs of the future science initiatives and world class user facilities are met for decades to come, while minimizing unwanted disruptions through resilience and reliability and ensuring safety.

The FY 2024 Request includes funding for ten ongoing line-item construction projects:
1. Princeton Plasma Innovation Center at PPPL;
2. Critical Infrastructure Recovery & Renewal at PPPL;
3. Ames Infrastructure Modernization at AMES;
4. Seismic and Safety Modernization at LBNL;
5. CEBAF Renovation and Expansion at TJNAF;
6. Argonne Utilities Upgrade at ANL;
7. Linear Assets Modernization Project at LBNL;
8. Critical Utilities Infrastructure Revitalization at SLAC;
9. Utilities Infrastructure Project at FNAL; and
10. Biological and Environmental Program Integration Center at LBNL.

No new line-item construction projects are included within this request.

<u>21-SC-71, Princeton Plasma Innovation Center, PPPL</u>
The Princeton Plasma Innovation Center (PPIC) will provide a multi-purpose facility to PPPL, with space for offices, medium bay research labs for diagnostics and fabrication, remote participation and collaboration, and research support to meet the SC mission and fulfill the research needs of the Fusion Energy Sciences (FES), Advanced Scientific Computing Research (ASCR), and Basic Energy Sciences (BES) programs.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on January 22, 2021. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the second quarter of FY 2024. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary TEC range for this project is $78,300,000 to $96,300,000 and the preliminary Total Project Cost (TPC) range is $80,500,000 to $98,500,000. These cost ranges encompass the most feasible preliminary alternative at this time. The preliminary TEC point estimate for this project is $96,300,000 and the preliminary TPC point estimate for this project is $98,500,000.

<u>21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL</u>
The Critical Infrastructure Recovery & Renewal (CIRR) project at PPPL will revitalize critical infrastructure that supports the PPPL campus. Upgrades that may be completed as part of the CIRR project include: the electrical distribution system; standby power; chilled water generation and distribution; distribution networks for steam, compressed air, sanitary waste, and condenser, storm, canal, and potable water; HVAC systems; and communication systems.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on February 23, 2021. The project's CD-2, Approve Performance Baseline, is anticipated in the first quarter of FY 2026. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary TEC range for this project is $80,100,000 to $96,000,000. The preliminary TPC range for this project is $81,800,000 to $97,700,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $87,300,000 and the preliminary TPC point estimate for this project is $89,000,000.

21-SC-73, Ames Infrastructure Modernization, AMES

The Ames Infrastructure Modernization (AIM) project will support the SC mission by providing a safer and more operationally efficient campus for the employees, visitors, and guests at Ames, as well as reduce deferred maintenance costs. This project is designed to support DOE mission-critical programs and initiatives, increase the reliability of utility infrastructure, minimize facility costs through effective and efficient operations, and modernize laboratories in Ames's research buildings, thereby enhancing Ames Laboratory's ability to continue to deliver on SC's mission across multiple program offices.

Specifically, this project will provide updated infrastructure building systems in existing research and operations buildings at Ames National Laboratory, such as plumbing systems; building envelopes; electrical systems-emergency, backup power, and uninterruptible power supplies; and telecommunication systems. In addition, some of the laboratory spaces will be modernized to support the SC mission.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, and was approved on September 16, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the third quarter of FY 2023. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary TEC range for this project is $22,000,000 to $89,000,000. The preliminary TPC range for this project is $26,400,000 to $86,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $30,000,000 and the preliminary TPC point estimate for this project is $31,000,000.

20-SC-72, Seismic and Safety Modernization, LBNL

The Seismic and Safety Modernization project will address seismic safety issues and emergency response capabilities at LBNL. Specifically, facilities with large congregation areas, facilities that are necessary for emergency response personnel, and facilities necessary to maintain continuity of operations will be improved. The facilities that are the primary focus of this project are the Cafeteria and Health Services.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-3A/R1, Approve Alternative Selection and Cost Range (Revised), and was approved on January 13, 2023, and CD-3A Approve Early Site Preparation. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $112,800,000 to $183,300,000 and the preliminary TPC range of $116,000,000 to $188,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $141,000,000 and the preliminary TPC point estimate for this project is $145,000,000.

20-SC-73, CEBAF Renovation and Expansion, TJNAF

The CEBAF Renovation and Expansion (CRE) project will renovate existing space and provide new research, administrative, and support service space enabling TJNAF to better support SC missions. The CEBAF center at TJNAF has inadequate utility systems that are experiencing frequent failures. This project will renovate 131,000 to 250,000 gross square feet (gsf) of existing space in the CEBAF center and the Applied Research Center (ARC), upgrade high risk utility systems, and provide 82,000 to 150,000 gsf of additional space for visitors, users, research, education, and support.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range and was approved on March 18, 2020. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the fourth quarter of FY 2023. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $46,600,000 to $99,500,000 and a preliminary TPC range of $69,300,000 to $102,800,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $87,000,000 and the preliminary TPC point estimate for this project is $90,300,000.

20-SC-77, Argonne Utilities Upgrade, ANL
The Argonne Utilities Upgrade project at ANL will revitalize and selectively upgrade ANL's existing major utility systems to increase the reliability, capability, and safety of ANL's infrastructure to meet the DOE's mission. The project will focus on systems such as steam, water, sanitary sewer, chilled water, and electrical systems.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on July 1, 2021. The preliminary estimate for CD-2, Approve Baseline, is anticipated in the third quarter of FY 2024 This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $172,000,000 to $290,250,000. The preliminary TPC range for this project is $173,000,000 to $291,250,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate is $215,000,000 and the TPC point estimate for this project is $216,000,000.

20-SC-78, Linear Assets Modernization Project, LBNL
The Linear Assets Modernization Project at LBNL will upgrade high priority utility systems to increase the reliability, capability, resiliency, and safety of LBNL's infrastructure to meet the DOE's mission. The project will upgrade utility systems including, but not limited to, domestic water, natural gas, storm drain, sanitary sewer, electrical, and communications.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on April 13, 2022. The project's CD-3A is anticipated in the first quarter of FY 2026. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $164,000,000 to $376,000,000. The preliminary TPC range for this project is $170,000,000 to $386,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC is $236,000,000 and the preliminary TPC estimate for this project is $242,000,000.

20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC
The primary objective of CUIR is to close infrastructure gaps to support multi-program science missions as technologies, instruments, experimental parameters, sensitivities, and complexity associated with evolving science demand increases required reliability, resiliency, and service levels in electrical, mechanical, and civil systems site wide. The CUIR project will address the critical campus-wide utility and infrastructure issues by replacing, repairing, and modernizing the highest risk water/fire protection, sanitary sewer, storm drain, electrical, and cooling water system deficiencies.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on January 21, 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $160,000,000 to $306,000,000. The preliminary TPC range for this project is $164,500,000 to $310,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC estimate is $204,000,000 and the preliminary TPC estimate for this project is $208,500,000.

20-SC-80, Utilities Infrastructure Project, FNAL
The Utilities Infrastructure Project at FNAL will modernize the highest risk major utility systems across the FNAL campus. Specifically, this project will evaluate the current condition of the industrial cooling water system, potable water distribution system, sanitary sewer and storm collection systems, natural gas distribution system, electrical distribution system, and the Central Utility Building. Selected portions of the systems will be modernized to assure safe, reliable, and efficient service to mission critical facilities. In addition, upgrades to obsolete, end-of-life components will increase capacity, reliability, and personnel safety at critical utilities.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on February 23, 2022. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the second quarter of FY 2024. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $248,000,000 to $403,000,000 and the preliminary TPC range of $252,000,000 to $411,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC estimate is $310,000,000 and the preliminary TPC estimate for this project is $314,000,000.

19-SC-74, BioEPIC, LBNL

The BioEPIC project is constructing a new, state-of-the-art facility with laboratory space to support high performance research by the BER, ASCR, and BES programs. LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the DOE mission. This facility is being constructed in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be co-located to the BioEPIC building. Co-location of researchers in this unique experimental facility, near other important SC assets, will increase synergy and efficiency, which will better facilitate collaborative research in support of the SC mission.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, Approve Performance Baseline and Approve Start of Construction, and was approved on September 13, 2021. The preliminary estimate for CD-4, Approve Start of Operations, is anticipated in the fourth quarter of FY 2027. The TEC for this project is $165,000,000 and the TPC for this project is $167,200,000.

## Science Laboratories Infrastructure
## Construction

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | | Explanation of Changes FY 2024 Request vs FY 2023 Enacted | |
|---|---|---|---|---|---|
| **Construction** | **$229,350** | | **$228,982** | | **-$368** |
| 21-SC-71, Princeton Plasma Innovation Center, PPPL | $10,000 | | $15,000 | | +$5,000 |
| Funding will support ongoing PED activities and initiate construction activities. | | The Request will support ongoing PED activities and continuation of construction activities. | | Funding will support the continuation of PED activities for this project and continuation of construction activities. This project received supplemental funding under the Inflation Reduction Act. | |
| 21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL | $4,000 | | $10,000 | | +$6,000 |
| Funding will support ongoing PED activities and initiate construction and associated activities. | | The Request will support ongoing PED activities and continuation of construction and associated activities. | | Funding will support the continuation of PED activities for this project and enable the continuation of construction and associated activities. | |
| 21-SC-73, Ames Infrastructure Modernization | $2,000 | | $8,000 | | +$6,000 |
| Funding will support ongoing PED and construction activities. | | Final funding for this project is requested to be received in FY 2024 to support construction activities. | | Funding Request will provide final funding for this project. This project received supplemental funding under the Inflation Reduction Act. | |
| 20-SC-71, Critical Utilities Rehabilitation Project, BNL | $26,000 | | $ — | | -$26,000 |
| Funding will support ongoing construction activities. | | Funding will support ongoing construction activities for this project. | | Project was fully funded in FY 2023. | |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| 20-SC-72, Seismic and Safety Modernization, LBNL | $27,500 | $40,000 | +$12,500 |
| Funding will support construction and associated activities. | | The Request will support construction and associated activities. | Funding Request will provide final funding for this project. This project received supplemental funding under the Inflation Reduction Act. |
| 20-SC-73, CEBAF Renovation and Expansion, TJNAF | $15,000 | $11,000 | -$4,000 |
| Funding will support ongoing PED and construction activities. | | The Request will support ongoing PED and construction activities. | Funding will support ongoing PED and construction activities for this project. This project received supplemental funding under the Inflation Reduction Act. |
| 20-SC-75, Large Scale Collaboration Center, SLAC | $21,000 | $ — | -$21,000 |
| Funding will support ongoing construction activities. | | Final funding for this project is requested to be received in FY 2023. | Project was fully funded in FY 2023. |
| 20-SC-77, Argonne Utilities Upgrade, ANL | $8,000 | $8,007 | +$7 |
| Funding will support ongoing PED activities. | | The Request will support ongoing PED and initiate construction and associated activities. | Funding will support the continuation of construction and associated activities. |
| 20-SC-78, Linear Assets Modernization Project, LBNL | $23,425 | $18,900 | -$4,525 |
| Funding will support ongoing PED activities and early construction activities. | | The Request will support ongoing PED activities and early construction activities. | Funding will support ongoing PED activities and the early construction activities for this project. |
| 20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC | $25,425 | $35,075 | +$9,650 |
| Funding will support ongoing PED activities and initiate early construction activities. | | The Request will support ongoing PED activities and continuation of early construction activities. | Funding will support ongoing PED activities and the continuation of early construction activities for this project. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| 20-SC-80, Utilities Infrastructure Project, FNAL $20,000 | $45,000 | +$25,000 |
| Funding will support ongoing PED activities and initiate early construction activities. | The Request will support ongoing PED activities and continuation of early construction activities. | Funding will support ongoing PED activities and the continuation of early construction activities for this project. |
| 19-SC-74, BioEPIC, LBNL $45,000 | $38,000 | -$7,000 |
| Funding will support ongoing construction activities. | Final funding for this project is requested to be received in FY 2024. | Funding Request will provide final funding for this project. This project received supplemental funding under the Inflation Reduction Act. |

**Science Laboratories Infrastructure**
**Capital Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | | |
| Minor Construction Activities | | | | | | | |
| General Plant Projects | N/A | N/A | 14,250 | 65,890 | 13,700 | 32,104 | +18,404 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **14,250** | **65,890** | **13,700** | **32,104** | **+18,404** |

### Science Laboratories Infrastructure
### Minor Construction Activities

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | | |
| GPPs (greater than or equal to $5M and less than $30M) | | | | | | | |
| Welcome and Access Center at FNAL | 12,500 | 1,000 | 11,500 | – | – | – | – |
| Steam to Hydronics Conversion Project at PNNL | 5,400 | – | – | – | 5,400 | – | -5,400 |
| Emergency Generator Upgrades, Phase 1 at LBNL | 5,500 | – | – | – | 5,500 | – | -5,500 |
| Fire Alarm System Replacement | 8,200 | – | – | 8,200 | – | – | – |
| B510 Upgrade Electrical Distribution, II | 5,150 | – | – | 5,150 | – | – | – |
| LSL2 Building Steam to Hydronics Conversion | 8,220 | – | – | 8,220 | – | – | – |
| Cooling Tower Upgrade Phase II | 12,000 | – | – | 12,000 | – | – | – |
| HVAC System Upgrade Harley Wilhelm Mall | 6,200 | – | – | 6,200 | – | – | – |
| Upgrade HVAC Systems Improvement II | 9,300 | – | – | 9,300 | – | – | – |
| Life safety Improvements | 7,300 | – | – | 7,300 | – | – | – |
| HVAC Upgrade Life Sciences Laboratory (Bldg. 331) | 6,000 | – | – | – | – | 6,000 | +6,000 |
| Power Quality Compensation Equipment Installation | 8,300 | – | – | – | – | 8,300 | +8,300 |
| Chiller Replacement (Bldg. 450) | 6,530 | – | – | – | – | 6,530 | +6,530 |
| Electrical Component Replacement 88 Inch Cyclotron User (Bldg B88) | 6,000 | – | – | – | – | 6,000 | +6,000 |
| Total GPPs (greater than or equal to $5M and less than $30M) | N/A | N/A | 11,500 | 56,370 | 10,900 | 26,830 | +15,930 |
| Total GPPs less than $5M | N/A | N/A | 2,750 | 9,520 | 2,800 | 5,274 | +2,474 |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **14,250** | **65,890** | **13,700** | **32,104** | **+18,404** |

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **14,250** | **65,890** | **13,700** | **32,104** | **+18,404** |

*Note:*

- *GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.*

**Science Laboratories Infrastructure**
**Institutional General Plant Projects (IGPP)**

(dollars in thousands)

| | Total | FY 2022 Current | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|
| **Institutional General Plant Projects (IGPP)** | | | | | |
| IGPPs (greater than or equal to $5M and less than $30M) | | | | | |
| Sitewide Generator Upgrades Phase 1, LBNL | 16,750 | 16,750 | | | — |
| Former B7 Tensile Structure Installation, LBNL | 9,000 | 9,000 | | | — |
| 7625 Cooling Water System Replacement, ORNL | 9,600 | 9,600 | | | — |
| LSW High Ceiling Laboratory Conversion, PNNL | 5,951 | 5,951 | | | — |
| PNNL Richland North Infrastructure, PNNL | 24,600 | 24,600 | | | — |
| Secure Space Compliance Upgrades and Consolidation, ANL | 5,000 | | 5,000 | | -5,000 |
| Bldg. 221 Renovations, ANL | 8,800 | | 8,800 | | -8,800 |
| Autonomous Discovery Lab Renovations, ANL | 10,000 | | 10,000 | | -10,000 |
| Switch Station SW-A3 Improvements, LBNL | 21,000 | | 21,000 | | -21,000 |
| Helium Capture/Storage Capabilities, LBNL | 5,000 | | 5,000 | | -5,000 |
| Strawberry Gatehouse Replacement, LBNL | 6,000 | | 6,000 | | -6,000 |
| Modular HPC Datacenter, LBNL | 8,000 | | 8,000 | | -8,000 |
| Chemical Receiving Space, LBNL | 5,000 | | 5,000 | | -5,000 |
| B84 Lab Improvement, LBNL | 6,000 | | 6,000 | | -6,000 |
| 7600 Area (Experimental Gas Cooled Reactor - EGCR) Campus Utility Modernization, ORNL | 9,600 | | 9,600 | | -9,600 |
| Melton Valley Warehouse Expansion, ORNL | 11,000 | | 11,000 | | -11,000 |
| 4500N Library Renovations (includes swing office space), ORNL | 13,000 | | 13,000 | | -13,000 |
| 7667 Low Level Waste Site Improvements, ORNL | 10,000 | | 10,000 | | -10,000 |
| Advanced Microscopy Laboratory Expansion, ORLN | 9,600 | | 9,600 | | -9,600 |
| Sewage Treatment Plant - Lift station (3501), ORNL | 9,600 | | 9,600 | | -9,600 |
| 318 Hot Water Piping Upgrade, PNNL | 8,000 | | 8,000 | | -8,000 |
| Guest House Repurpose, PNNL | 6,250 | | 6,250 | | -6,250 |
| 300 Area Office, PNNL | 8,000 | | 8,000 | | -8,000 |
| Advanced Secure Communications, PNNL | 24,700 | | 24,700 | | -24,700 |
| East Campus Site & Utilities Improvement Project (ESUI), SLAC | 10,000 | | 10,000 | | -10,000 |
| Klystron Gallery Power Distribution Infrastructure, SLAC | 7,000 | | 7,000 | | -7,000 |

| | | | | | |
|---|---|---|---|---|---|
| Transit Hub and Utility Improvements Project (THUP), LBNL | 24,900 | | 24,900 | | -24,900 |
| Space Renovation Program - Bldg. 360 Area, ANL | 8,000 | | | 8,000 | +8,000 |
| Bldg. 362 Facility Modernization, ANL | 12,000 | | | 12,000 | +12,000 |
| Enterprise Data Center Hall #2 Build Out, ANL | 8,000 | | | 8,000 | +8,000 |
| High Voltage Substation and Transformer Upgrades, ANL | 12,950 | | | 12,950 | +12,950 |
| Sitewide Retaining Wall Improvements, LBNL | 5,000 | | | 5,000 | +5,000 |
| B66 4th Floor Lab Upgrades, LBNL | 10,000 | | | 10,000 | +10,000 |
| B2 Space Conversion, LBNL | 10,500 | | | 10,500 | +10,500 |
| B62 MEP Improvements, LBNL | 15,000 | | | 15,000 | +15,000 |
| B62 Highbay Renovations, LBNL | 5,000 | | | 5,000 | +5,000 |
| B71 Mechanical/Electrical Upgrades, LBNL | 15,500 | | | 15,500 | +15,500 |
| B62 Slab Repair and Space Conversion, LBNL | 21,050 | | | 21,050 | +21,050 |
| Transuranic Waste Certification and Loading Support Building, ORNL | 24,000 | | | 24,000 | +24,000 |
| 4508 Modernization, ORNL | 9,600 | | | 9,600 | +9,600 |
| 2000/3000 Utilities Modernization, ORNL | 9,600 | | | 9,600 | +9,600 |
| Vehicle charging stations, ORNL | 6,000 | | | 6,000 | +6,000 |
| 5500 High Bay Modifications, ORNL | 9,600 | | | 9,600 | +9,600 |
| Multi-program Office Building #2, ORNL | 11,000 | | | 11,000 | +11,000 |
| 4500N Wing 1 General use lab space, ORNL | 12,000 | | | 12,000 | +12,000 |
| 331 HVAC Upgrade, PNNL | 5,000 | | | 5,000 | +5,000 |
| PNNL Richland North Central Infrastructure, PNNL | | | | 6,200 | |
| 318 HVAC Upgrade, PNNL | | | | 10,000 | |
| 331 Research Support Office, PNNL | | | | 10,000 | |
| General Purpose Lab, PNNL | | | | 15,000 | |
| Secure Physical Sciences, PNNL | | | | 23,300 | |
| Total IGPPs (greater than or equal to $5M and less than $30M) | 566,651 | 65,901 | 226,450 | 274,300 | +47,850 |
| Total IGPPs less than $5M | 74,932 | 27,993 | 25,950 | 20,989 | -4,961 |
| **Total, Institutional General Plant Projects (IGPP)** | **641,583** | **93,894** | **252,400** | **295,289** | **+42,889** |

*Note:*

- *Institutional General Plant Projects (IGPPs) are indirect funded minor construction activities that are general institutional in nature and address general purpose, site-wide needs.*

**Science Laboratories Infrastructure**
**Construction Projects Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **22-SC-71, Critical Infrastructure Modernization Project, ORNL** | | | | | | | |
| Total Estimated Cost (TEC) | 416,000 | – | 1,000 | – | 1,000 | – | -1,000 |
| Other Project Cost (OPC) | 4,000 | 1,250 | 750 | – | – | – | – |
| **Total Project Cost (TPC)** | **420,000** | **1,250** | **1,750** | **–** | **1,000** | **–** | **-1,000** |
| **22-SC-72, Thomas Jefferson Infrastructure Improvements, TJNAF** | | | | | | | |
| Total Estimated Cost (TEC) | 96,000 | – | 1,000 | – | 1,000 | – | -1,000 |
| Other Project Cost (OPC) | 1,000 | 1,000 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **97,000** | **1,000** | **1,000** | **–** | **1,000** | **–** | **-1,000** |
| **21-SC-71, Princeton Plasma Innovation Center, PPPL** | | | | | | | |
| Total Estimated Cost (TEC) | 96,300 | 150 | 7,750 | 10,000 | 10,000 | 15,000 | +5,000 |
| Other Project Cost (OPC) | 2,200 | 1,823 | 106 | – | – | – | – |
| **Total Project Cost (TPC)** | **98,500** | **1,973** | **7,856** | **10,000** | **10,000** | **15,000** | **+5,000** |
| **21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL** | | | | | | | |
| Total Estimated Cost (TEC) | 87,300 | 150 | 2,000 | – | 4,000 | 10,000 | +6,000 |
| Other Project Cost (OPC) | 1,700 | 1,352 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **89,000** | **1,502** | **2,000** | **–** | **4,000** | **10,000** | **+6,000** |
| **21-SC-73, Ames Infrastructure Modernization** | | | | | | | |
| Total Estimated Cost (TEC) | 30,000 | 150 | 2,000 | 17,850 | 2,000 | 8,000 | +6,000 |
| Other Project Cost (OPC) | 1,000 | 257 | 250 | – | – | – | – |
| **Total Project Cost (TPC)** | **31,000** | **407** | **2,250** | **17,850** | **2,000** | **8,000** | **+6,000** |

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **20-SC-71, Critical Utilities Rehabilitation Project, BNL** | | | | | | | |
| Total Estimated Cost (TEC) | 92,000 | 40,000 | 26,000 | – | 26,000 | – | -26,000 |
| Other Project Cost (OPC) | 1,000 | 1,000 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **93,000** | **41,000** | **26,000** | **–** | **26,000** | **–** | **-26,000** |
| **20-SC-72, Seismic Safety and Infrastructure Upgrades, LBNL** | | | | | | | |
| Total Estimated Cost (TEC) | 141,000 | 15,000 | 18,000 | 22,500 | 27,500 | 40,000 | +12,500 |
| Other Project Cost (OPC) | 4,690 | 2,651 | 1,000 | – | 200 | – | -200 |
| **Total Project Cost (TPC)** | **145,690** | **17,651** | **19,000** | **22,500** | **27,700** | **40,000** | **+12,300** |
| **20-SC-73, CEBAF Renovation and Expansion, TJNAF** | | | | | | | |
| Total Estimated Cost (TEC) | 87,000 | 4,000 | 10,000 | 10,000 | 15,000 | 11,000 | -4,000 |
| Other Project Cost (OPC) | 3,300 | 1,492 | – | – | 600 | – | -600 |
| **Total Project Cost (TPC)** | **90,300** | **5,492** | **10,000** | **10,000** | **15,600** | **11,000** | **-4,600** |
| **20-SC-75, Large Scale Collaboration Center, SLAC** | | | | | | | |
| Total Estimated Cost (TEC) | 55,000 | 22,000 | 12,000 | – | 21,000 | – | -21,000 |
| Other Project Cost (OPC) | 2,000 | 504 | – | – | 400 | 950 | +550 |
| **Total Project Cost (TPC)** | **57,000** | **22,504** | **12,000** | **–** | **21,400** | **950** | **-20,450** |
| **20-SC-76, Tritium System Demolition and Disposal, PPPL** | | | | | | | |
| Total Estimated Cost (TEC) | 32,400 | 26,000 | 6,400 | – | – | – | – |
| Other Project Cost (OPC) | 1,000 | 1,000 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **33,400** | **27,000** | **6,400** | **–** | **–** | **–** | **–** |
| **20-SC-77, Argonne Utilities Upgrade, ANL** | | | | | | | |
| Total Estimated Cost (TEC) | 215,000 | 1,000 | 10,000 | – | 8,000 | 8,007 | +7 |
| Other Project Cost (OPC) | 1,000 | 1,000 | – | – | – | – | – |

(dollars in thousands)

| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|---|---|---|
| **Total Project Cost (TPC)** | **216,000** | **2,000** | **10,000** | **–** | **8,000** | **8,007** | **+7** |
| **20-SC-78, Linear Assets Modernization Project, LBNL** | | | | | | | |
| Total Estimated Cost (TEC) | 236,000 | 1,000 | 10,400 | – | 23,425 | 18,900 | -4,525 |
| Other Project Cost (OPC) | 6,000 | 2,317 | 946 | – | – | – | – |
| **Total Project Cost (TPC)** | **242,000** | **3,317** | **11,346** | **–** | **23,425** | **18,900** | **-4,525** |
| **20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC** | | | | | | | |
| Total Estimated Cost (TEC) | 204,000 | 1,000 | 8,500 | – | 25,425 | 35,075 | +9,650 |
| Other Project Cost (OPC) | 4,450 | 1,894 | 778 | – | – | – | – |
| **Total Project Cost (TPC)** | **208,450** | **2,894** | **9,278** | **–** | **25,425** | **35,075** | **+9,650** |
| **20-SC-80, Utilities Infrastructure Project, FNAL** | | | | | | | |
| Total Estimated Cost (TEC) | 310,000 | 1,000 | 10,500 | – | 20,000 | 45,000 | +25,000 |
| Other Project Cost (OPC) | 4,000 | 1,850 | 200 | – | – | – | – |
| **Total Project Cost (TPC)** | **314,000** | **2,850** | **10,700** | **–** | **20,000** | **45,000** | **+25,000** |
| **19-SC-71, Science User Support Center at BNL** | | | | | | | |
| Total Estimated Cost (TEC) | 85,000 | 47,000 | 38,000 | – | – | – | – |
| Other Project Cost (OPC) | 1,200 | 1,200 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **86,200** | **48,200** | **38,000** | **–** | **–** | **–** | **–** |
| **19-SC-73, Translational Research Capacity, ORNL** | | | | | | | |
| Total Estimated Cost (TEC) | 93,500 | 72,000 | 21,500 | – | – | – | – |
| Other Project Cost (OPC) | 1,500 | 1,400 | – | – | – | 100 | +100 |
| **Total Project Cost (TPC)** | **95,000** | **73,400** | **21,500** | **–** | **–** | **100** | **+100** |
| **19-SC-74, BioEPIC Building** | | | | | | | |
| Total Estimated Cost (TEC) | 165,000 | 40,000 | 35,000 | 7,000 | 45,000 | 38,000 | -7,000 |

| | (dollars in thousands) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total | Prior Years | FY 2022 Enacted | FY 2022 IRA Supp. | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
| Other Project Cost (OPC) | 2,200 | 1,536 | – | – | – | – | – |
| **Total Project Cost (TPC)** | **167,200** | **41,536** | **35,000** | **7,000** | **45,000** | **38,000** | **-7,000** |
| **18-SC-71, Energy Sciences Capability, PNNL** | | | | | | | |
| Total Estimated Cost (TEC) | 90,000 | 90,000 | – | – | – | – | – |
| Other Project Cost (OPC) | 3,000 | 1,362 | 1,638 | – | – | – | – |
| **Total Project Cost (TPC)** | **93,000** | **91,362** | **1,638** | **–** | **–** | **–** | **–** |
| **17-SC-71, Integrated Engineering Research Center at FNAL** | | | | | | | |
| Total Estimated Cost (TEC) | 85,000 | 74,750 | 10,250 | – | – | – | – |
| Other Project Cost (OPC) | 1,000 | 950 | 50 | – | – | – | – |
| **Total Project Cost (TPC)** | **86,000** | **75,700** | **10,300** | **–** | **–** | **–** | **–** |
| **Total, Construction** | | | | | | | |
| **Total Estimated Cost (TEC)** | **N/A** | **N/A** | **230,300** | **67,350** | **229,350** | **228,982** | **-368** |
| **Other Project Cost (OPC)** | **N/A** | **N/A** | **5,718** | **–** | **1,200** | **1,050** | **-150** |
| **Total Project Cost (TPC)** | **N/A** | **N/A** | **236,018** | **67,350** | **230,550** | **230,032** | **-518** |

**21-SC-71, Princeton Plasma Innovation Center, PPPL**
**Princeton Plasma Physics Laboratory, PPPL**
**Project is for Design and Construction**

### 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Princeton Plasma Innovation Center (PPIC) project is $15,000,000 of Total Estimated Cost (TEC) funding. The TEC range for this project is $78,300,000 to $96,300,000. The preliminary Total Project Cost (TPC) range for this project is $80,500,000 to $98,500,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $98,500,000.

This project will provide a multi-purpose facility with modern, flexible, efficient, and agile research laboratories and office space to conduct plasma research activities in support of multiple SC programs.

**Significant Changes**

This project was initiated in FY 2021 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on January 22, 2021. The project received $10,000,000 in Inflation Reduction Act (IRA) funding which will be used to mitigate the risks of escalation and allow the project schedule to be accelerated. FY 2024 funds will support construction activities after the appropriate CD approvals.

A Federal Project Director working towards the appropriate certification level was assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 9/9/19 | 8/25/20 | 1/22/21 | 3Q FY 2024 | 2Q FY 2024 | 3Q FY 2024 | 3Q FY 2028 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 3Q FY 2024 | 1Q FY 2024 |

**CD-3A** – Approve Long-Lead Procurements and Site Preparation Activities.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 8,900 | 87,400 | 96,300 | 2,200 | 2,200 | 98,500 |
| FY 2024 | 8,900 | 87,400 | 96,300 | 2,200 | 2,200 | 98,500 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 2. Project Scope and Justification

**Scope**

The Princeton Plasma Innovation Center (PPIC) is envisioned as a 77,000 to 107,000 gross square feet (gsf) multi-story office and laboratory building at Princeton Plasma Physics Laboratory (PPPL) to serve as a single new multi-use facility that will house space for offices, medium bay research labs for diagnostics and fabrication, remote experiment participation and collaboration, and research support. It is anticipated a review and approval for long-lead procurements (e.g. mechanical and electrical equipment) and site preparation (e.g. demolition) in support of CD-3A will occur in 1Q FY 2024.

**Justification**

To advance the plasma science and fusion frontier in support of the DOE mission, PPPL requires new or enhanced facilities and infrastructure to foster innovation to make fusion energy a practical reality and further U.S. economic competitiveness. The primary SC program relevant to the PPIC project is FES, and the primary Core Capability is Plasma and Fusion Energy Sciences. The missions of SC's ASCR and BES programs are also relevant mission needs for the PPIC with second order effect to Large Scale User Facilities/Advanced Instrumentation and Systems Engineering and Integration.

PPPL plays a key role in assisting FES achieve its strategic goals. The PPPL vision is "enabling a world powered by safe, clean, and plentiful fusion energy while leading discoveries in plasma science and technology." To support this vision, PPPL carries out experiments and computer simulations of the behavior of plasma, which is hot electrically charged gas. Plasmas with sufficient temperature generate fusion reactions. Therefore, PPPL's aim is to be a leading center for future fusion concepts. The understanding of plasma and its related technologies also has a broad impact on many other scientific fields and applications that are central to U.S. economic health and competitiveness. This impact extends to astrophysics and space sciences, plasma-material interactions, plasma processing, particle acceleration, and high energy density plasmas. Many industries, such as the microelectronics industry, utilize plasmas to synthesize and shape the materials in their products. These industries are increasingly seeking collaboration with PPPL to improve their understanding of existing plasma processes and to develop new modeling and measurement techniques potentially leading to new processes and applications. PPPL, in collaboration with Princeton University, is strengthening its efforts to develop innovations for the next generation microelectronics to advance economic competitiveness, national security, and future energy applications.

However, the current condition, capabilities, and configuration of PPPL infrastructure do not adequately accommodate current or planned scientific efforts. In particular, the lack of adequate laboratory infrastructure, modern collaboration space, and modern office infrastructure are not optimal to support PPPL research. PPPL would benefit from office and laboratories capabilities that can effectively accomplish the advancement of the FES mission.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multi-Story Building | 77,000 gsf | 107,000 gsf |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 150 | 150 | – | – |
| FY 2022 | 7,750 | 7,750 | 1,500 | – |
| FY 2022 - IRA Supp. | 1,000 | 1,000 | – | – |
| FY 2023 | – | – | 4,000 | 1,000 |
| FY 2024 | – | – | 2,400 | – |
| **Total, Design (TEC)** | **8,900** | **8,900** | **7,900** | **1,000** |
| Construction (TEC) | | | | |
| FY 2022 - IRA Supp. | 9,000 | 9,000 | – | – |
| FY 2023 | 10,000 | 10,000 | – | – |
| FY 2024 | 15,000 | 15,000 | 6,000 | 9,000 |
| Outyears | 53,400 | 53,400 | 72,400 | – |
| **Total, Construction (TEC)** | **87,400** | **87,400** | **78,400** | **9,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 150 | 150 | – | – |
| FY 2022 | 7,750 | 7,750 | 1,500 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 10,000 | 10,000 | 4,000 | 1,000 |
| FY 2024 | 15,000 | 15,000 | 8,400 | 9,000 |
| Outyears | 53,400 | 53,400 | 72,400 | – |
| **Total, TEC** | **96,300** | **96,300** | **86,300** | **10,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 1,823 | 1,823 | 1,823 | – |
| FY 2022 | 106 | 106 | 106 | – |
| Outyears | 271 | 271 | 271 | – |
| **Total, OPC** | **2,200** | **2,200** | **2,200** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 1,973 | 1,973 | 1,823 | – |
| FY 2022 | 7,856 | 7,856 | 1,606 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 10,000 | 10,000 | 4,000 | 1,000 |
| FY 2024 | 15,000 | 15,000 | 8,400 | 9,000 |
| Outyears | 53,671 | 53,671 | 72,671 | – |
| **Total, TPC** | **98,500** | **98,500** | **88,500** | **10,000** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 7,900 | 7,900 | **N/A** |
| Design - Contingency | 1,000 | 1,000 | **N/A** |
| **Total, Design (TEC)** | **8,900** | **8,900** | **N/A** |
| Construction | 72,000 | 72,000 | **N/A** |
| Construction - Contingency | 15,400 | 15,400 | **N/A** |
| **Total, Construction (TEC)** | **87,400** | **87,400** | **N/A** |
| **Total, TEC** | **96,300** | **96,300** | **N/A** |
| *Contingency, TEC* | *16,400* | *16,400* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 300 | 300 | **N/A** |
| Conceptual Design | 1,700 | 1,700 | **N/A** |
| OPC - Contingency | 200 | 200 | **N/A** |
| **Total, Except D&D (OPC)** | **2,200** | **2,200** | **N/A** |
| **Total, OPC** | **2,200** | **2,200** | **N/A** |
| *Contingency, OPC* | *200* | *200* | ***N/A*** |
| **Total, TPC** | **98,500** | **98,500** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***16,600*** | ***16,600*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 150 | 900 | — | 10,000 | — | 85,250 | 96,300 |
| | OPC | 1,860 | — | — | — | — | 340 | 2,200 |
| | TPC | 2,010 | 900 | — | 10,000 | — | 85,590 | 98,500 |
| FY 2024 | TEC | 150 | 7,750 | 10,000 | 10,000 | 15,000 | 53,400 | 96,300 |
| | OPC | 1,823 | 106 | — | — | — | 271 | 2,200 |
| | TPC | 1,973 | 7,856 | 10,000 | 10,000 | 15,000 | 53,671 | 98,500 |

*Notes:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 3Q FY 2028 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 3Q FY 2078 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | 1,336 | 1,336 | 46,774 | 46,774 |
| Utilities | 198 | 198 | 6,936 | 6,936 |
| Maintenance and Repair | 1,518 | 1,518 | 53,154 | 53,154 |
| Total, Operations and Maintenance | 3,052 | 3,052 | 106,864 | 106,864 |

## 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at PPPL .......... | 77,000-107,000 |
| Area of D&D in this project at PPPL .......... | 13,400 |
| Area at PPPL to be transferred, sold, and/or D&D outside the project, including area previously "banked" .......... | None[a] |
| Area of D&D in this project at other sites .......... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" .......... | None |
| Total area eliminated .......... | 13,400 |

## 8. Acquisition Approach

The PPPL Management and Operating (M&O) Contractor, Princeton University, is performing the acquisition for this project, overseen by the Princeton Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Project performance metrics will be performed by in-house management and Project Controls.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL**
**Princeton Plasma Physics Laboratory, PPPL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Critical Infrastructure Recovery & Renewal (CIRR) project is $10,000,000 of Total Estimated Cost (TEC) funding. The preliminary TEC range for this project is $80,100,000 to $96,000,000. The preliminary Total Project Cost (TPC) range for this project is $81,800,000 to $97,700,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $89,000,000.

Princeton Plasma Physics Laboratory's (PPPL's) increasingly unreliable, and antiquated utility infrastructure is negatively impacting laboratory operations. Scientific productivity is dependent on a capable, available, flexible, maintainable, reliable, and resilient support infrastructure. This project will provide critical infrastructure needed to operate the laboratory missions safely and efficiently. These systems will be modern and energy efficient, reducing the operating cost and improving the resilience of the facilities.

**Significant Changes**

This project was initiated in FY 2021 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on February 23, 2021. FY 2024 funds will continue design activities.

A Federal Project Director working towards the appropriate certification level was assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 9/16/19 | 2/23/21 | 2/23/21 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2025 | 4Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 4Q FY 2025 | 4Q FY 2024 |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 9,950 | 77,350 | 87,300 | 1,700 | 1,700 | 89,000 |
| FY 2024 | 9,950 | 77,350 | 87,300 | 1,700 | 1,700 | 89,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**2. Project Scope and Justification**

**Scope**
The CIRR project at PPPL will revitalize critical infrastructure that supports the PPPL campus to ensure reliability and resilience. Upgrades that may be completed as part of the CIRR project include: the electrical distribution system; standby power; chilled water generation and distribution; distribution networks for steam, compressed air, sanitary waste, and condenser, storm, canal, and potable water; HVAC systems; and communication systems. The scientific activities that require reliable and resilient utilities include National Spherical Torus Experiment-Upgrade (NSTX-U), Facility for Laboratory Reconnection Experiments (FLARE), and Lithium Tokamak Experiment-Beta (LTX-β).

The specifics of long-lead electrical equipment procurement will be reviewed and approved in support of CD-3A.

**Justification**
PPPL is a key DOE contributor to plasma science and directly supports the DOE mission to make fusion energy a practical reality and further U.S. economic competitiveness. To maintain system operability, it is essential to have reliable infrastructure in place. The current systems are past their useful life, obsolete, unreliable, and inefficient. Portions of the current system are part of the original infrastructure built in 1958. To maintain current missions and enable future ones, the infrastructure must be upgraded with modern, efficient, and reliable systems.

CIRR will deliver modern and resilient general-purpose infrastructure which will be more reliable, efficient, and sustainable and meet current industry standards. For example, replacing the obsolete hot deck/cold deck HVAC system will not only result in repair savings, but will generate energy savings as well. Every element of this project will be designed to consider the best available and most efficient technology and employ artificial intelligence systems to enhance operations and maintenance of new systems and equipment.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)
The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Chilled Water Generation | ▪ Improve configuration and efficiency of the Central Chilled Water Plant to ensure distribution of 1,200 tons of cooling capacity to the site. | ▪ N/A |
| Communications Distribution Network | ▪ Improve data infrastructure cabling and components by replacing existing copper cable with 2,000 linear feet of cat 6 cable.<br>▪ Provide 2,500 linear feet of 48 strand network fiber cable connected to the PU Computer Center.<br>▪ Provide 15,000 linear feet of 24 strand fiber optic cable to support site wide communication. | ▪ Threshold plus upgrade additional communication system components to improve security, reliability, and flexibility. |
| Electrical Distribution & Standby Power | ▪ Create redundancy and improve mission readiness of the primary electrical distribution system in the 138 kV Yard.<br>▪ Provide site-wide capacity of standby generation at 3,500 KW.<br>▪ Upgrade 8 Substations for priority buildings and facilities. | ▪ Increase site-wide capacity of standby generation up to 4,350 KW.<br>▪ Upgrade up to 10 substations for additional buildings/facilities to improve flexibility for maintenance and operations. |
| HVAC Systems | ▪ Upgrade 8 HVAC system equipment for priority buildings on C-Site and D-Site. | ▪ Upgrade up to 14 HVAC system equipment for additional buildings to meet sustainability goals and improve maintenance and operations. |
| Underground Distribution Network | ▪ Replace all failed critical underground piping, valves, and components for campus utilities.<br>▪ Replace 1,700 linear feet of electrical feeders (26kv) for improved reliability.<br>▪ Upgrade 9,500 sqft. of Storm Retention Basin liner. | ▪ Threshold plus upgrade additional underground system components to improve maintenance and reliability. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| Prior Years | 150 | 150 | – |
| FY 2022 | 2,000 | 2,000 | 1,000 |
| FY 2023 | 4,000 | 4,000 | 4,000 |
| FY 2024 | 3,800 | 3,800 | 4,000 |
| Outyears | – | – | 950 |
| **Total, Design (TEC)** | **9,950** | **9,950** | **9,950** |
| Construction (TEC) | | | |
| FY 2024 | 6,200 | 6,200 | – |
| Outyears | 71,150 | 71,150 | 77,350 |
| **Total, Construction (TEC)** | **77,350** | **77,350** | **77,350** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 150 | 150 | – |
| FY 2022 | 2,000 | 2,000 | 1,000 |
| FY 2023 | 4,000 | 4,000 | 4,000 |
| FY 2024 | 10,000 | 10,000 | 4,000 |
| Outyears | 71,150 | 71,150 | 78,300 |
| **Total, TEC** | **87,300** | **87,300** | **87,300** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 1,352 | 1,352 | 1,352 |
| Outyears | 348 | 348 | 348 |
| **Total, OPC** | **1,700** | **1,700** | **1,700** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 1,502 | 1,502 | 1,352 |
| FY 2022 | 2,000 | 2,000 | 1,000 |
| FY 2023 | 4,000 | 4,000 | 4,000 |
| FY 2024 | 10,000 | 10,000 | 4,000 |
| Outyears | 71,498 | 71,498 | 78,648 |
| **Total, TPC** | **89,000** | **89,000** | **89,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 7,600 | 7,600 | **N/A** |
| Design - Contingency | 2,350 | 2,350 | **N/A** |
| **Total, Design (TEC)** | **9,950** | **9,950** | **N/A** |
| Construction | 59,500 | 59,500 | **N/A** |
| Construction - Contingency | 17,850 | 17,850 | **N/A** |
| **Total, Construction (TEC)** | **77,350** | **77,350** | **N/A** |
| **Total, TEC** | **87,300** | **87,300** | **N/A** |
| *Contingency, TEC* | *20,200* | *20,200* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 200 | 200 | **N/A** |
| Conceptual Design | 1,300 | 1,300 | **N/A** |
| OPC - Contingency | 200 | 200 | **N/A** |
| **Total, Except D&D (OPC)** | **1,700** | **1,700** | **N/A** |
| **Total, OPC** | **1,700** | **1,700** | **N/A** |
| *Contingency, OPC* | *200* | *200* | ***N/A*** |
| **Total, TPC** | **89,000** | **89,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***20,400*** | ***20,400*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 150 | 2,000 | 4,000 | — | 81,150 | 87,300 |
| | OPC | 1,352 | — | — | — | 348 | 1,700 |
| | TPC | 1,502 | 2,000 | 4,000 | — | 81,498 | 89,000 |
| FY 2024 | TEC | 150 | 2,000 | 4,000 | 10,000 | 71,150 | 87,300 |
| | OPC | 1,352 | — | — | — | 348 | 1,700 |
| | TPC | 1,502 | 2,000 | 4,000 | 10,000 | 71,498 | 89,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2079 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | 1,100 | 1,100 | 55,000 | 55,000 |
| Utilities | N/A | N/A | N/A | N/A |
| Maintenance and Repair | 1,000 | 1,000 | 50,000 | 50,000 |
| Total, Operations and Maintenance | 2,100 | 2,100 | 105,000 | 105,000 |

### 7. D&D Information

This project replaces critical infrastructure components; no new construction area is anticipated to be constructed in this project and it will not replace existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at PPPL ........ | None |
| Area of D&D in this project at PPPL ........ | None |
| Area at PPPL to be transferred, sold, and/or D&D outside the project, including area previously “banked” ........ | None |
| Area of D&D in this project at other sites ........ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously “banked” ........ | None |
| Total area eliminated ........ | None |

**8. Acquisition Approach**

The PPPL Management and Operating (M&O) Contractor, Princeton University, will perform the acquisition for this project, overseen by the Princeton Site Office. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. Project performance metrics will be performed by in-house management and Project Controls.

**21-SC-73, Ames Infrastructure Modernization**
**Ames National Laboratory, AMES**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

### Summary

The FY 2024 Request for the Ames Infrastructure Modernization (AIM) project is $8,000,000 of Total Estimated Cost (TEC). The preliminary Total Estimated Cost (TEC) range for this project is $22,000,000 to $89,000,000. The preliminary Total Project Cost (TPC) range for this project is $26,400,000 to $86,500,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $31,000,000.

Ames objective is to support the SC mission by providing safer and more operationally efficient buildings that meet modern needs as well as to reduce deferred maintenance. This project is designed to support DOE mission-critical programs and initiatives, increase the reliability of utility infrastructure, minimize facility costs through effective and efficient operations, and modernize laboratories in Ames research buildings, thereby enhancing Ames ability to continue to deliver on SC mission across multiple program offices.

### Significant Changes

This project was initiated in FY 2021 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved September 16, 2019. The project received $17,850,000 in Inflation Reduction Act (IRA) funding which will be used to mitigate the risks of escalation and allow the project schedule to be accelerated. FY 2024 funds will support construction activities upon the appropriate CD approvals.

A Federal Project Director will be assigned to this project prior to CD-1 approval.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 9/16/19 | 2Q FY 2023 | 3Q FY 2023 | 3Q FY 2024 | 2Q FY 2024 | 3Q FY 2024 | 2Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 3Q FY 2024 | 1Q FY 2024 |

**CD-3A** – Approve Long-Lead Procurements.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2024 | 6,000 | 24,000 | 30,000 | 1,000 | 1,000 | 31,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**2. Project Scope and Justification**

**Scope**

The AIM project will provide updated infrastructure building systems in existing research and operations buildings at Ames Laboratory, such as: plumbing systems; building envelopes; electrical distribution systems, emergency backup power, and uninterruptible power supplies; and telecommunication systems. In addition, some existing laboratory spaces may be modernized to support the SC mission and associated equipment. It is anticipated a review and approval for long-lead procurements (e.g., mechanical and electrical equipment) in support of CD-3A will occur in 1Q FY 2024.

**Justification**

SC utilizes the capabilities of AMES to execute three of SC's 24 core capabilities and the mission of multiple SC program offices, including research by the offices of BES, ASCR, BER, and to a lesser extent, FES. These core capabilities are 1) Condensed Matter Physics and Materials Science, 2) Chemical and Molecular Science, and 3) Applied Materials Science and Engineering.

The current condition of the building systems and infrastructure impedes the execution and advancement of the SC mission for the following reasons: 1) deteriorating plumbing systems result in unplanned events such as sanitary sewer or major water leaks that lead to disruption of scientific operations, jeopardizing instrumentation, and presenting a safety and health risk to personnel; 2) deteriorating building envelopes negatively impact the SC mission through increased operational costs, elevated risk of scientific research equipment damage, and a poor work environment for Ames staff; 3) antiquated and unreliable electrical supply and distribution places sensitive scientific research equipment at risk of damage, limits program expansion and acquisition of new state-of-the-art equipment and instrumentation; 4) inadequate telecommunication systems impede program expansion and limit SC acquisition of new state-of-the-art instrumentation; and 5) inflexible research laboratory space limits the ability to house state-of-the-art equipment and instrumentation, implement best safety management practices, create collaborative environments; and attract, recruit, and retain the scientific talent.

Therefore, to better accommodate the current and future DOE Office of Science mission, minimize disruptions to critical research activities, reduce risks to operations and deferred maintenance, and improve the safety and reliability, AMES needs improved infrastructure systems and workspaces.

The project is being conducted in accordance with the project management principles in accordance with requirements of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets* for projects less than $50 million.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Replace and upgrade plumbing systems in mission critical buildings | ▪ Replace deficient domestic supply and sanitary sewer piping in two (2) mission critical buildings: Spedding Hall and Wilhelm Hall. | ▪ Replace deficient domestic supply and sanitary sewer piping in three (3) mission critical buildings: Spedding Hall, Wilhelm Hall, and Metals Development. |
| Upgrade building envelopes for mission critical buildings | ▪ Upgrade end-of-life built up roofs and facades on two (2) mission critical buildings: Spedding Hall and Wilhelm Hall. | ▪ Upgrade past end-of-life built up roofs and facades on three (3) mission critical buildings: Spedding Hall, Wilhelm Hall, and Metals Development. |
| Improve emergency/backup power systems | ▪ Replace two (2) existing backup generators at Wilhelm Hall for Ames Laboratory campus. | ▪ Replace three (3) existing backup generators: (2) at Wilhelm Hall, (1) at Sensitive Instrument Facility. |
| Improve telecommunications systems | ▪ Establish two (2) new telecom rooms and install new data cabling in two (2) mission critical buildings: Technical Administrative Services Facility (TASF)and Wilhelm Hall. | ▪ Establish three (3) new telecom rooms and install new data cabling in three (3) mission critical buildings: Spedding Hall, Wilhelm Hall, and Metals Development, as well as TASF. |
| Modernize existing laboratory spaces in mission critical buildings | ▪ Renovate wet labs, dry labs, office space, and common areas in two (2) mission critical buildings: Spedding Hall and Wilhelm Hall. | ▪ Renovate wet labs, dry labs, office space, and common areas in three (3) mission critical buildings: Spedding Hall, Wilhelm Hall, and Metals Development. |
| Replace and upgrade HVAC systems in mission critical buildings | ▪ Not Applicable. | ▪ Replace past end-of-life air handling units and associated controls in three (3) mission critical buildings: Spedding Hall, Wilhelm Hall, and Metals Development. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 150 | 150 | – | – |
| FY 2022 | 2,000 | 2,000 | – | – |
| FY 2022 - IRA Supp. | 3,850 | 3,850 | – | – |
| FY 2023 | – | – | – | 1,500 |
| FY 2024 | – | – | 1,050 | 2,350 |
| Outyears | – | – | 1,100 | – |
| **Total, Design (TEC)** | **6,000** | **6,000** | **2,150** | **3,850** |
| Construction (TEC) | | | | |
| FY 2022 - IRA Supp. | 14,000 | 14,000 | – | – |
| FY 2023 | 2,000 | 2,000 | – | – |
| FY 2024 | 8,000 | 8,000 | – | 6,000 |
| Outyears | – | – | 10,000 | 8,000 |
| **Total, Construction (TEC)** | **24,000** | **24,000** | **10,000** | **14,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 150 | 150 | – | – |
| FY 2022 | 2,000 | 2,000 | – | – |
| FY 2022 - IRA Supp. | 17,850 | 17,850 | – | – |
| FY 2023 | 2,000 | 2,000 | – | 1,500 |
| FY 2024 | 8,000 | 8,000 | 1,050 | 8,350 |
| Outyears | – | – | 11,100 | 8,000 |
| **Total, TEC** | **30,000** | **30,000** | **12,150** | **17,850** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 257 | 257 | 257 | – |
| FY 2022 | 250 | 250 | 250 | – |
| Outyears | 493 | 493 | 493 | – |
| **Total, OPC** | **1,000** | **1,000** | **1,000** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 407 | 407 | 257 | – |
| FY 2022 | 2,250 | 2,250 | 250 | – |
| FY 2022 - IRA Supp. | 17,850 | 17,850 | – | – |
| FY 2023 | 2,000 | 2,000 | – | 1,500 |
| FY 2024 | 8,000 | 8,000 | 1,050 | 8,350 |
| Outyears | 493 | 493 | 11,593 | 8,000 |
| **Total, TPC** | **31,000** | **31,000** | **13,150** | **17,850** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 5,000 | 2,500 | **N/A** |
| Design - Contingency | 1,000 | 500 | **N/A** |
| **Total, Design (TEC)** | **6,000** | **3,000** | **N/A** |
| Construction | 19,500 | 22,500 | **N/A** |
| Construction - Contingency | 4,500 | 4,500 | **N/A** |
| **Total, Construction (TEC)** | **24,000** | **27,000** | **N/A** |
| **Total, TEC** | **30,000** | **30,000** | **N/A** |
| *Contingency, TEC* | *5,500* | *5,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 250 | 250 | **N/A** |
| Conceptual Design | 250 | 250 | **N/A** |
| OPC - Contingency | 500 | 500 | **N/A** |
| **Total, Except D&D (OPC)** | **1,000** | **1,000** | **N/A** |
| **Total, OPC** | **1,000** | **1,000** | **N/A** |
| *Contingency, OPC* | *500* | *500* | ***N/A*** |
| **Total, TPC** | **31,000** | **31,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***6,000*** | ***5,500*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2024 | TEC | 150 | 2,000 | 17,850 | 2,000 | 8,000 | — | 30,000 |
| | OPC | 257 | 250 | — | — | — | 493 | 1,000 |
| | TPC | 407 | 2,250 | 17,850 | 2,000 | 8,000 | 493 | 31,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2Q FY 2029 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 2Q FY 2054 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs[a] | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 335 | 335 | 8,375 | 8,375 |
| Utilities | 1,024 | 1,024 | 25,600 | 25,600 |
| Maintenance and Repair | 1,685 | 1,685 | 42,125 | 42,125 |
| Total, Operations and Maintenance | 3,044 | 3,044 | 76,100 | 76,100 |

## 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at AMES | None |
| Area of D&D in this project at AMES | None |
| Area at AMES to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[b] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | None |

[a] Life-Cycle costs will be performed as part of CD-1.
[b] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The Ames Management and Operating (M&O) contractor, Iowa State University, will perform the acquisition for this project, overseen by the Ames Site Office. It will evaluate various acquisition approaches and consider project delivery methods prior to achieving CD-1. The M&O contractor will be responsible for awarding and administering all subcontracts related to this project. The M&O contractor's annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

**20-SC-72, Seismic and Safety Modernization, LBNL**
**Lawrence Berkeley National Laboratory, LBNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Seismic and Safety Modernization (SSM) project is $40,000,000 of Total Estimated Cost (TEC) funding. The TEC range for this project is $95,400,000 to $183,000,000. The preliminary Total Project Cost (TPC) range for this project is $97,600,000 to $187,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $145,000,000.

**Significant Changes**

This project was initiated in FY 2020 Enacted Appropriations. Based on a completed design, the SSM project team received bids in 2022 that exceeded the CD-1 cost range. Therefore, the SSM project revisited CD-1, Approve Alternative Selection and Cost Range, in the second quarter of FY 2023. The selected alternative remained the same, but the revised TEC range for this project is $112,800,000 to $183,300,000. The revised TPC range for this project is $116,000,000 to $188,500,000. The revised preliminary point estimate is $145,000,000 which is within the estimated cost range for the project.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-3A/R1, which was approved on January 9, 2023, for demolition and site stabilization. Additionally, the CD-0, Approve Mission Need, was updated and approved December 21, 2022, to remove seismic upgrades to the firehouse and address the upgrades immediately with laboratory overhead funds as a separate activity. The project received $22,500,000 in Inflation Reduction Act (IRA) funding to increase the TPC and initiate long lead procurement and site preparation to mitigate the risks of escalation. FY 2024 funds will support the highest priority project construction scope at time the funds are costed.

A Federal Project Director with the appropriate certification level has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 12/21/22 | 6/17/19 | 01/13/23 | 2Q FY 2024 | 10/01/21 | 2Q FY 2024 | 4Q FY 2028 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

*Note:*

- *CD-0 was originally approved on 9/6/2018, and has been updated to remove seismic upgrades to the firehouse.*

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2024 | 2Q FY 2024 | 01/13/23 |

**CD-3A** – Approve Long-Lead Procurement and Site Preparation Activities.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 9,000 | 86,400 | 95,400 | 2,200 | 2,200 | 97,600 |
| FY 2024 | 12,000 | 129,000 | 141,000 | 4,000 | 4,000 | 145,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**2. Project Scope and Justification**

**Scope**

The SSM project will construct a new 47,000 (approximately) gross square feet facility on the existing cafeteria site to house the cafeteria, health services and operational support services (human resources, conferencing, and other potential groups) to meet the requirements of Risk Category III of the California Building Code (CBC).

**Justification**

LBNL executes 22 of the Office of Science's (SC'S) 24 core capabilities and the mission of multiple SC program offices, including ASCR, BER, BES, and HEP programs. LBNL is located on a 202-acre site in the hills above the University of California, Berkeley campus, employs approximately 3,400 full time employees, and is home to five SC national user facilities: the Advanced Light Source, the Energy Sciences Network, the Joint Genome Institute, the Molecular Foundry, and the National Energy Research Scientific Computing Center. In FY 2016, over 11,000 researchers used these facilities, representing roughly one third of the total for all SC user facilities. In pursuing the SC mission, LBNL leverages collaborative science to bring together teams of individuals with different fields of expertise to work together on common solutions to the SC mission. However, these research activities must be executed with a unique caution since LBNL is located less than one mile from the Hayward Fault and less than 25 miles from the San Andreas Fault, which would both pose a life safety risk to employees, visitors, and guests during a significant seismic event.

The U.S. Geological Survey's earthquake forecast, the third Uniform California Earthquake Rupture Forecast, states a 98 percent probability of a 6.0 magnitude or higher earthquake in the San Francisco Bay Area before 2043. Recent engineering evaluations from a San Francisco Bay Area structural engineering firm have identified significant and extensive seismic safety hazards in critical LBNL support buildings, including the Cafeteria and Health Services. Structural deficiencies identified in these buildings will likely cause significant structural damage with life safety hazards during a magnitude 6.0+ earthquake on the Hayward Fault or a magnitude 8.3 earthquake on the San Andreas Fault and will impede LBNL's ability to resume operations.

The SSM project will address seismic safety issues and emergency response capabilities, specifically related to facilities with large congregation areas as well as transportation capabilities that are necessary for emergency response personnel and maintaining continuity of operations. Demolition of the existing cafeteria and site preparation activities are being conducted prior to CD-2 under the CD-3A authorization to minimize risks and schedule delays and ultimately allow for construction of a new, more sustainable, and operationally resilient facility. Additional supporting functions such as utilities or site modifications may be included in the project if they are deemed necessary.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| New Facility to include a Cafeteria, Health Services & Operational Support Services | ▪ 35,000 gross square feet (gsf).<br>▪ Meet requirements of Risk Category III of the CBC. | ▪ 60,000 gsf<br>▪ N/A |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 12,000 | 12,000 | 7,590 | – |
| FY 2022 | – | – | 1,200 | – |
| FY 2023 | – | – | 3,210 | – |
| **Total, Design (TEC)** | **12,000** | **12,000** | **12,000** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 3,000 | 3,000 | – | – |
| FY 2022 | 18,000 | 18,000 | – | – |
| FY 2022 - IRA Supp. | 22,500 | 22,500 | – | – |
| FY 2023 | 27,500 | 27,500 | 6,000 | 8,000 |
| FY 2024 | 40,000 | 40,000 | 10,500 | 14,500 |
| Outyears | 18,000 | 18,000 | 90,000 | – |
| **Total, Construction (TEC)** | **129,000** | **129,000** | **106,500** | **22,500** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 15,000 | 15,000 | 7,590 | – |
| FY 2022 | 18,000 | 18,000 | 1,200 | – |
| FY 2022 - IRA Supp. | 22,500 | 22,500 | – | – |
| FY 2023 | 27,500 | 27,500 | 9,210 | 8,000 |
| FY 2024 | 40,000 | 40,000 | 10,500 | 14,500 |
| Outyears | 18,000 | 18,000 | 90,000 | – |
| **Total, TEC** | **141,000** | **141,000** | **118,500** | **22,500** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 2,651 | 2,651 | 2,651 | – |
| FY 2022 | 260 | 260 | 260 | – |
| FY 2023 | 250 | 250 | 250 | – |
| Outyears | 839 | 839 | 839 | – |
| **Total, OPC** | **4,000** | **4,000** | **4,000** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 17,651 | 17,651 | 10,241 | – |
| FY 2022 | 18,260 | 18,260 | 1,460 | – |
| FY 2022 - IRA Supp. | 22,500 | 22,500 | – | – |
| FY 2023 | 27,750 | 27,750 | 9,460 | 8,000 |
| FY 2024 | 40,000 | 40,000 | 10,500 | 14,500 |
| Outyears | 18,839 | 18,839 | 90,839 | – |
| **Total, TPC** | **145,000** | **145,000** | **122,500** | **22,500** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 10,300 | 8,300 | **N/A** |
| Design - Contingency | 1,700 | 700 | **N/A** |
| **Total, Design (TEC)** | **12,000** | **9,000** | **N/A** |
| Construction | 108,000 | 71,400 | **N/A** |
| Construction - Contingency | 21,000 | 15,000 | **N/A** |
| **Total, Construction (TEC)** | **129,000** | **86,400** | **N/A** |
| **Total, TEC** | **141,000** | **95,400** | **N/A** |
| *Contingency, TEC* | *22,700* | *15,700* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 600 | 200 | **N/A** |
| Conceptual Design | 2,200 | 1,800 | **N/A** |
| OPC - Contingency | 1,200 | 200 | **N/A** |
| **Total, Except D&D (OPC)** | **4,000** | **2,200** | **N/A** |
| **Total, OPC** | **4,000** | **2,200** | **N/A** |
| *Contingency, OPC* | *1,200* | *200* | ***N/A*** |
| **Total, TPC** | **145,000** | **97,600** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***23,900*** | ***15,900*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 15,000 | 27,500 | — | 27,500 | — | 25,400 | 95,400 |
| | OPC | 1,070 | — | — | — | — | 1,130 | 2,200 |
| | TPC | 16,070 | 27,500 | — | 27,500 | — | 26,530 | 97,600 |
| FY 2024 | TEC | 15,000 | 18,000 | 22,500 | 27,500 | 40,000 | 18,000 | 141,000 |
| | OPC | 2,651 | 260 | — | 250 | — | 839 | 4,000 |
| | TPC | 17,651 | 18,260 | 22,500 | 27,750 | 40,000 | 18,839 | 145,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**6. Related Operations and Maintenance Funding Requirements**

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2028 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2078 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | N/A | N/A | N/A | N/A |
| Utilities | 53 | 53 | 2,658 | 2,658 |
| Maintenance and Repair | 318 | 318 | 15,882 | 15,882 |
| Total, Operations and Maintenance | 371 | 371 | 18,540 | 18,540 |

**7. D&D Information**

The new area being constructed in this project is replacing existing facilities.

| | **Square Feet** |
|---|---|
| New area being constructed by this project at LBNL | 35,000 - 60,000 |
| Area of D&D in this project at LBNL | 13,000 - 60,000 |
| Area at LBNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[d] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | 13,000 - 60,000 |

**8. Acquisition Approach**

The LBNL Management and Operating (M&O) Contractor, University of California, will perform the acquisition for this project, overseen by the Berkeley Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Project performance metrics will be performed by in-house management and Project Controls.

[d] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 20-SC-73, CEBAF Renovation and Expansion, TJNAF
## Thomas Jefferson National Accelerator Facility, TJNAF
## Project is for Design and Construction

### 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Continuous Electron Beam Accelerator Facility (CEBAF) Renovation and Expansion (CRE) project is $11,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $46,600,000 to $99,500,000. The preliminary Total Project Cost (TPC) range for this project is $69,300,000 to $102,800,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $90,300,000.

The CEBAF center at TJNAF has inadequate utility systems that are experiencing frequent failures. This project will renovate 131,000 to 250,000 gross square feet (gsf) of existing space in the CEBAF center and the Applied Research Center (ARC), upgrade high risk utility systems, and provide 82,000 to 150,000 gsf of additional space for visitors, users, research, education, and support.

**Significant Changes**

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on March 18, 2020. FY 2024 funds will support design activities, and construction and associated activities. The project received $10,000,000 in Inflation Reduction Act funding which will be used to mitigate the risks of escalation and allow the project schedule to be accelerated.

A Federal Project Director with the appropriate certification has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 7/20/18 | 10/16/19 | 3/18/20 | 4Q FY 2023 | 3Q FY 2024 | 4Q FY 2023 | 4Q FY 2029 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2024 | 4Q FY 2023 | 2Q FY 2023 | N/A |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities;
**CD-3B** – Approve Start of Remaining Construction Activities

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 5,000 | 82,000 | 87,000 | 3,000 | 3,000 | 90,000 |
| FY 2024 | 7,000 | 80,000 | 87,000 | 3,300 | 3,300 | 90,300 |

*Notes:*

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 2. Project Scope and Justification

**Scope**

The scope of the CRE project will include renovating 131,000 to 250,000 gsf of existing space and providing 82,000 to 150,000 gsf of additional office and laboratory space (including acquisition of the ARC) for 120 to 200 research, education, and support staff. The renovation will include reconfiguration to provide more functional, flexible, and efficient spaces that meet current code standards. CRE will replace the mechanical systems in the existing CEBAF Center, which have exceeded their service life and experienced multiple failures. The renovated building will be energy sustainable and will meet modern building performance standards, including energy conservation, green building principles, and sustainable design. Upon completion, SC will relocate administrative and support staff from the Service Support Center (SSC) (leased space) and CEBAF into the ARC, and TJNAF will dedicate the CEBAF Center to scientific staff which will collectively and efficiently address functional workspace needs for TJNAF staff and users.

**Justification**

With nearly 1,600 users, TJNAF supports one of the largest nuclear physics user communities in the world. The expanded scientific scope associated with the 12 GeV upgrade (e.g., double the energy with simultaneous delivery to four experimental halls) is creating more and larger collaborations, requiring more technical workshops, and resulting in more visitors to the Laboratory. The Laboratory expects staff and user population to increase 2 percent per year for the next 10 years and will soon exceed available space, which is already near capacity. Further, TJNAF is actively pursuing several large inter-entity transfer projects such as the cryomodules and cryogenics plants for Linac Coherent Light Source (LCLS)-I, LCLS-II-High Energy, Facility for Rare Isotope Beams (FRIB), and the Utilities Upgrade Project (UUP) that will require additional staffing. TJNAF will continue to play a key role in the design and development of emerging SC initiatives.

Currently, TJNAF is lacking technically equipped and functional space to accommodate advanced scientific research and major missions on the immediate horizon. The existing CEBAF Center is well beyond full capacity. The current occupant density of this building is 110 gsf per occupant which is significantly below the DOE standard of 180 gsf per occupant. In addition, utility systems at the CEBAF center are inadequate, failing, and inefficient for the existing usage.

TJNAF also continues to advance a strategic campus plan designed to deliver more efficient, collaborative, and functional workspaces by consolidating the Laboratory workforce scattered over several leased buildings into a single center. The project consolidates workers currently housed in the ARC and SSC leased spaces to address functional workspace needs more efficiently for TJNAF staff and users, allows leases to be discontinued, and reduces the cost to sustain existing buildings and infrastructure. This project will provide upgraded laboratories and additional space for visitors, users, research, education, and support especially for new science capabilities such as 12 GeV and the newly planned Electron Ion Collider (EIC) at BNL. The CRE project will be designed to support climate resilience by accounting for projected changes in temperature and precipitation, energy and water efficiency, and enhanced monitoring of assets to reduce the risk of failure.

TJNAF must be prepared to accommodate planned staff and user growth which means additional office space must be available soon. The Laboratory is pursuing Major Items of Equipment (MIEs), several large inter-entity transfer projects for other national laboratories, and a pivotal technical role in the proposed EIC at BNL.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| CEBAF Center Renovation | 66,000 gsf | 128,000 gsf |
| CEBAF Center Expansion | 22,000 gsf | 57,000 gsf |
| ARC Renovation | 65,000 gsf | 122,000 gsf |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 4,000 | 4,000 | 3,311 | – |
| FY 2022 | – | – | 489 | – |
| FY 2023 | 2,000 | 2,000 | 1,200 | – |
| FY 2024 | 1,000 | 1,000 | 2,000 | – |
| **Total, Design (TEC)** | **7,000** | **7,000** | **7,000** | **–** |
| Construction (TEC) | | | | |
| FY 2022 | 10,000 | 10,000 | – | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 13,000 | 13,000 | 4,000 | – |
| FY 2024 | 10,000 | 10,000 | 3,000 | – |
| FY 2024 - IRA Supp. | – | – | – | 10,000 |
| Outyears | 37,000 | 37,000 | 63,000 | – |
| **Total, Construction (TEC)** | **80,000** | **80,000** | **70,000** | **10,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 4,000 | 4,000 | 3,311 | – |
| FY 2022 | 10,000 | 10,000 | 489 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 15,000 | 15,000 | 5,200 | – |
| FY 2024 | 11,000 | 11,000 | 5,000 | – |
| FY 2024 - IRA Supp. | – | – | – | 10,000 |
| Outyears | 37,000 | 37,000 | 63,000 | – |
| **Total, TEC** | **87,000** | **87,000** | **77,000** | **10,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 1,492 | 1,492 | 1,492 | – |
| FY 2023 | 600 | 600 | 600 | – |
| Outyears | 1,208 | 1,208 | 1,208 | – |
| **Total, OPC** | **3,300** | **3,300** | **3,300** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 5,492 | 5,492 | 4,803 | – |
| FY 2022 | 10,000 | 10,000 | 489 | – |
| FY 2022 - IRA Supp. | 10,000 | 10,000 | – | – |
| FY 2023 | 15,600 | 15,600 | 5,800 | – |
| FY 2024 | 11,000 | 11,000 | 5,000 | – |
| FY 2024 - IRA Supp. | – | – | – | 10,000 |
| Outyears | 38,208 | 38,208 | 64,208 | – |
| **Total, TPC** | **90,300** | **90,300** | **80,300** | **10,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 6,000 | 3,500 | **N/A** |
| Design - Contingency | 1,000 | 1,500 | **N/A** |
| **Total, Design (TEC)** | **7,000** | **5,000** | **N/A** |
| Construction | 63,000 | 65,000 | **N/A** |
| Construction - Contingency | 17,000 | 17,000 | **N/A** |
| **Total, Construction (TEC)** | **80,000** | **82,000** | **N/A** |
| **Total, TEC** | **87,000** | **87,000** | **N/A** |
| *Contingency, TEC* | *18,000* | *18,500* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 2,700 | 2,400 | **N/A** |
| Conceptual Design | 600 | 400 | **N/A** |
| OPC - Contingency | N/A | 200 | **N/A** |
| **Total, Except D&D (OPC)** | **3,300** | **3,000** | **N/A** |
| **Total, OPC** | **3,300** | **3,000** | **N/A** |
| *Contingency, OPC* | ***N/A*** | *200* | ***N/A*** |
| **Total, TPC** | **90,300** | **90,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***18,000*** | ***18,700*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 4,000 | 10,000 | — | 2,000 | — | 71,000 | 87,000 |
| | OPC | 1,467 | — | — | 600 | — | 933 | 3,000 |
| | TPC | 5,467 | 10,000 | — | 2,600 | — | 71,933 | 90,000 |
| FY 2024 | TEC | 4,000 | 10,000 | 10,000 | 15,000 | 11,000 | 37,000 | 87,000 |
| | OPC | 1,492 | — | — | 600 | — | 1,208 | 3,300 |
| | TPC | 5,492 | 10,000 | 10,000 | 15,600 | 11,000 | 38,208 | 90,300 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2079 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 288 | 288 | 14,400 | 14,400 |
| Utilities | 432 | 432 | 21,600 | 21,600 |
| Maintenance and Repair | 1,008 | 1,008 | 50,400 | 50,400 |
| Total, Operations and Maintenance | 1,728 | 1,728 | 86,400 | 86,400 |

### 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at TJNAF ........ | 82,000 – 150,000 |
| Area of D&D in this project at TJNAF........ | None |
| Area at TJNAF to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None[e] |
| Area of D&D in this project at other sites ........ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None |
| Total area eliminated ........ | None |

[e] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The TJNAF Management and Operating (M&O) contractor, Jefferson Science Associates, will perform the acquisition for this Design-Bid-Build project, overseen by the Thomas Jefferson Site Office. The M&O contractor will be responsible for awarding and administering all subcontracts related to this project. Its annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

**20-SC-77, Argonne Utilities Upgrade, ANL**
**Argonne National Laboratory, ANL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Argonne Utilities Upgrade (AU2) project is $8,007,000 of Total Estimated Cost (TEC) funding. The preliminary TEC range for this project is $172,000,000 to $290,250,000. The preliminary Total Project Cost (TPC) range for this project is $173,000,000 to $291,250,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $216,000,000.

AU2 is proposed to revitalize and selectively upgrade ANL's existing major utility systems including steam, water, sanitary sewer, chilled water, and electrical systems.

To facilitate its execution, the AU2 project is comprised of two subprojects consisting of scope needed to achieve complete and usable assets:

- **Chilled Water and Utility Piping:** Consists of site preparation, demolition and construction of a new chilled water plant.

- **Steam and Utility Piping:** Consists of construction of a new steam plant and repair, replacement, and modernization of several major utility systems, including steam and condensate, domestic water, canal water and sewer systems.

**Significant Changes**

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on July 1, 2021. FY 2024 funds will support design and preparatory construction activities.

A Federal Project Director working towards the appropriate certification level was assigned to this project.

**Critical Milestone History**

| | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| AU2 - Overall, ANL | 5/17/19 | 10/30/20 | 7/1/21 | 2Q FY 2030 | 1Q FY 2030 | 2Q FY 2030 | 4Q FY 2034 |
| AU2 - Chilled Water Plant , ANL | – | – | – | 2Q FY 2026 | 1Q FY 2026 | 2Q FY 2027 | 4Q FY 2030 |
| AU2 - Steam Plant and Utility Piping, ANL | – | – | – | 2Q FY 2030 | 1Q FY 2030 | 2Q FY 2030 | 4Q FY 2034 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| | Performance Baseline Validation | CD-3A |
|---|---|---|
| AU2 - Overall, ANL | 3Q FY2024 | N/A |
| AU2 - Chilled Water Plant , ANL | 2Q FY 2026 | 2Q FY 2026 |
| AU2 - Steam Plant and Utility Piping, ANL | 2Q FY 2030 | – |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 37,500 | 177,500 | 215,000 | 1,000 | 1,000 | 216,000 |
| FY 2024 | 37,500 | 177,500 | 215,000 | 1,000 | 1,000 | 216,000 |

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**2. Project Scope and Justification**

**Scope**

The preliminary scope of the AU2 project includes upgrading failing 1940s-era utilities across the ANL campus. These utilities include steam, water, sanitary sewer, chilled water, and electrical systems. The specifics of these procurements will be reviewed and approved in support of CD-3A to purchase long-lead electrical equipment.

**Justification**

An efficient, maintainable, and reliable infrastructure is critical to the success and mission capability of ANL's research facilities. Due to their age and limitations to meeting modern demands, there is a mission need to revitalize and selectively upgrade ANL's existing major utility systems including steam, water, sanitary sewer, chilled water and electrical systems. For example, steam is a critical infrastructure for Argonne facilities; improving the performance and resilience of this plant would prevent catastrophic climate related damage to buildings and major pieces of scientific equipment. Additionally, the Advanced Photon Source (APS) is dependent on the steam utility for holding extremely tight temperature and humidity ranges required for beam line operations and stability requirements and would operate more efficiently and effectively with modern engineered controls.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Utility Plants (Chilled Water, Steam & Condensate) | ▪ Construct new combined 6,300-ton chilled water plant with N+1 reliability and boiler house with peak demand of 250,000 lbs./hour of 200 psi saturated steam with N+1 reliability. | ▪ Equipment & controls upgrades at the 371, 450, and 528 chilled water plants.<br>▪ Potential capacity upgrades, new equipment, equipment replacements, and various other utility system reliability projects to increase reliability of laboratory internal utilities. |
| Utility Piping (Chilled Water, Steam & Condensate, Sewer, Domestic, Lab, & Canal Water) | ▪ Repair, replace or construct new distribution piping for 7,500 linear feet of utility piping and support structures (e.g., vaults, pipe supports, valves, culverts, etc.) | ▪ Replace or construct new distribution piping for up to 15,000 linear feet of utility piping and support structures (e.g., vaults, pipe supports, valves, culverts, etc.)<br>▪ Install between 50 and 250 new smart meters. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 10,000 | 10,000 | 2,063 |
| FY 2023 | 8,000 | 8,000 | 6,000 |
| FY 2024 | 6,000 | 6,000 | 12,000 |
| Outyears | 12,500 | 12,500 | 17,437 |
| **Total, Design (TEC)** | **37,500** | **37,500** | **37,500** |
| Construction (TEC) | | | |
| FY 2024 | 2,007 | 2,007 | – |
| Outyears | 175,493 | 175,493 | 177,500 |
| **Total, Construction (TEC)** | **177,500** | **177,500** | **177,500** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 10,000 | 10,000 | 2,063 |
| FY 2023 | 8,000 | 8,000 | 6,000 |
| FY 2024 | 8,007 | 8,007 | 12,000 |
| Outyears | 187,993 | 187,993 | 194,937 |
| **Total, TEC** | **215,000** | **215,000** | **215,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 1,000 | 1,000 | 1,000 |
| **Total, OPC** | **1,000** | **1,000** | **1,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 2,000 | 2,000 | 1,000 |
| FY 2022 | 10,000 | 10,000 | 2,063 |
| FY 2023 | 8,000 | 8,000 | 6,000 |
| FY 2024 | 8,007 | 8,007 | 12,000 |
| Outyears | 187,993 | 187,993 | 194,937 |
| **Total, TPC** | **216,000** | **216,000** | **216,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 30,000 | 30,000 | **N/A** |
| Design - Contingency | 7,500 | 7,500 | **N/A** |
| **Total, Design (TEC)** | **37,500** | **37,500** | **N/A** |
| Construction | 142,000 | 142,000 | **N/A** |
| Construction - Contingency | 35,500 | 35,500 | **N/A** |
| **Total, Construction (TEC)** | **177,500** | **177,500** | **N/A** |
| **Total, TEC** | **215,000** | **215,000** | **N/A** |
| *Contingency, TEC* | *43,000* | *43,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 1,000 | 1,000 | **N/A** |
| **Total, Except D&D (OPC)** | **1,000** | **1,000** | **N/A** |
| **Total, OPC** | **1,000** | **1,000** | **N/A** |
| *Contingency, OPC* | ***N/A*** | *N/A* | ***N/A*** |
| **Total, TPC** | **216,000** | **216,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***43,000*** | ***43,000*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 1,000 | 500 | 8,000 | — | 205,500 | 215,000 |
| | OPC | 1,000 | — | — | — | — | 1,000 |
| | TPC | 2,000 | 500 | 8,000 | — | 205,500 | 216,000 |
| FY 2024 | TEC | 1,000 | 10,000 | 8,000 | 8,007 | 187,993 | 215,000 |
| | OPC | 1,000 | — | — | — | — | 1,000 |
| | TPC | 2,000 | 10,000 | 8,000 | 8,007 | 187,993 | 216,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | Subproject 1 – 4Q FY 2030<br>Subproject 2 – 4Q FY 2034 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | N/A |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs[f] | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | 2,955 | N/A | 147,750 |
| Utilities | N/A | 4,423 | N/A | 221,150 |
| Maintenance and Repair | N/A | 739 | N/A | 36,950 |
| Total, Operations and Maintenance | N/A | 8,117 | N/A | 405,850 |

[f] Life-Cycle costs will be performed as part of CD-1.

## 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at ANL ........ | None |
| Area of D&D in this project at ANL........ | None |
| Area at ANL to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None [g] |
| Area of D&D in this project at other sites ........ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None |
| Total area eliminated ........ | None |

## 8. Acquisition Approach

The ANL Management and Operating (M&O) Contractor, UChicago Argonne, LLC, will perform the acquisition for this project, overseen by the Argonne Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Project performance metrics will be performed by in-house management and Project Controls.

[g] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with the decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-78, Linear Assets Modernization Project, LBNL**
**Lawrence Berkeley National Laboratory, LBNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Linear Assets Modernization Project (LAMP) is $18,900,000 of Total Estimated Cost (TEC) funding. The preliminary TEC range for this project is $164,000,000 to $376,000,000. The preliminary Total Project Cost (TPC) range for this project is $170,000,000 to $386,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $242,000,000.

LAMP will upgrade high priority utility systems to increase the reliability, capability, resilience, and safety of LBNL's infrastructure to meet DOE's mission. The project will upgrade utility systems, including, but not limited to, domestic water, natural gas, storm drain, sanitary sewer, electrical, and communication.

**Significant Changes**

This project was initiated in the FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) for LAMP, CD-1, Approve Alternative Selection and Cost Range, was for the entire project and was approved on April 13, 2022.

To facilitate its execution, LAMP is comprised of two subprojects consisting of scope needed to achieve complete and usable assets:

- The Grizzly Substation/Lawrence Corridor Subproject will focus on increasing the Lab's primary electrical substation to provide new switch stations and systems capable of supporting all existing and future lab loads, distributing power for advanced supercomputing needs (NERSC), and upgrading multiple utility systems including IT/communications, natural gas, compressed air, sanitary sewer, and storm drain/hydraugers, providing for overall increased reliability and ease of maintenance.
- The East Canyon-McMillan Subproject will establish common utility corridors for high voltage duct banks which will be developed to segregate lines and upgrade multiple utility systems, including IT/communication, natural gas, compressed air, domestic water, sanitary sewer, and storm drain/ hydraugers providing for overall increased reliability and ease of maintenance.

A Level 2 Federal Project Director, working towards the appropriate certification level, was assigned to this project at CD-1.

**Critical Milestone History**

**20-SC-78 Linear Assets Modernization Project, LBNL**

| | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| LAMP - Overall, LBNL | 5/17/19 | 4/13/22 | 4/13/22 | 1Q FY 2027 | 1Q FY 2027 | 1Q FY 2027 | 4Q FY 2031 |
| LAMP - Grizzly Sub - Lawrence Corridor, LBNL | – | – | – | 2Q FY 2026 | 2Q FY 2026 | 2Q FY 2026 | 1Q FY 2029 |
| LAMP - McMillan and East Canyon Corridors, LBNL | – | – | – | 1Q FY 2027 | 1Q FY 2027 | 1Q FY 2027 | 4Q FY 2031 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

**20-SC-78 Linear Assets Modernization Project, LBNL**

| | Performance Baseline Validation | CD-3A |
|---|---|---|
| LAMP - Overall, LBNL | 1Q FY 2027 | 1Q FY 2026 |
| LAMP - Grizzly Sub - Lawrence Corridor, LBNL | 2Q FY 2026 | 1Q FY 2026 |
| LAMP - McMillan and East Canyon Corridors, LBNL | 1Q FY 2027 | – |

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 50,000 | 186,000 | 236,000 | 6,000 | 6,000 | 242,000 |
| FY 2024 | 50,000 | 186,000 | 236,000 | 6,000 | 6,000 | 242,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**2. Project Scope and Justification**

**Scope**

LAMP will upgrade the highest priority utility systems to increase the reliability, capability, and safety of LBNL's infrastructure to meet the DOE's mission. The utility systems include, but are not limited to, domestic water, natural gas, storm drain, sanitary sewer, electrical, and communication.

The project will aim to upgrade the most critical utility components considering operational risk and efficiencies, redundancy, utility bundling, and capacity needed for strategic growth including expanding the primary switching substation at Grizzly Peak to power the NERSC to full capacity. LAMP will implement a multi-system approach for the repair and improvement of LBNL's utility assets, considering geographical limitations as well as potential synergies with nearby sustainment and improvement projects, that provide opportunities for enhancement.

FY2024 funds will support long-lead procurement activities after the appropriate CD approval. The specifics of these procurements will be reviewed and approved in support of the CD-3A to procure electrical equipment.

**Justification**

SC uses the capabilities of LBNL to execute 23 of the 24 core capabilities and the mission of multiple SC program offices, including ASCR, BER, BES, and HEP. The SC mission and multiple scientific programs require increased reliability, capability, and safety of LBNL's utility infrastructure. Utility infrastructure represents almost half of LBNL's large, deferred maintenance backlog and represents a significant capability gap in LBNL's ability to provide reliable and safe services to meet DOE's mission needs. Direct infrastructure investment is necessary to address deferred maintenance reduction, restore operational reliability, increase resiliency, and provide the backbone necessary for scientific advancements. Existing infrastructure is insufficient to support planned facility modernization and growth. Without a modern utility infrastructure backbone, future growth of the science mission at LBNL may not be achievable.

LBNL has begun measures to strengthen the laboratory's resilience to outages due to planned safety outages or natural phenomena such as earthquake, wildfire, and extreme weather. The mission need of this project is to modernize distributed utilities to increase reliability, resilience, and capacity to meet growing demands. The first sub-project of the LAMP project will enable an optimized NERSC-10 upgrade which will play a central role in breakthrough science.

LAMP will deliver modern and resilient general-purpose infrastructure which will be more efficient and sustainable. For example, the underground utility corridors will not only be upgraded to the best available technology but will be designed to be maintainable and monitored using artificial intelligence to enable predictive maintenance.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)
The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

<table>
<tr><th>Performance Measure</th><th>Threshold</th><th>Objective</th></tr>
<tr><td rowspan="2">Storm Drainage System, Hydrauger/ Slope Stability</td><td rowspan="2">Install 1,000 Linear Feet of hydraugers.</td><td>Install up to 2,500 Linear Feet of hydraugers. (Lawrence Corridor).</td></tr>
<tr><td>Install up to 3,000 Linear Feet of hydraugers. (East Canyon/McMillan Corridor).</td></tr>
<tr><td rowspan="3">Sanitary Sewer</td><td rowspan="3">Install 150 Linear Feet of pipe.</td><td>Install up to 2,500 Linear Feet of pipe. (Lawrence Corridor).</td></tr>
<tr><td>Install up to 3,500 Linear Feet of pipe. (McMillan Corridor).</td></tr>
<tr><td>Install up to 1,000 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor).</td></tr>
<tr><td rowspan="2">High Pressure City Water</td><td rowspan="2">Install 1,500 Linear Feet of pipe.</td><td>Install up to 3,500 Linear Feet of pipe. (East Canyon Corridor).</td></tr>
<tr><td>Install up to 2,000 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor).</td></tr>
<tr><td rowspan="4">Communications & Data</td><td rowspan="4">Install 2,600 Linear Feet of ductbank.</td><td>Install up to 4,000 Linear Feet of ductbank with manholes and cables. (Lawrence Corridor).</td></tr>
<tr><td>Install up to 2,500 Linear Feet of ductbank with manholes and cables. (East Canyon Corridor).</td></tr>
<tr><td>Install up to 1,500 Linear Feet of ductbank with manholes and cables along the electrical distribution loop corridors. (East Canyon Corridor).</td></tr>
<tr><td>Install up to 1,500 Linear Feet of ductbank with manholes and cables. (McMillan Corridor).</td></tr>
</table>

| Performance Measure | Threshold | Objective |
|---|---|---|
| | | Install up to 5,000 Linear Feet of ductbank with manholes and cables along the electrical distribution loop corridors. (McMillan Corridor). |
| Electrical Distribution/Grizzly Substation | Expand the Grizzly Substation to 70 MW capacity. | Expand the Grizzly Substation up to 150 MW capacity with two redundant lines with SCADA for new equipment. |
| | | Provide a new SCADA Control Building. |
| | | Provide two remote SCADA Control Rooms. |
| | | Provide SCADA remote control and monitoring of existing and new circuit breakers. |
| | | Install up to 400 Linear Feet of electrical feeders segregating lines 1 and 2 for SW-A1. |
| | | Install SCADA for existing 115kV equipment. |
| Electrical Distribution/Grizzly Substation (Con't) | Install 1,500 Linear Feet of electrical feeders segregating lines 1 and 2. (Lawrence Corridor). | Install up to 3,500 Linear Feet of electrical feeders segregating lines 1 and 2. |
| | | Feed B59 (NERSC) with up to 80 MW of electrical power with 3,500 Linear Feet of redundant and segregated lines. |
| | | Install up to 2,000 Linear Feet of electrical feeders and Pad Mounted Switches for electrical distribution loops, segregating lines 1 and 2. |
| | | Provide SCADA remote control and monitoring of existing and new circuit breakers. |
| | Install 1,200 Linear Feet of electrical feeders segregating lines 1 and 2. (East Canyon/McMillan Corridor). | Install up to 2,600 Linear Feet of electrical feeders segregating lines 1 and 2. (East Canyon Corridor). |
| | | Install up to 5,700 Linear Feet of electrical feeders and Pad Mounted Switches for electrical distribution loops, segregating lines 1 and 2. (East Canyon Corridor). |
| | | Provide SCADA remote control and monitoring of existing and new circuit breakers. (East Canyon Corridor). |
| | Install 1,200 Linear Feet of electrical feeders segregating lines 1 and 2. (East Canyon/McMillan Corridor) (Con't). | Install up to 2,200 Linear Feet of electrical feeders segregating lines 1 and 2. (McMillan Corridor). |
| | | Install up to 6,300 Linear Feet of electrical feeders and Pad Mounted Switches for electrical distribution loops, segregating lines 1 and 2. (McMillan Corridor). |
| | | Provide SCADA remote control and monitoring of existing and new circuit breakers. (McMillan Corridor). |
| Natural Gas | Install 200 Linear Feet of pipe. | Install up to 1,000 Linear Feet of pipe. (Lawrence Corridor). |

| Performance Measure | Threshold | Objective |
|---|---|---|
| | | Install up to 2,500 Linear Feet of pipe. (McMillan Corridor). |
| | | Install up to 2,000 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor). |
| Compressed Air | Not Applicable | Install up to 3,500 Linear Feet of pipe. (Lawrence Corridor). |
| | | Install up to 3,500 Linear Feet of pipe. (East Canyon Corridor). |
| | | Install up to 2,500 Linear Feet of pipe. (McMillan Corridor). |
| | | Install up to 1,500 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor). |
| Controls/Artificial Intelligence | Not Applicable | Install up to 40 Smart Meters for new wet utility construction. (Lawrence Corridor). |
| | | Provide integration with SCADA. (Lawrence Corridor). |
| | | Provide integration with Microgrid enhancement. (Lawrence Corridor). |
| | | Install up to 60 Smart Meters for new wet utility construction. (East Canyon Corridor). |
| | | Install up to 50 Smart Meters for new wet utility construction. (McMillan Corridor). |
| | | Provide integration with SCADA. (East Canyon/McMillan Corridors). |
| | | Provide integration with Microgrid enhancement. (East Canyon/McMillan Corridors). |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 10,400 | 10,400 | 6,000 |
| FY 2023 | 21,600 | 21,600 | 9,000 |
| FY 2024 | – | – | 13,000 |
| Outyears | 17,000 | 17,000 | 22,000 |
| **Total, Design (TEC)** | **50,000** | **50,000** | **50,000** |
| Construction (TEC) | | | |
| FY 2023 | 1,825 | 1,825 | – |
| FY 2024 | 18,900 | 18,900 | – |
| Outyears | 165,275 | 165,275 | 186,000 |
| **Total, Construction (TEC)** | **186,000** | **186,000** | **186,000** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 10,400 | 10,400 | 6,000 |
| FY 2023 | 23,425 | 23,425 | 9,000 |
| FY 2024 | 18,900 | 18,900 | 13,000 |
| Outyears | 182,275 | 182,275 | 208,000 |
| **Total, TEC** | **236,000** | **236,000** | **236,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 2,317 | 2,317 | 2,317 |
| FY 2022 | 946 | 946 | 946 |
| Outyears | 2,737 | 2,737 | 2,737 |
| **Total, OPC** | **6,000** | **6,000** | **6,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 3,317 | 3,317 | 2,317 |
| FY 2022 | 11,346 | 11,346 | 6,946 |
| FY 2023 | 23,425 | 23,425 | 9,000 |
| FY 2024 | 18,900 | 18,900 | 13,000 |
| Outyears | 185,012 | 185,012 | 210,737 |
| **Total, TPC** | **242,000** | **242,000** | **242,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 38,500 | 49,000 | **N/A** |
| Design - Contingency | 11,500 | 1,000 | **N/A** |
| **Total, Design (TEC)** | **50,000** | **50,000** | **N/A** |
| Construction | 144,000 | 135,000 | **N/A** |
| Construction - Contingency | 42,000 | 51,000 | **N/A** |
| **Total, Construction (TEC)** | **186,000** | **186,000** | **N/A** |
| **Total, TEC** | **236,000** | **236,000** | **N/A** |
| *Contingency, TEC* | *53,500* | *52,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Design | 2,610 | 3,600 | **N/A** |
| Start-up | 2,190 | 1,200 | **N/A** |
| OPC - Contingency | 1,200 | 1,200 | **N/A** |
| **Total, Except D&D (OPC)** | **6,000** | **6,000** | **N/A** |
| **Total, OPC** | **6,000** | **6,000** | **N/A** |
| *Contingency, OPC* | *1,200* | *1,200* | ***N/A*** |
| **Total, TPC** | **242,000** | **242,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***54,700*** | ***53,200*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 1,000 | 500 | 23,425 | — | 211,075 | 236,000 |
| | OPC | 2,423 | 1,000 | — | — | 2,577 | 6,000 |
| | TPC | 3,423 | 1,500 | 23,425 | — | 213,652 | 242,000 |
| FY 2024 | TEC | 1,000 | 10,400 | 23,425 | 18,900 | 182,275 | 236,000 |
| | OPC | 2,317 | 946 | — | — | 2,737 | 6,000 |
| | TPC | 3,317 | 11,346 | 23,425 | 18,900 | 185,012 | 242,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2031 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | N/A |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 1,200 | 1,200 | 60,000 | 60,000 |
| Utilities | 12 | 12 | 600 | 600 |
| Maintenance and Repair | 3,000 | 3,000 | 150,000 | 150,000 |
| Total, Operations and Maintenance | 4,212 | 4,212 | 210,600 | 210,600 |

### 7. D&D Information

This project replaces critical infrastructure components; no new construction area is anticipated to be constructed in this project and it will not replace existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at LBNL........................................ | None |
| Area of D&D in this project at LBNL........................................ | None |
| Area at LBNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................ | None[a] |
| Area of D&D in this project at other sites ........................................ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................ | None |
| Total area eliminated ........................................ | None |

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with the decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The LBNL Management and Operating (M&O) Contractor, University of California will perform the acquisition for this project, overseen by the Berkeley Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Project performance metrics will be performed by in-house management and Project Controls.

**20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC**
**SLAC National Accelerator Laboratory, SLAC**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Critical Utilities Infrastructure Revitalization (CUIR) project is $35,075,000 of Total Estimated Cost (TEC) funding. The preliminary Total Estimated Cost (TEC) range for this project is $160,000,000 to $306,000,000. The preliminary Total Project Cost (TPC) range for this project is $164,500,000 to $310,500,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $208,500,000.

The primary objective of this project is to close utilities infrastructure gaps, such as utility piping breaks, power fluctuations, faults, and cooling water interruptions, to support multi-program science missions at SLAC. Evolving technologies, instruments, experimental parameters, sensitivities, and complexity require increased reliability, resiliency, and service levels in electrical, mechanical, and civil systems site wide. The CUIR project will address the critical campus-wide utility and infrastructure issues by replacing, repairing, and modernizing the highest risk water/fire protection, sanitary sewer, storm drain, electrical, and cooling water system deficiencies. These needs have been identified through condition assessments, inspections, and recommendations from subject matter experts responsible for stewardship of the systems.

To facilitate its execution, CUIR is comprised of three subprojects consisting of scope needed to achieve complete and usable assets:

- Critical Electrical Work Subproject to replace and upgrade electrical components that present the greatest risk of failure or substandard performance of the Linac and associated Science projects.
- Linac Utilities and Equipment Subproject will replace and reconfigure various electrical and mechanical equipment components and domestic/fire water piping.
- Sitewide Utilities Subproject will replace waveguide water heat exchangers, controls, and pumps.

**Significant Changes**

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternatives Selection and Cost Range, which was approved on January 21, 2022.

FY 2024 funds will support long-lead procurement and early construction activities after the appropriate CD approvals.

A Federal Project Director working towards the appropriate certification level was assigned to this project.

**Critical Milestone History**

| | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| CUIR - Overall, SLAC | 5/17/19 | 4/15/21 | 1/21/22 | 3Q FY 2028 | 1Q FY 2028 | 3Q FY 2028 | 1Q FY 2034 |
| CUIR - Critical Electrical Work, SLAC | – | – | – | 4Q FY 2024 | 2Q FY 2024 | 4Q FY 2024 | 4Q FY 2026 |
| CUIR - Linac Utilities and Equipment, SLAC | – | – | – | 4Q FY 2025 | 2Q FY 2025 | 4Q FY 2025 | 4Q FY 2030 |
| CUIR - Sitewide Utilities, SLAC | – | – | – | 3Q FY 2028 | 1Q FY 2028 | 3Q FY 2028 | 1Q FY 2034 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| | Performance Baseline Validation | CD-3A |
|---|---|---|
| CUIR - Overall, SLAC | 3Q FY 2028 | 3Q FY 2023 |
| CUIR - Critical Electrical Work, SLAC | 4Q FY 2025 | 3Q FY 2023 |
| CUIR - Linac Utilities and Equipment, SLAC | – | – |
| CUIR - Sitewide Utilities, SLAC | – | – |

**CD-3A** – Approve Long-Lead Procurements, Original Scope.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 15,000 | 189,000 | 204,000 | 4,500 | 4,500 | 208,500 |
| FY 2024 | 13,000 | 191,000 | 204,000 | 4,500 | 4,500 | 208,500 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

**2. Project Scope and Justification**

**Scope**

CUIR's preliminary scope is to update major electrical gear, instrumentation, and cooling water systems for the two-mile long klystron gallery and accelerator housing constructed in 1962. Additionally, it will upgrade underground domestic water/fire protection, sanitary sewer, and storm drain systems site-wide.

**Justification**

SLAC is currently implementing a Campus Strategy designed to support the DOE Science Mission, increase reliability, and minimize costs through safe, effective, resilient, and efficient operations. The objective of the CUIR project is to reduce risks and close the capability gaps identified in SLAC's infrastructure assessments and surveys as they relate to storm water, sanitary sewer, domestic water/fire protection, electrical, and cooling water systems.

Disruptions caused by power fluctuations, faults, and cooling water interruptions, and utility piping breaks have frequently impacted science research site wide. Electrical systems, pumps, and motors fail, valves on piping systems freeze, and there are inoperable or unsafe electrical components that require broad outages to respond and repair, which impact science research and the greater SLAC population. Workarounds and administrative controls have been placed on existing equipment and systems because they are underrated, not operating as intended, or not designed/operational for today's science needs, which results in create tremendous inefficiencies and safety concerns, and sub-optimized operations. CUIR will retire $18,000,000 in deferred maintenance.

The CUIR project will reduce operational risks in critical infrastructure and utility support systems for all science programs. It will decrease dependency on unique, old, and outdated equipment. If these existing reliability gaps are not fulfilled, the operational efficiency, reliability, productivity, and competitive viability in science programs and other related science research breakthroughs will continue to be impeded.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. The Objective KPPs are shown adjacent to the applicable Threshold KPPs in the following charts. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| **Subproject 1:** Critical Electrical Work | | |
| | Install and test three (3) 12kV circuits. | Install and test (5) 12kV circuits along the 3 km linac to allow independent utility operation of each segment. |
| | Install and test 12 kV Sub-station to provide 3.5MVA power. | Install and test 12 kV Sub-station to provide 5MVA power. |
| | Install and test one new 60MVA (or larger) 230/12kV transformer. | Install and test two new 60MVA (or larger) 230/12kV transformer. |
| | Provide redundant N+1 (N active and one spare) electrical feeder circuits. Install and test Switchgear to allow feeder cable selection. | |
| | Replace monitoring equipment to provide AI/ML input at 9 substation relay doors with 1 integration hub. | Replace monitoring equipment to provide AI/ML input at 12 substation relay doors with 1 integration hub. Also integrate data from the substation, backup generator and transformer into the data-analytics platform. |
| | Install and test 1.5MVA backup generator. | |
| **Subproject 2:** Linac Utilities and Equipment | | |
| | Replace and reconfigure medium-voltage equipment for 4 Variable Voltage Substations (VVS). | |

| Performance Measure | Threshold | Objective |
|---|---|---|
| | Replace low voltage sections for 10 K-subs, 10 VVS and 16 Motor Control Centers (MCC). | |
| | Replace 4 klystron water heat exchangers, 4 controls, and 4 pumps. | |
| | Replace 12,000 linear feet of domestic/fire water piping. Install submeters, flow and pressure sensors at 2 domestic water main branches. | Replace 18,000 linear feet of domestic/fire water piping. Install submeters, flow and pressure sensors at 4 domestic water main branches. |
| | Replace 2,700 linear feet of water main, laterals, and valves. Install 5 backflow preventors and 5 fire hydrants. Install submeter flow and pressure sensors at 1 domestic water key node. | |
| | Replace 1,000 linear feet of sanitary sewer piping. Install sensors to measure sewage flow, Total Dissolved Solids (TDS) at 2 effluent stations. | Install sensors to measure sewage flow, Total Dissolved Solids (TDS) at 5 existing effluent stations. |
| | Replace or re-line 5,000 linear feet of storm drain piping. | Replace or re-line 10,000 linear feet of storm drain piping. |
| | | Integrate substation and water-cooling system monitor output into data-analytics platform. |
| **Subproject 3:** Sitewide Utilities | | |
| | Replace 11 waveguide water heat exchangers, controls, and pumps. | |
| | Replace 3 klystron water heat exchangers, controls, and pumps. | |
| | Replace 11 accelerator, klystron, and waveguide monitoring devices. | |

| Performance Measure | Threshold | Objective |
|---|---|---|
| | Install 2 natural gas main meters, replace 6 existing BTU energy meter, and integrate each into data analytics platform. | Install 4 main gas meters and 8 gas submeters, replace 12 energy BTU meters and integrate each into the data analytics platform. |
| | | Replace 10 programmable logic controller (PLC) to provide AI/ML input. |
| | | Integrate substation and water-cooling system monitor output into data-analytics platform. |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 4,000 | 4,000 | 3,800 |
| FY 2023 | – | – | 1,200 |
| Outyears | 8,000 | 8,000 | 8,000 |
| **Total, Design (TEC)** | **13,000** | **13,000** | **13,000** |
| Construction (TEC) | | | |
| FY 2022 | 4,500 | 4,500 | 2,500 |
| FY 2023 | 25,425 | 25,425 | 20,000 |
| FY 2024 | 35,075 | 35,075 | 25,000 |
| Outyears | 126,000 | 126,000 | 143,500 |
| **Total, Construction (TEC)** | **191,000** | **191,000** | **191,000** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 8,500 | 8,500 | 6,300 |
| FY 2023 | 25,425 | 25,425 | 21,200 |
| FY 2024 | 35,075 | 35,075 | 25,000 |
| Outyears | 134,000 | 134,000 | 151,500 |
| **Total, TEC** | **204,000** | **204,000** | **204,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 1,894 | 1,894 | 1,894 |
| FY 2022 | 778 | 778 | 778 |
| FY 2023 | 50 | 50 | 50 |
| Outyears | 1,778 | 1,778 | 1,778 |
| **Total, OPC** | **4,500** | **4,500** | **4,500** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 2,894 | 2,894 | 1,894 |
| FY 2022 | 9,278 | 9,278 | 7,078 |
| FY 2023 | 25,475 | 25,475 | 21,250 |
| FY 2024 | 35,075 | 35,075 | 25,000 |
| Outyears | 135,778 | 135,778 | 153,278 |
| **Total, TPC** | **208,500** | **208,500** | **208,500** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 11,400 | 12,000 | **N/A** |
| Design - Contingency | 1,600 | 3,000 | **N/A** |
| **Total, Design (TEC)** | **13,000** | **15,000** | **N/A** |
| Construction | 152,000 | 150,000 | **N/A** |
| Construction - Contingency | 39,000 | 39,000 | **N/A** |
| **Total, Construction (TEC)** | **191,000** | **189,000** | **N/A** |
| **Total, TEC** | **204,000** | **204,000** | **N/A** |
| *Contingency, TEC* | *40,600* | *42,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 3,200 | 2,700 | **N/A** |
| Conceptual Design | 1,300 | 1,800 | **N/A** |
| **Total, Except D&D (OPC)** | **4,500** | **4,500** | **N/A** |
| **Total, OPC** | **4,500** | **4,500** | **N/A** |
| *Contingency, OPC* | ***N/A*** | *N/A* | ***N/A*** |
| **Total, TPC** | **208,500** | **208,500** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***40,600*** | ***42,000*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 1,000 | 500 | 25,425 | — | 177,075 | 204,000 |
| | OPC | 1,895 | — | — | — | 2,605 | 4,500 |
| | TPC | 2,895 | 500 | 25,425 | — | 179,680 | 208,500 |
| FY 2024 | TEC | 1,000 | 8,500 | 25,425 | 35,075 | 134,000 | 204,000 |
| | OPC | 1,894 | 778 | 50 | — | 1,778 | 4,500 |
| | TPC | 2,894 | 9,278 | 25,475 | 35,075 | 135,778 | 208,500 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2034 |
| Expected Useful Life | Average 30 years (based system) |
| Expected Future Start of D&D of this capital asset | 1Q FY 2064 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 7,805 | 8,673 | 885,000 | 260,176 |
| Utilities | 14,940 | 10,487 | 158,930 | 314,624 |
| Maintenance and Repair | 5,700 | 8,461 | 702,000 | 253,833 |
| Total, Operations and Maintenance | 28,445 | 27,621 | 1,745,930 | 828,632 |

### 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at SLAC.................................................................................. | None |
| Area of D&D in this project at SLAC.................................................................................................................. | None |
| Area at SLAC to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................................................................................................................... | None[i] |
| Area of D&D in this project at other sites ...................................................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ......................................................................................................................... | None |
| Total area eliminated ......................................................................................................................................... | None |

### 8. Acquisition Approach

The SLAC Management and Operating (M&O) contractor, Stanford University, will perform the acquisition for this project, overseen by the Stanford Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. The M&O contractor is evaluating various acquisition alternatives and project delivery methods. Potential acquisition and project delivery methods include, but are not limited to, firm-fixed-price contracts for design-bid-build, construction management, and design-build subcontracts. The M&O contractor will also evaluate potential benefits of using single or multiple contracts to procure materials, equipment, construction, commissioning, and other project scope elements. Its annual performance and evaluation measurement plan will include project performance metrics for SLAC on which it will be evaluated.

[i] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-80, Utilities Infrastructure Project, FNAL**
**Fermi National Accelerator Laboratory, FNAL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

**Summary**

The FY 2024 Request for the Utilities Infrastructure Project (UIP) is $45,000,000 of Total Estimated Cost (TEC) funding. The preliminary Total TEC range for this project is $248,000,000 to $403,000,000. The preliminary Total Project Cost (TPC) range for this project is $252,000,000 to $411,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $314,000,000.

This project will modernize obsolete and severely deteriorated utilities infrastructure at FNAL and will provide resiliency, reliability, and increased safety of operations to ensure the infrastructure can continue supporting the Laboratory's scientific missions.

To facilitate its execution, UIP is comprised of three subprojects consisting of scope needed to achieve complete and usable assets:

- The New Chilled Water Plant and Central Utility Plant Upgrades Subproject preliminary plans are to 1) remove existing chilled water system from the existing Central Utility Building and relocated it to the new Chilled Water Plant, enabling the expansion of chilled water capacity to support current and future loads, and 2) revitalize the existing Central Utility Building and the associated hot water, and low conductivity water systems. Both the Central Utility Plant and the Chilled Water Plant are being scheduled to support FNAL's FY 2027-2029 Long Accelerator Shutdown to allow the utility systems to be tied in.
- The Kautz Road Substation Replacement Subproject preliminary plans are to enhance the reliability of the Kautz Road Substation and reduce safety risks to personnel by replacing aging infrastructure, facilitating energy control, and reducing arc-flash incident energies. The primary construction phase of this Subproject needs to support FNAL's FY 2027-2029 Long Accelerator Shutdown since the substation feeds power to the accelerator complex.
- The Linear Utilities Replacement Subproject preliminary plans are to revitalize aging linear utilities across the FNAL site including sanitary sewers, domestic water, industrial cooling water, natural gas, and electrical feeders and equipment. These improvements plan to enhance system reliability and reduce deferred maintenance.

**Significant Changes**

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on February 23, 2022.

FY 2024 funds will support Design, long lead procurement, and early construction activities after the appropriate CD approvals.

A Federal Project Director is working towards the appropriate CD approvals.

**Critical Milestone History**

| | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| UIP - Overall, FNAL | 5/17/19 | – | 2/23/22 | 3Q FY 2028 | 4Q FY 2027 | 3Q FY 2028 | 3Q FY 2032 |
| UIP - New Chill Water Plant, Cent Utility Build Upgrades, FNAL | – | – | – | 3Q FY 2024 | 2Q FY 2025 | 3Q FY 2025 | 1Q FY 2029 |
| UIP - Kautz Road Substation Replacement, FNAL | – | – | – | 1Q FY 2025 | 4Q FY 2024 | 3Q FY 2024 | 2Q FY 2030 |
| UIP - Linear Utilities, FNAL | – | – | – | 3Q FY 2028 | 4Q FY 2027 | 3Q FY 2028 | 3Q FY 2032 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| | Performance Baseline Validation | CD-3A |
|---|---|---|
| UIP - Overall, FNAL | – | – |
| UIP - New Chill Water Plant, Cent Utility Build Upgrades, FNAL | 3Q FY 2024 | 3Q FY 2024 |
| UIP - Kautz Road Substation Replacement, FNAL | 1Q FY 2025 | 4Q FY 2024 |
| UIP - Linear Utilities, FNAL | – | – |

**CD-3A** – Approve Long-Lead Procurements and Site Preparation Activities.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 43,800 | 266,200 | 310,000 | 4,000 | 4,000 | 314,000 |
| FY 2024 | 43,800 | 266,200 | 310,000 | 4,000 | 4,000 | 314,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 2. Project Scope and Justification

**Scope**

The UIP's preliminary scope includes upgrading the highest risk major utility systems across the FNAL campus. Specifically, this project will first evaluate and identify the condition and risks of failure and inadequate performance of the industrial cooling water system, potable water distribution system, sanitary sewer and storm collection systems, natural gas distribution system, electrical distribution system, Kautz Road Substation, and the Central Utility Building. Selected portions of the systems will then be replaced or upgraded to assure safe, reliable, and efficient service to mission critical facilities. In addition, the project will perform upgrades to obsolete, end-of-life components, which will increase capacity, reliability, and personnel safety for critical utilities. It is anticipated a review and approval for long-lead procurements (e.g., mechanical, and electrical equipment) and site preparation in support of CD-3A.

**Justification**

DOE's Office of Science (SC) advances new experiments, international partnerships, and research programs to transform the understanding of nature and to advance U.S. energy, economic and national security interests. This mission requires the modernization of obsolete and severely deteriorated utilities infrastructure at FNAL. SC has identified a need to recapitalize FNAL's Central Utilities Building and distributed site utility infrastructure to ensure the stewardship of SC's investments and to provide modern, world-class facilities for scientific experiments and research.

Although there has been substantial investment in recent years to modernize and construct new research facilities at FNAL, much of FNAL's utility infrastructure serving these facilities is over 50 years old. Efficient, maintainable, and reliable utilities are critical to the success and mission capability of FNAL's research facilities. Currently, a significant portion of FNAL's utility infrastructure is beyond useful life and suffering from failures, decreased reliability, lack of redundancy, and limitations in capacity. As such, there is an urgent need to revitalize and selectively upgrade FNAL's existing major utility systems to ensure reliable service, meet capacity requirements, and enable readiness of facilities critical to the research mission.

The UIP will deliver modern and resilient enabling infrastructure. The project includes installation of a combination of data collection and artificial intelligent monitoring systems that adjust to trends, predict failures, and react to extreme weather events, such as automatically transferring power to minimize impacts to mission critical scientific operations. Additionally, modern utility systems will be more efficient and sustainable. For example, inefficient boilers will be replaced, and electrical metering equipment will be improved in order to identify future energy savings projects.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The KPPs are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Chilled Water Plant and CUB Upgrades | ▪ Construct a new building for chilled water production (6,000 tons cooling capacity). | ▪ Add additional 25 percent square footage to new chilled water plant for future growth. |
| | ▪ Revitalize the existing Central Utility Building envelope<br>▪ Replace mechanical infrastructure in the CUB to support the Wilson Hall footprint area. | ▪ Upgrade existing CUB envelope and roof with environmentally sustainable improvements. |

| Performance Measure | Threshold | Objective |
|---|---|---|
| Kautz Road Substation | ▪ Revitalize / Upgrade the KRS to improve arc flash safety requirements. | ▪ Install new feeder from KRS to the Accelerator Complex (PIP-II area). |
| Linear Utilities Replacement | ▪ Revitalize 5 miles of the Industrial Cooling Water (ICW) system. | ▪ Revitalize 16 miles of the Industrial Cooling Water (ICW) system. |
| | ▪ Revitalize 5 miles of the Domestic Water System (DWS). | ▪ Revitalize 19 miles of the Domestic Water System (DWS). |
| | ▪ Revitalize 3.5 miles of the Sanitary Sewer systems. | ▪ Revitalize 11 miles of the Sanitary Sewer System. |
| | ▪ Revitalize 2 miles of underground Natural Gas lines. | ▪ Revitalize 22 miles of underground Natural Gas lines. |
| | ▪ Revitalize 2 miles of electrical distribution feeders and associated unit substations, transformers, etc. | ▪ Revitalize 65 miles of electrical distribution feeders and associated unit substations, transformers, etc.<br>▪ Provide Electrical Code upgrades to Master Substation<br>▪ Revitalize 100 percent of the High-Pressure Sodium exterior lights along sidewalks, roads, and parking lots with LED. |

## 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 10,500 | 10,500 | 2,000 |
| FY 2023 | 20,000 | 20,000 | 9,000 |
| FY 2024 | 2,300 | 2,300 | 6,000 |
| Outyears | 10,000 | 10,000 | 26,800 |
| **Total, Design (TEC)** | **43,800** | **43,800** | **43,800** |
| Construction (TEC) | | | |
| FY 2024 | 42,700 | 42,700 | 15,000 |
| Outyears | 223,500 | 223,500 | 251,200 |
| **Total, Construction (TEC)** | **266,200** | **266,200** | **266,200** |
| Total Estimated Cost (TEC) | | | |
| Prior Years | 1,000 | 1,000 | – |
| FY 2022 | 10,500 | 10,500 | 2,000 |
| FY 2023 | 20,000 | 20,000 | 9,000 |
| FY 2024 | 45,000 | 45,000 | 21,000 |
| Outyears | 233,500 | 233,500 | 278,000 |
| **Total, TEC** | **310,000** | **310,000** | **310,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| Prior Years | 1,850 | 1,850 | 1,850 |
| FY 2022 | 200 | 200 | 200 |
| Outyears | 1,950 | 1,950 | 1,950 |
| **Total, OPC** | **4,000** | **4,000** | **4,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| Prior Years | 2,850 | 2,850 | 1,850 |
| FY 2022 | 10,700 | 10,700 | 2,200 |
| FY 2023 | 20,000 | 20,000 | 9,000 |
| FY 2024 | 45,000 | 45,000 | 21,000 |
| Outyears | 235,450 | 235,450 | 279,950 |
| **Total, TPC** | **314,000** | **314,000** | **314,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 36,100 | 33,300 | **N/A** |
| Design - Contingency | 7,700 | 10,500 | **N/A** |
| **Total, Design (TEC)** | **43,800** | **43,800** | **N/A** |
| Construction | 221,300 | 192,700 | **N/A** |
| Construction - Contingency | 44,900 | 73,500 | **N/A** |
| **Total, Construction (TEC)** | **266,200** | **266,200** | **N/A** |
| **Total, TEC** | **310,000** | **310,000** | **N/A** |
| *Contingency, TEC* | *52,600* | *84,000* | ***N/A*** |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 880 | 2,300 | **N/A** |
| Conceptual Design | 1,170 | 700 | **N/A** |
| OPC - Contingency | 1,950 | 1,000 | **N/A** |
| **Total, Except D&D (OPC)** | **4,000** | **4,000** | **N/A** |
| **Total, OPC** | **4,000** | **4,000** | **N/A** |
| *Contingency, OPC* | *1,950* | *1,000* | ***N/A*** |
| **Total, TPC** | **314,000** | **314,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***54,550*** | ***85,000*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 1,000 | 500 | 20,000 | — | 288,500 | 310,000 |
| | OPC | 2,100 | 500 | — | — | 1,400 | 4,000 |
| | TPC | 3,100 | 1,000 | 20,000 | — | 289,900 | 314,000 |
| FY 2024 | TEC | 1,000 | 10,500 | 20,000 | 45,000 | 233,500 | 310,000 |
| | OPC | 1,850 | 200 | — | — | 1,950 | 4,000 |
| | TPC | 2,850 | 10,700 | 20,000 | 45,000 | 235,450 | 314,000 |

*Notes:*
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 3Q FY 2033 |
| Expected Useful Life | 30 years |
| Expected Future Start of D&D of this capital asset | 3Q FY 2063 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 287 | 287 | 8,610 | 8,610 |
| Utilities | 577 | 577 | 17,310 | 17,310 |
| Maintenance and Repair | 287 | 287 | 8,610 | 8,610 |
| Total, Operations and Maintenance | 1,151 | 1,151 | 34,530 | 34,530 |

## 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at FNAL ........ | 10,000 – 30,000 |
| Area of D&D in this project at FNAL........ | None |
| Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None[j] |
| Area of D&D in this project at other sites ........ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None |
| Total area eliminated ........ | None |

[j] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The FNAL Management and Operating (M&O) contractor, FNAL Research Alliance LLC, will perform the acquisition for this project, overseen by the FNAL Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Project performance metrics will be performed by in-house management and Project Controls.

**19-SC-74, BioEPIC, LBNL**
**Lawrence Berkeley National Laboratory, LBNL**
**Project is for Design and Construction**

## 1. Summary, Significant Changes, and Schedule and Cost History

### Summary

The FY 2024 Request for the Biological and Environmental Program Integration Center (BioEPIC) project is $38,000,000 of Total Estimated Cost (TEC) funding. The Total Estimated Cost (TEC) for this project is $165,000,000. The Total Project Cost (TPC) for the project is $167,200,000.

This project will construct a new building with high performance laboratory space in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be co-located into this building, allowing for better facilitation of BER, ASCR, and BES program research activities.

### Significant Changes

This project was initiated in FY 2019 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, Approve Baseline and Start of Construction, which was approved on September 13, 2021. The FY 2024 Request will support construction and associated activities after the appropriate CD approvals. The project design is complete. Approximately $275,000 of the contingent funding is being moved from Design into Construction. The project received $7,000,000 in Inflation Reduction Act funding which is being used to mitigate the risks of escalation and accelerate the project schedule.

A Federal Project Director with the appropriate certification level has been assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | CD-4 |
|---|---|---|---|---|---|---|---|
| FY 2024 | 3/13/18 | 5/9/19 | 5/9/19 | 9/13/21 | 2/22/21 | 9/13/21 | 4Q FY 2027 |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range; **Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable); **CD-1** – Approve Alternative Selection and Cost Range; **CD-2** – Approve Performance Baseline; **Final Design Complete** – Estimated/Actual date the project design will be/was complete(d); **CD-3** – Approve Start of Construction; **D&D Complete** – Completion of D&D work; **CD-4** – Approve Start of Operations or Project Closeout.

| Fiscal Year | Performance Baseline Validation |
|---|---|
| FY 2024 | 9/22/21 |

### Project Cost History

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|
| FY 2023 | 15,000 | 150,000 | 165,000 | 2,200 | 2,200 | 167,200 |
| FY 2024 | 14,725 | 150,275 | 165,000 | 2,200 | 2,200 | 167,200 |

*Note:*

- *Other Project Costs (OPC) are funded through laboratory overhead.*

## 2. Project Scope and Justification

**Scope**

The scope of the BioEPIC project is to construct a new, state-of-the-art facility approximately 72,000 gross square feet (gsf) with laboratory space to support high performance research by BER, ASCR, and BES programs. This facility will be constructed in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be collocated to the BioEPIC building. Co-location of researchers in this unique experimental facility, near other important SC assets, will increase synergy and efficiency, which will better facilitate collaborative research in support of the SC mission.

**Justification**

The mission need of this project is to increase the synergy and efficiency of biosciences and other SC research at LBNL. LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the DOE mission. Much of the biological sciences program at LBNL is located off-site, away from the main laboratory, while others are dispersed across several locations on the LBNL campus. This arrangement has resulted in research and operational capability gaps that limit scientific progress and is a significant roadblock to the kind of collaborative science that is required for understanding, predicting, and harnessing the Earth's microbiome for energy and environmental benefits.

This project will close the present capability gaps by providing a resilient and sustainable state-of-the-art facility that will collocate LBNL's four BER 'science focus area' programs to focus on how soil-plant-microbe interactions impact growth of alternative energy feedstocks, agricultural productivity, water resources, and terrestrial carbon storage. Understanding and predicting responses to climate change is a central theme of all four programs.

These important SC programs and unique capabilities that are currently housed in leased space and buildings both on and off the LBNL campus that are near 'end-of-life', are not energy efficient, and are prone to prolonged outages in the face of regular wildfire risks that trigger power shutdowns by the LBNL's local power authority. The experiments hosted within this resilient new facility will not be disrupted by power shutdown events because of the modern systems built into BioEPIC. The BioEPIC building is designed to directly address these issues through pursuit of The Guiding Principles of Highly Sustainable Facility and LEED gold certification including provision of adequate emergency power. BioEPIC will have energy-saving all-electric mechanical and plumbing systems in place of natural gas for space and water heating. BioEPIC will bring together the LBNL's four BER 'science focus area' programs to focus on how soil-plant-microbe interactions impact growth of alternative energy feedstocks, agricultural productivity, water resources, and terrestrial carbon storage. Understanding and predicting responses to climate change is a central theme of all four programs.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)

The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Biosciences and other research space | 55,000 gsf | 90,000 gsf |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | | |
| Design (TEC) | | | | |
| Prior Years | 15,000 | 15,000 | 13,801 | – |
| FY 2022 | -275 | -275 | 924 | – |
| **Total, Design (TEC)** | **14,725** | **14,725** | **14,725** | **–** |
| Construction (TEC) | | | | |
| Prior Years | 25,000 | 25,000 | 3 | – |
| FY 2022 | 35,275 | 35,275 | 40,095 | – |
| FY 2022 - IRA Supp. | 7,000 | 7,000 | – | – |
| FY 2023 | 45,000 | 45,000 | 53,344 | 7,000 |
| FY 2024 | 38,000 | 38,000 | 26,713 | – |
| Outyears | – | – | 23,120 | – |
| **Total, Construction (TEC)** | **150,275** | **150,275** | **143,275** | **7,000** |
| Total Estimated Cost (TEC) | | | | |
| Prior Years | 40,000 | 40,000 | 13,804 | – |
| FY 2022 | 35,000 | 35,000 | 41,019 | – |
| FY 2022 - IRA Supp. | 7,000 | 7,000 | – | – |
| FY 2023 | 45,000 | 45,000 | 53,344 | 7,000 |
| FY 2024 | 38,000 | 38,000 | 26,713 | – |
| Outyears | – | – | 23,120 | – |
| **Total, TEC** | **165,000** | **165,000** | **158,000** | **7,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Other Project Cost (OPC)** | | | | |
| Prior Years | 1,536 | 1,536 | 1,536 | – |
| Outyears | 664 | 664 | 664 | – |
| **Total, OPC** | **2,200** | **2,200** | **2,200** | **–** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs | IRA Supp. Costs |
|---|---|---|---|---|
| **Total Project Cost (TPC)** | | | | |
| Prior Years | 41,536 | 41,536 | 15,340 | – |
| FY 2022 | 35,000 | 35,000 | 41,019 | – |
| FY 2022 - IRA Supp. | 7,000 | 7,000 | – | – |
| FY 2023 | 45,000 | 45,000 | 53,344 | 7,000 |
| FY 2024 | 38,000 | 38,000 | 26,713 | – |
| Outyears | 664 | 664 | 23,784 | – |
| **Total, TPC** | **167,200** | **167,200** | **160,200** | **7,000** |

*Note:*

- *Design funding was completed and remaining contingency funding was redirected for Construction.*

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | 14,725 | 15,000 | 15,000 |
| **Total, Design (TEC)** | **14,725** | **15,000** | **15,000** |
| Construction | 125,000 | 125,000 | 125,000 |
| Construction - Contingency | 25,275 | 25,000 | 25,000 |
| **Total, Construction (TEC)** | **150,275** | **150,000** | **150,000** |
| **Total, TEC** | **165,000** | **165,000** | **165,000** |
| *Contingency, TEC* | *25,275* | *25,000* | *25,000* |
| **Other Project Cost (OPC)** | | | |
| Conceptual Planning | 1,500 | 1,500 | **N/A** |
| Conceptual Design | 600 | 600 | **N/A** |
| OPC - Contingency | 100 | 100 | **N/A** |
| **Total, Except D&D (OPC)** | **2,200** | **2,200** | **N/A** |
| **Total, OPC** | **2,200** | **2,200** | **N/A** |
| *Contingency, OPC* | *100* | *100* | ***N/A*** |
| **Total, TPC** | **167,200** | **167,200** | **165,000** |
| ***Total, Contingency (TEC+OPC)*** | ***25,375*** | ***25,100*** | ***25,000*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Fiscal Year | Type | Prior Years | FY 2022 | FY 2022 IRA Supp. | FY 2023 | FY 2024 | Outyears | Total |
|---|---|---|---|---|---|---|---|---|
| FY 2023 | TEC | 40,000 | 35,000 | — | 45,000 | — | 45,000 | 165,000 |
| | OPC | 1,536 | — | — | — | — | 664 | 2,200 |
| | TPC | 41,536 | 35,000 | — | 45,000 | — | 45,664 | 167,200 |
| FY 2024 | TEC | 40,000 | 35,000 | 7,000 | 45,000 | 38,000 | — | 165,000 |
| | OPC | 1,536 | — | — | — | — | 664 | 2,200 |
| | TPC | 41,536 | 35,000 | 7,000 | 45,000 | 38,000 | 664 | 167,200 |

*Note:*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2027 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2077 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 150 | 150 | 5,700 | 5,700 |
| Utilities | 270 | 270 | 11,900 | 11,900 |
| Maintenance and Repair | 530 | 530 | 20,600 | 20,600 |
| Total, Operations and Maintenance | 950 | 950 | 38,200 | 38,200 |

### 7. D&D Information

The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at LBNL | 72,000 |
| Area of D&D in this project at LBNL | None |
| Area at LBNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[k] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | None |

[k] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The LBNL Management and Operating (M&O) Contractor, University of California, is performing the acquisition for this project, overseen by the Berkeley Site Office. The M&O contractor evaluated various acquisition approaches and project delivery methods prior to achieving CD-1 and selected a tailored Design-Bid-Build approach with a Construction Manager as General Contractor as the overall best project delivery method with the lowest risk to DOE. The M&O contractor is also responsible for awarding and administering all subcontracts related to this project. The M&O contractor's annual performance evaluation and measurement plan includes project performance metrics on which it will be evaluated.

## Safeguards and Security

### Overview
The Department of Energy's (DOE) Office of Science (SC) Safeguards and Security (S&S) program is designed to ensure appropriate security measures are in place to support the SC mission requirements of open scientific research and to protect critical assets within SC laboratories. Accomplishing this mission depends on providing physical and cyber controls that will mitigate possible risks to the laboratories' employees, nuclear and special materials, classified and sensitive information, hazardous materials, mission essential functions and facilities. The SC S&S program also provides funding for cybersecurity for the laboratories' information technology systems to protect computers, networks, and data from unauthorized access.

### Highlights of the FY 2024 Request
The FY 2024 Request for S&S is $200.0 million. The FY 2024 Request supports sustained levels of operations in S&S program elements including Protective Forces, Security Systems, Information Security, Cybersecurity, Personnel Security, Material Control and Accountability, and Program Management.

The FY 2024 Request includes $83.7 million in Cybersecurity to address long-standing gaps in infrastructure, operations, and compliance to ensure adequate detection, mitigation, and recovery from cyber intrusions and attacks against DOE laboratories. Funding in this Request supports the implementation of Executive Order 14028 requirements for Maximum Multi-Factor Authentication (MFA), Maximum Encryption, Cloud Strategy/Security, Improved Logging and Supply Chain Management, and Zero Trust Infrastructure.

The FY 2024 Request supports the S&S program's highest priority, which is to provide adequate security for the protection of Category I quantities of special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL).

The FY 2024 Request supports the implementation of key and mandatory National and Departmental security policies. Funding supports the sustainment of security operations at the national laboratories at the asset-level and along the site and building boundaries and security areas. These protections include the sustainment of physical countermeasures that provide deterrence, detection, delay, and response; asset-level accounting and control programs; employee and visitor verification and eligibility programs, and program performance and assurance processes. The funding also supports the continuation of the phased implementation of new standards, such as the standard to conduct background investigations on long-term uncleared personnel with physical and logical access. The funding supports the modernization and/or replacement of select risk and priority-driven security systems infrastructure. These systems mitigate threats to a range of national security interests, to include protection of employees (e.g., active shooter), high-consequence hazardous materials, classified matter, and intellectual property as outlined in the Department's Design Basis Threat (DBT) policy. The FY 2024 Request provides the resources to continue to implement the administration's policies associated with foreign national collaborations that assure the protection of U.S. science and technology. These new security mandates include the review of curriculum vitae to determine what intellectual capital to permit access to and rigorous validation of immigration documentation.

### Description
The S&S program is organized into seven program elements:
1. Protective Forces
2. Security Systems
3. Information Security
4. Cybersecurity
5. Personnel Security
6. Material Control and Accountability
7. Program Management

Protective Forces
The Protective Forces program element supports security officers that control access and protect S&S interests, along with their related equipment and training. Activities within this program element include access control and security response operations as well as physical protection of the Department's critical assets and SC facilities. The Protective Forces mission includes providing effective response to emergency situations, random prohibited article inspections, security alarm monitoring, and performance testing of the protective force response to various event scenarios.

Security Systems
The Security Systems program element provides the backbone of the physical protection of Departmental personnel, material, equipment, property, and facilities through the deployment of HSPD-12 and local credentials, entry control points, fences, barriers, lighting, sensors, surveillance devices, access control systems, and power systems operated and used to support the protection of people, DOE property, classified information, and other interests of national security.

Information Security
The Information Security program element provides support to ensure that sensitive and classified information is accurately, appropriately, and consistently identified, reviewed, marked, protected, transmitted, stored, and ultimately destroyed. Specific activities within this element include management, planning, training, and oversight for maintaining security containers and combinations, marking documents, and administration of control systems, operations security, special access programs, technical surveillance countermeasures, and classification and declassification determinations.

Cybersecurity
The Cybersecurity program develops and maintains a comprehensive cybersecurity program for ten national laboratories and four dedicated offices. There are numerous adversaries with the goals of disrupting vital DOE SC missions and stealing critical research intellectual property. The cyber goals for the Cybersecurity program are to empower mission and science, align cyber funding to opportunities for risk reduction, strengthen Cybersecurity security posture by embracing new security designs, and offer unified guidance and cybersecurity procedures. The Cybersecurity program responds to cyber incidents by supporting the activities needed to for incident management, prosecution, and investigation of cyber intrusions. The program supports both disaster recovery and incident recovery, as well as notifications within the cybersecurity community. Based on DOE directives, the DOE cybersecurity program management, site cybersecurity initiatives, and cybersecurity infrastructure management comprise the final component of the cybersecurity program.

Personnel Security
The Personnel Security program element encompasses the processes for employee suitability and security clearance determinations at each site to ensure that individuals are trustworthy and eligible for access to classified information or matter. This element also includes the management of security clearance programs, adjudications, security education, awareness programs for Federal and contractor employees, and processing and hosting approved foreign visitors.

Material Control and Accountability (MC&A)
The MC&A program element provides assurance that Departmental materials are properly controlled and accounted for at all times. This element supports administration, including testing performance and assessing the levels of protection, control, and accountability required for the types and quantities of materials at each facility; documenting facility plans for materials control and accountability; assigning authorities and responsibilities for MC&A functions; and establishing programs to detect and report occurrences such as material theft, the loss of control or inability to account for materials, or evidence of malevolent acts.

Program Management
The Program Management program element coordinates the management of Protective Forces, Security Systems, Information Security, Personnel Security, and MC&A to achieve and ensure appropriate levels of protections are in place through the conduct of security and/or vulnerability assessments, local threat assessments, and performance assurance activities.

**Safeguards and Security**
**Funding**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Safeguards and Security** | | | | |
| Protective Forces | 46,710 | 52,341 | 53,911 | +1,570 |
| Security Systems | 22,490 | 24,693 | 35,812 | +11,119 |
| Information Security | 4,490 | 5,660 | 5,830 | +170 |
| Cybersecurity | 81,260 | 81,260 | 83,697 | +2,437 |
| Personnel Security | 5,750 | 9,055 | 9,327 | +272 |
| Material Control and Accountability | 2,500 | 2,965 | 3,054 | +89 |
| Program Management | 6,800 | 8,125 | 8,369 | +244 |
| **Total, Safeguards and Security** | **170,000** | **184,099** | **200,000** | **+15,901** |

**Safeguards and Security**
**Explanation of Major Changes**

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Safeguards and Security** | **$184,099** | **$200,000** | **+$15,901** |
| Protective Forces | $52,341 | $53,911 | +$1,570 |
| Funding supports security officers and their required equipment and training necessary to maintain proper protection levels at all SC laboratories. | | The Request will maintain support for security officers and their required equipment and training necessary to maintain proper protection levels at all SC laboratories. | Funding will support sustained levels of operations at increased overhead, inflation, and contractually obligated Cost of Living Adjustments for Protective Forces. |
| Security Systems | $24,693 | $35,812 | +$11,119 |
| Funding supports security systems in place as well as continued implementation of security modifications that address both the revised DBT and Science and Technology Policy. | | The Request will maintain support for the security systems in place as well as continued implementation of security modifications that address both the revised DBT and Science and Technology Policy. | Funding will support the continued implementation of Homeland Security Presidential Directive 12 (HSPD-12) for uncleared long-term contractor personnel and the associated modernization and replacement of security systems. Funding will support prioritized investments in security infrastructure to provide enhanced protection of assets and to replace end-of-life systems. Funding increases will address sustained levels of operations at increased overhead and inflation rates. |
| Information Security | $5,660 | $5,830 | +$170 |
| Funding supports personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories. | | The Request will maintain support for the personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories. | Funding will support sustained levels for Information Security activities at increased overhead and inflation rates. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Cybersecurity $81,260 | $83,697 | +$2,437 |
| Funding supports investments in cyber infrastructure and cyber capability including new cyber tools, incident response enhancements, cyber workforce development, data protections, and protections for unique SC facilities and capabilities that cannot be protected with commercial tools. Additionally, the funding continues implementation of Executive Order 14028 requirements at both federal and Management & Operating sites to build out Maximum MFA, Maximum Encryption, Cloud Strategy/Security, Improved Logging and Supply Chain Management, Zero Trust Infrastructure, Secure Critical Software, Controlled Unclassified Information protections, participate in the Department of Homeland Security (DHS) Continuous Diagnostics and Monitoring program, build out Industrial Control Systems protections, and protect Government Furnished Equipment on foreign travel. | The Request will support investments in cyber infrastructure and cyber capability including new cyber tools, incident response enhancements, cyber workforce development, data protections, and protections for unique SC facilities and capabilities that cannot be protected with commercial tools. Additionally, the Request will continue implementation of Executive Order 14028 requirements at both federal and Management & Operating sites to build out Maximum MFA, Maximum Encryption, Cloud Strategy/Security, Improved Logging and Supply Chain Management, Zero Trust Infrastructure, Secure Critical Software, Controlled Unclassified Information cyber protections, participate in the Department of Homeland Security (DHS) Continuous Diagnostics and Monitoring program, build out Industrial Control Systems protections, and protect Government Furnished Equipment on foreign travel. | Funding will support sustained efforts to continue implementing Executive Order 14028 requirements to include Zero Trust Infrastructure at increased overhead and inflation rates. |
| Personnel Security $9,055 | $9,327 | +$272 |
| Funding supports Personnel Security efforts at SC laboratories as well as SC Headquarters security investigations. | The Request will continue support for Personnel Security efforts at SC laboratories as well as SC Headquarters security investigations. | Funding will provide sustained support for personnel security activities at increased overhead and inflation rates. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| Material Control and Accountability $2,965 | $3,054 | +$89 |
| Funding supports functions ensuring Departmental materials are properly controlled and accounted for at all times. | The Request will continue to support functions ensuring Departmental materials are properly controlled and accounted for at all times. | Funding will provide sustained support for MC&A activities at increased overhead and inflation rates. |
| Program Management $8,125 | $8,369 | +$244 |
| Funding supports oversight, administration, and planning for security programs at SC laboratories and provides integration of all security elements and security procedures protecting SC Research missions. | The Request will continue support for oversight, administration, and planning for security programs at SC laboratories and provides integration of all security elements and security procedures protecting SC Research missions. | Funding will provide sustained support for Program Management activities at increased overhead and inflation rates. |

# Program Direction

## Overview

The Office of Science (SC) Program Direction (PD) budget supports a highly skilled federal workforce to develop and oversee SC investments and Administration priorities in basic research on climate change and clean energy, advanced computing, cybersecurity, fundamental science to transform manufacturing, quantum information sciences, artificial intelligence and machine learning (AI/ML), biopreparedness, critical materials, fusion energy, isotope research and production, and construction and operation of scientific user facilities, which are critical to the American scientific enterprise. SC research and facility investments transform our understanding of nature and advance the energy, economic, and national security of the United States. In addition, SC accelerates discovery and innovation by providing broad public access to all DOE research and development findings.

SC continues to increase investments in sophisticated and experienced scientific and technical program and project managers, as well as experts in acquisition, finance, legal, construction management, and environmental, safety, and health oversight. The SC basic research portfolio includes extramural grants and contracts supporting nearly 32,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all 50 states and the District of Columbia. The portfolio of 28 scientific user facilities serves nearly 37,000 users per year. SC oversees ten of the U.S. Department of Energy's (DOE) 17 national laboratories. SC also continues to update its business processes for awards management and research related activities to advance diversity, equity, and inclusion in its extramural research programs.

<u>Headquarters</u>

The SC Headquarters (HQ) includes the eight SC program offices (Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, Nuclear Physics, Isotope R&D and Production, and Accelerator R&D and Production), Workforce Development for Teachers and Scientists, Project Assessment, and Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) Programs Offices, as well as several resource management functions, and HQ-based field management functions.

The FY 2024 Request includes the transfer of the Artificial Intelligence and Technology Office (AITO) to SC. AITO will continue to be the principal organizer of cross-cutting AI/ML activities including research, development, demonstration, strategy, and AI activities for the DOE. AITO will continue to identify and work in collaboration with the program offices and national laboratories to address gaps in research, development, implementation, and deployment of AI investments.

The SC HQ federal staff:

- Conducts scientific program and research infrastructure planning, execution, and management across SC, in part by extensive engagement with the scientific community to identify research opportunities and develop priorities.
- Establishes and maintains competitive research portfolios, which include high-risk, high-reward research, to achieve mission goals and objectives.
- Conducts rigorous external peer review of research proposals and ongoing programs. Each year, SC manages over 5,000 ongoing laboratory, university, non-profit, and private industry research awards and conducts over 36,000 peer reviews of new and renewal proposals.
- Organizes, participates in, or lead committees composed of agency and/or interagency personnel.
- Provides safety, security, and infrastructure oversight and management of all SC user facilities and other current research investments.
- Provides oversight and management of all line item construction projects and other capital asset projects.
- Provides oversight and management of the maintenance and operational integrity of the ten SC-stewarded national laboratories.
- Provides policy, strategy, and resource management in the areas of laboratory oversight, information management, grants and contracts, budget, and human capital.
- Provides communications to the public to inform and ensure DOE and SC are represented in national conversation around basic energy research, including how and where it is conducted and its benefits to society. Provides ongoing collaboration across DOE programs on AI/ML investments.

Consolidated Service Center

The Consolidated Service Center (CSC) provides business management to support SC's federal responsibilities. These functions include legal and technical support; financial management; grant and contract processing; safety, security, and health management; intellectual property and patent management; environmental compliance; facility infrastructure operations and maintenance; and information management. As part of this, the CSC:

- Provides necessary information technology equipment and systems to ensure connectivity between Headquarters and field sites to successfully support the mission of the Office of Science.
- Monitors the multi-appropriation, multi-program funding allocations for all ten SC national laboratories through administration of laboratory Management and Operating (M&O) contracts and is responsible for over 3,000 financial assistance awards (grants and cooperative agreements) per year to university, non-profit, and small business-based researchers.
- Provides support to SC and other DOE programs for solicitations and funding opportunity announcements, as well as the negotiation, award, administration, and closeout of contracts and financial assistance awards using certified contracting officers and professional acquisition staff.

Site Offices

SC Site Offices provide contract management and critical support for the scientific mission execution at the ten SC national laboratories. This includes day to-day business management; approvals to operate hazardous facilities; safety and security oversight; leases; property transfers; sub-contracts; and activity approvals required by laws, regulations, and DOE policy. As part of this, the site offices:

- Maintain a comprehensive contract management program to ensure contractual mechanisms are managed effectively and consistently with guidelines and regulations.
- Evaluate laboratory activities including nuclear, radiological, and other complex hazards.
- Provide federal project directors to oversee construction projects and other major capital asset projects.

Office of Scientific and Technical Information

Office of Scientific and Technical Information (OSTI) fulfills the Department's responsibilities for providing public access to the unclassified results of its research investments and limited access to classified research results. DOE researchers produce over 50,000 research publications, datasets, software, and patents annually. OSTI's physical and electronic collections exceed one million research outputs from the 1940s to the present, providing access to the results of DOE's research investments. OSTI implements DOE's public access mandates, including the government-wide requirement that peer-reviewed publications resulting from federal funding is made available to the public within 12 months of publication in a journal.

**Highlights of the FY 2024 Request**

The FY 2024 Request is $226.2 million and will support a total level of approximately 820 full-time equivalents (FTEs). The Request supports a pay raise of 5.2 percent. SC will utilize available human capital workforce reshaping tools to manage federal staff in a manner consistent with its long-term workforce restructuring plan as part of the DOE Agency Reform Plan.[a] SC will continue to review, analyze, and prioritize mission requirements and identify those organizations and functions aligning with Administration and Department program objectives and SC strategic goals while maximizing efficiency through functional consolidation.

The FY 2024 Request supports:

- Three-hundred and seventy-one (371) SC HQ federal staff, spread among the eight program offices, Workforce Development for Teachers and Scientists, Project Assessment, and SBIR/STTR Programs Offices, as well as several resource management functions, and HQ-based field management functions.
- Two (2) FTEs to support the Office of the Under Secretary for Science and Innovation.
- Twenty-four (24) FTEs in the Office of the Chief Human Capital Officer operating the Shared Service Center (SSC) and supporting HR Advisory Offices.
- Thirty-three (33) FTEs in the DOE Office of the Chief Counsel.
- Six (6) FTEs in the AITO which is transferred to SC in FY 2024.

[a] OMB Memo M-17-22

- One (1) FTEs in the DOE Congressional and Intergovernmental Affairs to support Regional Offices.
- One (1) FTEs supporting the President's Council of Advisors on Science and Technology (PCAST).[b]
- Three hundred-forty (340) CSC and site office federal staff.
- Forty-two (42) OSTI federal staff to manage SC's public access program.

In addition, SC announced a realignment in January 2023 which establishes a new streamlined SC organizational structure. With the recent legislation and appropriations, expectations are growing for SC's contributions to important national priorities, which build on SC's well-recognized historical achievements. The new structure will establish one pillar for Science Programs and one pillar for Operations. In most cases, SC will be moving entire offices under one of two Deputy Directors. This realignment is intended to optimize efficiency in the execution of SC work and to enable SC to deliver more results more quickly to the scientific community and the American people. This new structure, which is endorsed by DOE leadership, will further bolster and solidify organizational efficiency and partnership between the Science Programs and the Operations teams to enable and advance SC's critical scientific mission. With this structure, SC is poised to become an even more significant foundation for the U.S. R&D enterprise.

[b] PCAST is required by Executive Order 13539, as amended by Executive Order 13596.

## Program Direction
## Funding

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Program Direction** | | | | |
| Salaries and Benefits | 148,799 | 159,319 | 168,485 | +9,166 |
| Travel | 2,000 | 3,076 | 3,500 | +424 |
| Support Services | 28,838 | 28,517 | 31,005 | +2,488 |
| Other Related Expenses | 14,136 | 14,344 | 16,000 | +1,656 |
| Working Capital Fund | 8,227 | 5,955 | 7,210 | +1,255 |
| **Total, Program Direction** | **202,000** | **211,211** | **226,200** | **+14,989** |
| Federal FTE | 775 | 800 | 820 | +20 |

## Program Direction

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| **Program Direction** | **$211,211** | **$226,200** | **+$14,989** |
| Salaries and Benefits | $159,319 | $168,485 | +$9,166 |
| The funding supports 800 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices.<br><br>The funding supports costs associated with Federal employee benefits, including health insurance costs and retirement allocations in Federal Employees Retirement System. | | The Request will support 820 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices.<br><br>The Request will support costs associated with Federal employee benefits, including health insurance costs and retirement allocations in Federal Employees Retirement System. | The increase will support a 5.2 percent pay raise and the projected salary and benefit requirements for the requested FTE levels. The increase will also support the transfer of six FTEs for the AITO. |
| Travel | $3,076 | $3,500 | +$424 |
| The funding supports facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and facility operations reviews. Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. | | The Request will support facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and facility operations reviews. Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. | The increase in travel reflects the return to work with travel to conferences and site visits while continuing videoconferencing instead of travel, where possible. |

(dollars in thousands)

| FY 2023 Enacted | FY 2024 Request | Explanation of Changes<br>FY 2024 Request vs FY 2023 Enacted |
|---|---|---|
| The funding also supports travel for the SC Federal Advisory Committees, which will include over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.<br><br>The funding continues to support the PCAST advisory committee travel. | The Request will also support travel for the SC Federal Advisory Committees, which will include over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.<br><br>The Request will continue to support the PCAST advisory committee travel. | |
| Support Services $28,517 | $31,005 | +$2,488 |
| The funding supports select administrative and professional services including: support for the SBIR/STTR program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar R&D program through information systems managed and administered by OSTI; travel processing; correspondence control; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions.<br><br>The funding supports essential information technology infrastructure; necessary upgrades to SC's financial management system; ongoing operations and maintenance of information technology systems; and safety management support. | The Request will support select administrative and professional services including: support for the SBIR/STTR program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar R&D program through information systems managed and administered by OSTI; travel processing; correspondence control; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions.<br><br>The Request will support essential information technology infrastructure; necessary upgrades to SC's financial management system; ongoing operations, maintenance, and enhancement of information technology systems; and safety management support. | The increase will support the projected support service contract requirements and a new communication strategy in FY 2024. The increase will also support a new content management system. |

(dollars in thousands)

| FY 2023 Enacted | | FY 2024 Request | Explanation of Changes FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|
| The funding supports federal staff training and education to maintain appropriate certification and update skills. | | The Request will fund federal staff training and education to maintain appropriate certifications and update skills.<br><br>The Request will initiate a new communication strategy to focus on outreach and enhance communication on SC activities and science discoveries, development of a new content management system for SC staff. | |
| Other Related Expenses | $14,344 | $16,000 | +$1,656 |
| The funding supports fixed requirements associated with rent, utilities, and telecommunications; building and grounds maintenance; computer/video maintenance and support; IT equipment leases, purchases, and maintenance; and site-wide health care units. The funding also supports miscellaneous purchases for supplies, materials, and subscriptions. | | The Request will support fixed requirements associated with rent, utilities, and telecommunications; building and grounds maintenance; computer/video maintenance and support; the purchasing, leasing and maintenance of IT equipment and systems to support customers' evolving needs; and site-wide health care units. It will also include miscellaneous purchases for supplies, materials, and subscriptions. | The increase will support the projected fixed requirements for FY 2024. |
| Working Capital Fund | $5,955 | $7,210 | $1,255 |
| The funding supports a portion of the SC contribution to the Working Capital Fund for business lines: building occupancy, supplies, printing and graphics, health services, corporate training services, and corporate business systems. SC research programs also contribute to Working Capital Fund. | | The Request will support a portion of the SC contribution to the Working Capital Fund for business lines: building occupancy, supplies, printing and graphics, health services, corporate training services, and corporate business systems. SC research programs also will contribute to Working Capital Fund. | The increase will support the projected Working Capital Fund requirements for FY 2024. |

**Program Direction Funding**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Program Direction** | | | | |
| HQ Salaries and Benefits | 77,899 | 90,812 | 96,037 | +5,225 |
| HQ Travel | 1,514 | 2,301 | 2,450 | +149 |
| HQ Support Services | 21,710 | 19,787 | 22,005 | +2,218 |
| HQ Other Related Expenses | 6,736 | 6,340 | 7,585 | +1,245 |
| HQ Working Capital Fund | 8,227 | 5,955 | 7,210 | +1,255 |
| **Total, Headquarters** | **116,086** | **125,195** | **135,287** | **+10,092** |
| Field Offices Salaries and Benefits | 64,092 | 60,541 | 64,024 | +3,483 |
| Field Offices Travel | 436 | 725 | 1,000 | +275 |
| Field Offices Support Services | 4,145 | 5,017 | 5,192 | +175 |
| Field Offices Other Related Expenses | 6,333 | 6,904 | 7,148 | +244 |
| **Total, Field Offices** | **75,006** | **73,187** | **77,364** | **+4,177** |
| OSTI Salaries and Benefits | 6,808 | 7,966 | 8,424 | +458 |
| OSTI Travel | 50 | 50 | 50 | – |
| OSTI Support Services | 2,983 | 3,713 | 3,808 | +95 |
| OSTI Other Related Expenses | 1,067 | 1,100 | 1,267 | +167 |
| **Total, Office of Scientific and Technical Information** | **10,908** | **12,829** | **13,549** | **+720** |
| **Total, Program Direction** | **202,000** | **211,211** | **226,200** | **+14,989** |
| **Program Direction Summary** | | | | |
| Salaries and Benefits | 148,799 | 159,319 | 168,485 | +9,166 |
| Travel | 2,000 | 3,076 | 3,500 | +424 |
| Support Services | 28,838 | 28,517 | 31,005 | +2,488 |
| Other Related Expenses | 14,136 | 14,344 | 16,000 | +1,656 |
| Working Capital Fund | 8,227 | 5,955 | 7,210 | +1,255 |
| **Total, Program Direction** | **202,000** | **211,211** | **226,200** | **+14,989** |
| Federal FTE | 775 | 800 | 820 | +20 |

**Program Direction**
**Funding Detail**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| **Technical Support** | | | | |
| System review and reliability analyses | 1,373 | 1,421 | 1,450 | +29 |
| | | | | |
| **Management Support** | | | | |
| Automated data processing | 10,850 | 11,638 | 13,060 | +1,422 |
| Training and education | 577 | 705 | 710 | +5 |
| Reports and analyses, management, and general administrative services | 16,038 | 14,753 | 15,785 | +1,032 |
| **Total, Management Support** | **27,465** | **27,096** | **29,555** | **+2,459** |
| **Total, Support Services** | **28,838** | **28,517** | **31,005** | **+2,488** |
| | | | | |
| **Other Related Expenses** | | | | |
| Rent to GSA | 775 | 847 | 909 | +62 |
| Rent to others | 2,162 | 2,220 | 2,370 | +150 |
| Communications, utilities, and miscellaneous | 2,622 | 3,537 | 3,709 | +172 |
| Other services | 2,000 | 927 | 1,689 | +762 |
| Operation and maintenance of facilities | 1,340 | 1,389 | 1,496 | +107 |
| Supplies and materials | 491 | 651 | 691 | +40 |
| Equipment | 4,746 | 4,773 | 5,136 | +363 |
| **Total, Other Related Expenses** | **14,136** | **14,344** | **16,000** | **+1,656** |
| | | | | |
| **Working Capital Fund** | **8,227** | **5,955** | **7,210** | **+1,255** |

**Public Access**

The Department of Energy fulfills Legislative and Executive requirements to provide increased public access to scholarly publications and digital data resulting from DOE research funding. DOE's enabling authorization and subsequent legislation require DOE to provide publicly available collections of unclassified R&D results through the OSTI. The DOE Public Access Plan, originally required by a 2013 Office of Science and Technology Policy (OSTP) memorandum, added peer-reviewed, final accepted manuscripts to the types of unclassified scientific and technical information already made publicly accessible as required by longstanding statutes. For digital data resulting from sponsored research (as defined by OMB Circular A-110), the Plan requires the submission of data management plans with funding proposals to DOE and provides guidelines for preserving and ensuring access to digital research data as appropriate. In 2022, OSTP updated its public access guidance to agencies, requiring new agency public access plans for providing immediate access to accepted manuscripts, rather than the 12-month embargo in the 2013 memorandum; immediate access to data underlying publications; and wide adoption of persistent identifiers (PIDs). PIDs are an essential element in promoting research integrity, reproducibility, and discoverability.

Following OSTP review, DOE will implement its new Plan through internal agency policy directive, with requirements specified in national labs' management & operating contracts and annual performance plans, and in the terms and conditions of DOE financial assistance awards (grants and cooperative agreements). As under the previous policy, DOE-funded researchers are required to submit metadata and final accepted manuscripts to DOE, and DOE will make these research papers freely and immediately accessible to the public through the portal DOE PAGES (Public Access Gateway for Energy and Science), developed and hosted by OSTI. Since implementation of the DOE policy, DOE is among the top agencies in implementing public access, with DOE PAGES providing free access to over 180,000 scholarly publications resulting from DOE research funding. For scientific data, DOE will implement new data management plan requirements, enabling immediate access to data underlying publications and expanded access to other data. For PIDs, DOE has taken a leadership role in the federal government in assigning persistent identifiers to research outputs and will build on these efforts to expand PIDs in DOE's searchable metadata to include PIDs for DOE-funded researchers, their outputs, and organizations.

**Science**
**Facilities Maintenance and Repair**

The Department's Facilities Maintenance and Repair activities are tied to its programmatic missions, goals, and objectives. The Facilities Maintenance and Repair activities funded by the budget and displayed below and are intended to ensure that the scientific community has the facilities required to conduct cutting edge scientific research now and, in the future, to meet Department of Energy (DOE) goals and objectives.

**Costs for Direct-Funded Maintenance and Repair (including Deferred Maintenance Reduction)**

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2022 Planned Cost** | **FY 2022 Actual Cost** | **FY 2023 Planned Cost** | **FY 2024 Planned Cost** |
| Brookhaven National Laboratory | 5,578 | 6,715 | 6,863 | 7,014 |
| Lawrence Berkeley National Laboratory | 19,089 | 1,640 | 21,850 | 21,200 |
| Oak Ridge Institute for Science and Education | — | 1,159 | 582 | — |
| Oak Ridge National Laboratory | 28,886 | 32,048 | 33,009 | 34,000 |
| Oak Ridge Office | 6,410 | 4,869 | 5,376 | 4,229 |
| Office of Scientific and Technical Information | 397 | 492 | 569 | 586 |
| Pacific Northwest National Laboratory | | | - | - |
| SLAC National Accelerator Laboratory | 3,934 | 6,509 | - | - |
| Thomas Jefferson National Accelerator Facility | 133 | 95 | 81 | 83 |
| **Total, Direct-Funded Maintenance and Repair** | **64,427** | **53,527** | **68,330** | **67,112** |

General purpose infrastructure includes multiprogram research laboratories, administrative and support buildings, as well as cafeterias, power plants, fire stations, utilities, roads, and other structures. Together, the Office of Science (SC) laboratories have over 1,600 operational buildings and real property trailers, with nearly 24 million gross square feet of space.

Generally, facilities maintenance and repair expenses are funded through an indirect overhead charge. In some cases, however, a laboratory may charge maintenance directly to a specific program. One example would be when maintenance is performed in a building used only by a single program. Such direct-funded charges are not directly budgeted.

**Indirect-Funded Maintenance and Repair (including Deferred Maintenance Reduction)**

Facilities maintenance and repair activities funded indirectly through overhead charges at SC laboratories are displayed in the table below. Since this funding is allocated to all work done at each laboratory, the cost of these activities is charged to funding from SC and other DOE organizations, as well as other Federal agencies and other entities doing work at SC laboratories. Maintenance reported to SC for non-SC laboratories is also shown. The figures are total projected costs across all SC laboratories.

**Costs for Indirect-Funded Maintenance and Repair (including Deferred Maintenance Reduction)**

(dollars in thousands)

| | FY 2022 Planned Cost | FY 2022 Actual Cost | FY 2023 Planned Cost | FY 2024 Planned Cost |
|---|---|---|---|---|
| Ames Laboratory | 2,400 | 2,634 | 2,900 | 3,000 |
| Argonne National Laboratory | 51,237 | 53,454 | 57,734 | 58,965 |
| Brookhaven National Laboratory | 33,352 | 41,250 | 42,158 | 43,085 |
| Fermi National Accelerator Laboratory | 23,183 | 21,648 | 21,167 | 21,836 |
| Lawrence Berkeley National Laboratory | 31,051 | 39,327 | 49,904 | 49,498 |
| Oak Ridge Institute for Science and Education | 656 | 642 | 731 | 753 |
| Oak Ridge National Laboratory and Y-12 | 55,925 | 62,482 | 64,356 | 66,287 |
| Oak Ridge Office | 2,236 | 1,703 | 2,559 | 2,622 |
| Pacific Northwest National Laboratory | 11,270 | 9,863 | 14,172 | 12,728 |
| Princeton Plasma Physics Laboratory | 6,280 | 6,267 | 7,285 | 7,600 |
| SLAC National Accelerator Laboratory | 14,089 | 17,051 | 21,128 | 22,784 |
| Thomas Jefferson National Accelerator Facility | 7,634 | 8,403 | 9,004 | 9,274 |
| **Total, Indirect-Funded Maintenance and Repair** | **239,313** | **264,724** | **293,098** | **298,432** |

**Science**
**Report on FY 2022 Expenditures for Maintenance and Repair**

This report responds to the requirements established in Conference Report (H.Rep. 108-10) accompanying Public Law 108-7 (pages 886–887), which requires the DOE to provide an annual year-end report on maintenance expenditures to the Committees on Appropriations. This report compares the actual maintenance expenditures in FY 2022 to the amount planned for FY 2022, including Congressionally directed changes.

**Total Costs for Maintenance and Repair**

(dollars in thousands)

| | FY 2022 Planned Costs | FY 2022 Actual Costs |
|---|---|---|
| Ames Laboratory | 2,400 | 2,634 |
| Argonne National Laboratory | 51,237 | 53,454 |
| Brookhaven National Laboratory | 38,930 | 47,965 |
| Fermi National Accelerator Laboratory | 23,183 | 21,648 |
| Lawrence Berkeley National Laboratory | 50,140 | 40,967 |
| Oak Ridge Institute for Science and Education | 656 | 1,801 |
| Oak Ridge National Laboratory and Y-12 | 84,811 | 94,530 |
| Oak Ridge Office | 8,646 | 6,572 |
| Office of Scientific and Technical Information | 397 | 492 |
| Pacific Northwest National Laboratory | 11,270 | 9,863 |
| Princeton Plasma Physics Laboratory | 6,280 | 6,267 |
| SLAC National Accelerator Laboratory | 18,023 | 23,560 |
| Thomas Jefferson National Accelerator Facility | 7,767 | 8,498 |
| **Total, Maintenance and Repair** | **303,740** | **318,251** |

## Science
## Excess Facilities

Excess Facilities are facilities no longer required to support the Department's needs, present or future missions or functions, or the discharge of its responsibilities. The table below reports the funding to deactivate and dispose of excess infrastructure, including stabilization and risk reduction activities at high-risk excess facilities. These activities result in surveillance and maintenance cost avoidance and reduced risk to workers, the public, the environment, and programs. This includes reductions in costs related to maintenance of excess facilities (including high-risk excess facilities) necessary to minimize the risk posed by those facilities prior to disposition. SC has no direct funded excess facilities costs to report.

**Costs for Indirect-Funded Excess Facilities**

(dollars in thousands)

| | FY 2022 Planned Cost | FY 2022 Actual Cost | FY 2023 Planned Cost | FY 2024 Planned Cost |
|---|---|---|---|---|
| Argonne National Laboratory | 400 | 597 | 550 | 600 |
| Brookhaven National Laboratory | 619 | 689 | 330 | 1,070 |
| Fermi National Accelerator Laboratory | 20 | 50 | 1,500 | 1,500 |
| Lawrence Berkeley National Laboratory | 2 | 330 | 200 | 550 |
| Oak Ridge National Laboratory | 250 | 1,110 | 1,492 | 1,500 |
| SLAC National Accelerator Laboratory | — | 176 | 650 | 157 |
| **Total, Indirect-Funded Excess Facilities** | **1,291** | **2,952** | **4,722** | **5,377** |

**Science**
**Research and Development**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted |
|---|---|---|---|---|
| Basic | 5,795,405 | 6,374,837 | 6,807,475 | +432,638 |
| Applied | – | – | – | – |
| Subtotal, R&D | 5,795,405 | 6,374,837 | 6,807,475 | +432,638 |
| Equipment | 258,389 | 251,699 | 207,901 | -43,798 |
| Construction | 1,261,206 | 1,255,013 | 1,388,973 | +133,960 |
| **Total, R&D** | **7,315,000** | **7,881,549** | **8,404,349** | **+522,800** |

**Science**
**Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR)**

(dollars in thousands)

| | FY 2022 Enacted | FY 2023 Enacted | FY 2024 Request | FY 2024 Request vs FY 2023 Enacted | |
|---|---|---|---|---|---|
| Office of Science | | | | | |
| Advanced Scientific Computing Research | | | | | |
| SBIR | 28,194 | 10,112 | 12,093 | +1,981 | +19.59% |
| STTR | 3,965 | 1,422 | 1,701 | +279 | +19.62% |
| Basic Energy Sciences | | | | | |
| SBIR | 61,375 | 35,557 | 36,306 | +749 | +2.11% |
| STTR | 8,643 | 5,000 | 5,105 | +105 | +2.10% |
| Biological and Environmental Research | | | | | |
| SBIR | 25,184 | 21,327 | 22,278 | +951 | +4.46% |
| STTR | 3,545 | 2,999 | 3,137 | +138 | +4.60% |
| Fusion Energy Sciences | | | | | |
| SBIR | 13,457 | 10,921 | 18,765 | +7,844 | +71.82% |
| STTR | 1,899 | 1,536 | 2,642 | +1,106 | +72.01% |
| High Energy Physics | | | | | |
| SBIR | 22,179 | 13,911 | 13,073 | -838 | -6.02% |
| STTR | 3,119 | 1,956 | 1,838 | -118 | -6.03% |
| Nuclear Physics | | | | | |
| SBIR | 21,390 | 8,336 | 7,541 | -795 | -9.54% |
| STTR | 3,006 | 1,173 | 1,060 | -113 | -9.63% |
| Accelerator R&D and Production | | | | | |
| SBIR | 576 | 686 | 686 | – | – |
| STTR | 81 | 96 | 97 | +1 | +1.04% |
| **Total, Office of Science SBIR** | **172,355** | **100,850** | **110,742** | **+9,892** | **+9.81%** |
| **Total, Office of Science STTR** | **24,258** | **14,182** | **15,580** | **+1,398** | **+9.86%** |

*Note:*
- *The other DOE programs SBIR/STTR funding amounts are listed in the other DOE budget volumes.*
- *Starting in FY 2023, Scientific User Facility operations funding is excluded from SBIR/STTR contribution.*