Department of Energy Crosscuts Overview

In FY 2023, the Department of Energy will increase its emphasis on crosscutting efforts that enable the Department and Administration to accelerate progress on climate and energy goals through fully integrated science and applied energy research, development, demonstration, and deployment (RDD&D).

DOE's climate and energy crosscuts enhance collaboration, coordination and integration across its science and applied energy programs with oversight provided by the Office of the Under Secretary for Science and Innovation in close partnership with the Office of the Under Secretary for Infrastructure to ensure that available resources are focused on achieving the nation's most critical energy and climate challenges. This coordination also helps align the considerable capabilities of DOE's stakeholders including national laboratories, universities, industry, and other partners. Within DOE, crosscutting initiatives may be coordinated through Working Groups, Science and Energy Tech Teams (SETTs), Grand Challenges or other mechanisms.

Where possible, science and applied energy program offices and functional offices have also highlighted crosscut information in their program narrative. Alignment to key Bipartisan Infrastructure Law provisions is noted in each science and energy crosscut narrative. Key contributing offices that are engaged in crosscut activities include Office of Technology Transitions, Loan Programs Office, Office of General Counsel, Office of the Chief Financial Officer, Office of Artificial Intelligence and Technology, Office of Economic Impact and Diversity, and the Office of Policy. These offices may contribute staff time or funding as noted in specific crosscut narratives to enhance impact of the Departments efforts.

The FY 2023 priority crosscut initiatives include a combination of existing and new topics including:

- Advanced Manufacturing
- Biotechnology
- Carbon Dioxide Removal
- Critical Minerals and Materials
- Energy Storage
- Water-Energy Nexus
- Grid Modernization
- Hydrogen
- Industrial Decarbonization
- Subsurface Energy Innovations

A major focus in key crosscutting efforts are the launch and execution of 'Energy Earthshots' that target the major RD&D innovation breakthroughs that we know we must achieve to solve the climate crisis and reach a net-zero carbon economy by 2050. The Energy Earthshots Initiative is an all-hands-on-deck call for innovation, collaboration, and acceleration of our clean energy economy by tackling the toughest remaining barriers to demonstrate and deploy emerging clean energy technologies at scale. With each Energy Earthshot, the Department is setting tough, yet achievable cost or performance targets to transform these technologies over the next 10 years—lowering costs, raising performance, creating new jobs, and clearing the way to our clean energy goals. In 2021 DOE launched three Energy Earthshots: Hydrogen Shot, Long Duration Storage Shot, and Carbon Negative Shot. In FY 2022 DOE is scoping additional candidate Energy Earthshot concepts and in FY 2023 DOE is requesting funding through the

Office of Science to support research in Energy Earthshot technology areas. Each Energy Earthshot is guided by an integrated DOE crosscut team that will create a multi-year roadmap and be implemented with extensive stakeholder engagement from research and national laboratory, industry, environmental, environmental justice, and interagency partners.

Additional DOE crosscuts include:

- Safeguards and Security
- Research and Development
- Small Business Innovation Research/Small Business Technology Transfer
- Pensions
- Infrastructure
- Exascale Computing
- Cybersecurity
- Energy Sector Cybersecurity

Advanced Manufacturing Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**65,775**	**0**	**TBD**	**TBD**
Advanced Research Projects Agency – Energy*	65,775	0	TBD	TBD
Energy Efficiency and Renewable Energy	**534,102**	**542,364**	**895,700**	**+361,598**
Advanced Manufacturing	396,000	396,000	582,500	+186,500
Bioenergy Technologies	15,500	15,500	16,000	+500
Building Technologies	0	0	5,000	+5,000
Hydrogen and Fuel Cell Technologies	28,000	22,000	25,000	-3,000
Solar Energy Technologies	42,500	50,000	179,200	+136,700
Strategic Programs	540	0	0	-540
Vehicle Technologies	31,000	31,000	50,000	+19,000
Water Power Technologies	3,850	10,500	12,000	+8,150
Wind Energy Technologies	16,712	17,364	26,000	+9,288
Fossil Energy and Carbon Management	**8,050**	**8,050**	**2,500**	**-5,550**
Advanced Materials	8,050	8,050	2,500	-5,550
National Nuclear Security Administration	**111,908**	**111,908**	**113,338**	**+1,430**
Nuclear Energy	**34,869**	**33,000**	**11,250**	**-23,619**
Crosscutting Technology Development	5,000	8,000	11,250	+6,250
Transformational Challenge Reactor	29,869	25,000	0	-29,869
Science	**0**	**0**	**27,000**	**+27,000**
Basic Energy Sciences	0	0	20,000	+20,000
Biological and Environmental Research	0	0	3,000	+3,000
Fusion Energy Sciences	0	0	3,000	+3,000
Isotope R&D and Production	0	0	1,000	+1,000
Grand Total	**754,704**	**696,322**	**1,049,788**	**+360,859**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

Advanced Manufacturing is a family of activities that: integrate advanced automation, computation, software, sensing, and networking into manufacturing processes; make use of cutting edge materials and emerging capabilities to improve product manufacturability; decrease the carbon intensity and improve the sustainability of manufacturing processes; increase facility operation efficiency and electrification into an increasingly decarbonized electric grid; and enable the next generation of clean energy technologies through development of innovative processes. Advanced Manufacturing research, development, demonstration, and deployment (RDD&D) activities for new tools and technologies that are more sustainable and efficient for a growing and competitive economy and accelerate the adoption of technologies and practices will drive U.S. economic competitiveness and energy productivity.

This crosscut encompasses multiple offices across DOE that sponsor RDD&D to foster the innovations required to sustainably manufacture the clean energy technologies needed for the industrial, transportation, and buildings sectors, as well as the energy production and delivery systems needed to power these sectors in the future. Advanced Manufacturing is the engine that will drive the transition to a decarbonized future, new jobs, and U.S. manufacturing competitiveness.

Crosscut activities will enable new and improved materials, processes, and systems across supply chains and product lifecycles. Advanced Manufacturing is critical for a transformation of the national and global energy systems to meet our climate goals, and create a competitive, resilient, agile manufacturing sector.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment of: battery material processing, as well as battery manufacturing and recycling; clean hydrogen production; wind energy technology manufacturing; solar energy manufacturing; and advanced energy manufacturing and recycling. These investments are essential in addressing the development of new technologies and advancing supply chain needs to support growth in clean energy. Provisions for industrial decarbonization are covered in that crosscut narrative.

Coordination Efforts:
The participating DOE offices plan to increase intra-departmental collaboration in their Advanced Manufacturing activities, pursuing coordinated roadmapping exercises, leveraging best practices and advances that are relevant across technologies, and identifying joint funding opportunities where appropriate. Participating DOE offices include Advanced Research Projects Agency – Energy (ARPA-E), Energy Efficiency and Renewable Energy (EERE), Fossil Energy and Carbon Management (FECM) Nuclear Energy (NE), the National Nuclear Security Administration (NNSA), and Science (SC).

Crosscutting efforts in Advanced Manufacturing are coordinated through working groups focused on Industrial Decarbonization and Clean Energy Technology Manufacturing. These will maintain cross-office alignment on these topics.

In addition to the funding offices identified here, various crosscutting offices (including the Office of Economic Impact & Diversity, Office of Policy, Office Artificial Intelligence and Technology, and the Office of Technology Transitions) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments.

Crosscut Objectives

- *Advance the materials and production processes for energy products, technologies, and systems.*
- *Improve resiliency and agility of material supply chains needed for energy products, technologies, and systems.*
- *Accelerate the transition from technology innovation to demonstration and commercialization.*
- *Make knowledge and transformational tools accessible across manufacturing organizations and develop a diverse future manufacturing workforce.*

Crosscut Action Areas:

1. ***Action Area #1 - Industrial Innovations - Efficiency, Decarbonization and Manufacturing Innovations:*** Focus on reducing greenhouse gas (GHG) emissions from industries through new

manufacturing technologies. Key activities include the development and demonstration of decarbonization solutions for energy-intensive industries and crosscutting decarbonization technologies while prioritizing the key industries of chemicals, iron and steel, cement, and food products.

2. ***Action Area #2 - Foundational Technologies - Materials and Manufacturing :*** Focus on solving foundational materials and manufacturing challenges for both decarbonization and clean energy by developing novel materials with improved properties, as well as new production processes. Key activities include advanced materials and foundational manufacturing technologies. Prioritize critical materials including high conductivity metals, innovative manufacturing processes such as additive manufacturing, and agile manufacturing.
3. ***Action Area #3 - Clean Energy Technology Manufacturing*:** Focus on solving key manufacturing challenges for clean energy technology that are critical for achieving economy-wide decarbonization. Prioritize research and development to address manufacturing innovation needs to drive down cost, improve performance, and accelerate commercialization of innovative clean energy technologies such as energy storage systems, hydrogen systems, solar energy products, wind turbine blades, semiconductors for multiple applications, and critical materials R&D addressing supply, substitution, and reuse.

Program Organization:

1. **Advanced Research Projects Agency–Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy.
    a. In FY 2021 ARPA-E funded projects within its Open 2021 Funding Opportunity Announcement (FOA) and Supporting Entrepreneurial Energy Discoveries (SEED) Exploratory Topic programs with Advanced Manufacturing components.
    b. ARPA-E is developing programs for transformational research across a wide range of energy technologies and applications. The assessment process for new programs is now underway and any potential future investments in Advanced Manufacturing will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):** Many EERE technology programs support advanced manufacturing work across DOE and work in close coordination with other DOE offices.
    a. *Advanced Manufacturing Office (AMO)*: AMO plays a leading role in the decarbonization of the industrial sector and addressing the climate crisis by driving innovations that lead to a more resilient and competitive domestic manufacturing sector and that deliver the clean energy technologies needed to decarbonize other sectors. In FY 2023 AMO will support:
        i. *Crosscut Action Area #1 - Industrial Innovations:* RD&D enabling decarbonization of energy-intensive industries, including chemicals, iron and steel, cement, and food products, as well as crosscutting technologies, such as carbon capture and utilization, energy efficient thermal processes, and industrial electrification. Demonstration projects at pilot scale will also be pursued where they advance our emissions and energy efficiency objectives. Support for opportunities identified in the Industrial Decarbonization Roadmap and aligned demonstration projects, including joint FOAs with other DOE offices, where

appropriate, as well as support for one new Clean Energy Manufacturing Innovation Institute, and the sixth year of National Alliance for Water Innovation.

ii. *Crosscut Action Area #2 – Foundational Technologies:* RD&D on materials that support clean energy manufacturing, industrial decarbonization, and economy-wide decarbonization including high conductance materials and materials for harsh service conditions. AMO will provide additional funding for the Critical Materials Institute, R&D for additive manufacturing via the Manufacturing Demonstration Facility, and support for the High-Performance Computing for Manufacturing program. AMO will support efforts to keep the United States as the global leader in technologies like Cadmium Telluride photovoltaics (PV) and develop the next generation of PV materials for potential domestic manufacture, such as perovskites. AMO Critical materials work will span applied R&D to demonstration, with an emphasis at the early supply chain stages, such as lithium extraction from brines.

iii. *Crosscut Action Area #3 - Clean Energy Technology Manufacturing:* AMO will partner with other EERE offices to invest in low-cost, high-volume manufacturing processes for clean energy sources, including a robust, domestic solar manufacturing sector through the Solar Manufacturing Accelerator in partnership with EERE's Solar Energy Office; megawatt (MW)-scale electrolyzers and complete fuel cell systems and recycling systems at end of life; novel processing technologies for conventional electrodes in electric vehicle (EV) batteries; and component, operational, and production manufacturing efficiencies for wind turbines. AMO will support identified opportunities currently under development on advanced manufacturing applications for hydropower; and RD&D to increase the conversion efficiencies and reduce manufacturing costs and material usage in PVs. AMO will have a particular focus on promising technologies that can be made in the United States with the potential to be exported, such as concentrating solar thermal power systems for electricity generation and industrial processes along with thermal energy storage assets.

b. *Bioenergy Technologies Office (BETO):* DOE's Bioenergy Technologies Office (BETO) supports the research and development of valuable chemicals and materials that can replace petrochemicals with renewable alternatives. This work includes R&D on bioderived polymers and plastics that provide performance advantages to traditional materials, including polymers and plastics that are design for enhanced recyclability. BETO also supports development of novel biological processes to recycle traditional plastics and polymer materials that can reduce energy-intensity of recycling operations.

c. *Building Technologies Office (BTO):* BTO will fund projects to accelerate advanced manufacturing especially in the areas of new low to no global warming potential refrigerants and highly efficient cost-effective heat pumps to support rapid adoption of decarbonization technologies. BTO will begin work with AMO on manufacturing scale up support for advanced heating, ventilation, and air conditioning (HVAC) and dehumidification technologies. Many BTO funded R&D projects have shown value in emerging technologies for dehumidification that significantly reduce energy use. These emerging technologies are mostly new membrane or chemical based and require very different manufacturing processes and equipment compared to regular vapor compression-based air conditioning and refrigerant equipment. BTO will work with AMO to explore innovative manufacturing technologies that can scale production of advanced dehumidification equipment.

d. *Hydrogen and Fuel Cell Technologies Office (HFTO):* HFTO invests in advanced manufacturing processes to enable accelerating the deployment of hydrogen and fuel cell technologies to address decarbonization of the transportation and industrial sectors. Activities span manufacturing processes for electrolyzer and fuel cell systems and components, hydrogen refueling components, quality control monitoring diagnostics, and clean production of metals and chemicals. Work aligned to Crosscut Action Areas for FY 2023 is delineated here:
    i. *Crosscut Action Area #1 - Industrial Innovations:* demonstrate use of clean hydrogen for decarbonizing industrial applications (e.g., steel manufacturing, ammonia, etc.)
    ii. *Crosscut Action Area #2 – Foundational Technologies:* continue to collaborate and address industry's need to identify advanced materials for safe use of hydrogen and hydrogen blends across sectors in collaboration with FECM.
    iii. *Crosscut Action Area #3 - Clean Energy Technology Manufacturing:* collaborate on defining BIL activities, including manufacturing and recycling.

e. *Solar Energy Technologies Office (SETO):* SETO supports the research, development, demonstration, and commercialization of advanced manufacturing relevant technologies to help develop new products for domestic manufacture, support new technologies to drive down domestic manufacturing costs, develop robust domestic supply chains, and mitigate issues related to material availability. SETO's efforts focus on Crosscut Action Area #3 and the Request supports new programming centered on supporting the development of a sustainable, robust, and resilient American solar supply chain. Domestic supply chains are critical to ensuring the U.S. has access to the volume of solar energy cells, modules, and system components to meet decarbonization goals. The primary effort from SETO will be to launch the new Solar Manufacturing Accelerator, with the Advanced Manufacturing Office, that will help establish domestic manufacturing capabilities of advanced PV technologies that rely less on foreign sourced materials, in particular those materials where one country controls the market and where unfair labor practices may exist. The Accelerator's focus will be on reducing solar manufacturing costs while solidifying domestic material, equipment, and product supply chains. Additionally, the Request encompasses new programming under the American-Made Challenges to spur U.S. business innovation in solar, including new rounds of the American-Made Solar Prize to incentivize and transition new solar technologies into prototypes ready for real world validation. Other efforts supported in the Request to enhance U.S. solar manufacturing include continued support for the American-Made Network to provide commercialization resources, a crosscutting initiative designed to support a qualified, diverse, and inclusive clean energy manufacturing workforce and connect trainees with the industry, and continued support for the Incubator program to accelerate the prototyping, development and demonstration of new solar energy technologies for commercialization and domestic manufacturing.

f. *Vehicle Technologies Office (VTO):* VTO supports Crosscut Action Areas 2 and 3. In FY 2023, VTO priority focus areas include (1) new joining technologies for multi-material structures required in order to incorporate these lightweight polymer matrix composites and other new lightweight materials (aluminum and magnesium) into vehicle applications for increasing fuel economy and reducing the environmental impact of vehicles, (2) support for the Lightweight Metals Core Program to develop scalable processing methods to locally enhance the properties of aluminum and magnesium, (3) support battery materials scale-up at National Laboratories, and (4) support Battery Processing Science and Engineering dedicated to solid state materials processing.

i. VTO will continue and scale up efforts related to solid state processing and new joining technologies for multi-material structures in vehicles. New joining materials will be required to incorporate these lightweight polymer matrix composites and other new lightweight materials (aluminum and magnesium) into vehicle applications for increasing fuel economy and reducing the environmental impact of vehicles. The Lightweight Metals Core Program will develop scalable processing methods to locally enhance the properties of aluminum and magnesium.

ii. VTO will continue electric vehicle battery innovations to develop novel processing technologies for conventional electrodes as well as lithium metal anodes and solid-state batteries. Projects involve either active materials scale-up or scientific investigations of novel processing approaches for lithium intercalation cathode materials, lithium metal batteries, or solid-state electrolytes.

g. Water Power Technologies Office (WPTO): WPTO has been funding foundational and application-based research for advanced manufacturing opportunities for hydropower. An opportunities analysis is being performed to that will support development of a roadmap that will inform the hydropower program and industry towards future research and engagement. The goal of FY 2023 activities is to encourage and enable the hydropower industry to recognize the opportunities to apply advanced manufacturing technologies and techniques to hydropower challenges for existing and new infrastructure. An opportunities analysis for advanced manufacturing applications for hydropower is currently being prepared by Oak Ridge National Laboratory (ORNL). Outputs will be utilized to inform a roadmap in FY 2022, and then will be used to build a program in partnership with the Manufacturing Demonstration Facility at ORNL to provide support and validation of technologies for hydropower. (*Crosscut Action Areas #2 - Foundational Technologies and #3- Clean Energy Technology Manufacturing)*. In marine energy, building on a materials strategy to be released in FY 2022, WPTO will support advancement of composites and other materials that can withstand the forces and ocean environment necessary to advance marine energy technologies at all scales. (*Crosscut Action Area #2 - Foundational Technologies)*

h. *Wind Energy Technologies Office (WETO):* WETO uses Advanced Manufacturing to address the issues and challenges associated with turbine scaling for both land-based and offshore wind technologies. These activities will enable wind turbine technologies that overcome transportation constraints, allow for larger and lightweight turbine components through novel designs and materials, and increase material and component production throughput. In FY 2023, WETO will continue work leveraging prior R&D in additive manufacturing, in addition to broadening into other advanced manufacturing methods such as high performance computing (HPC), artificial intelligence (AI), and advanced machine learning (AML). The use of these methodologies will allow WETO to address several issues associated with the scaling of wind turbines through component design and material optimization, and reduction of critical rare-earth materials. This work explores the use of these technologies and their application to wind turbine blades, generators, foundations and towers (*Crosscut Action Areas #2– Foundational Technologies and #3 – Clean Energy Technology Manufacturing*). Demonstration activities of these technologies will also be examined in the short to longer term *(applies to all Crosscut Action Areas).*

3. Fossil Energy and Carbon Management (FECM): FECM plays a leading role in the decarbonization of the industrial sector and power sector by developing crosscutting carbon capture, carbon reduction, CO_2 conversion, carbon storage, and clean hydrogen production and

utilization technologies. FECM's RDD&D program focuses on technologies that help to ensure clean and affordable energy for all and facilitates the transition towards a carbon-pollution-free economy. This RDD&D is targeted at improving overall system efficiency, reducing capital and operating costs, and enabling affordable carbon management. Carbon management technologies have an important role in the decarbonization of the manufacturing sector for industries such as steel, cement, and chemicals. Additionally, advanced manufacturing capabilities such as roll-to-roll manufacturing and 3D printing, can help enable many of the advanced carbon management technologies that are under development today and on the verge of commercial deployment. By applying these techniques to reduce material costs, improve designs and manufacturability of these technologies, advanced manufacturing will enable the potential deployment and buildout point-source carbon capture and storage and carbon removal. As the Department moves to establish a clean hydrogen economy, hydrogen-resistant materials will need to be developed to allow for its production, use, transport, and storage.

a. *Crosscut Action Area #1 - Industrial Innovations:*
   - R&D and pilot-scale tests of capture technologies supporting decarbonization of energy-intensive industries including chemicals, steel, cement, and clean hydrogen.
   - Commercial deployment efforts for retrofitting existing facilities with CCS for hydrogen and ethanol production, and more recently feasibility and front-end engineering design (FEED) studies for cement, steel, and chemicals.

b. *Crosscut Action Area #2 - Foundational Technologies:*
   - Leveraging manufacturing capabilities to facilitate development of CCUS technologies. For example:
     i. R&D on producing "smart packing" used for solvent-based carbon capture systems.
     ii. Investigation of additive manufacturing via the Manufacturing Demonstration Facility to mass produce carbon capture process equipment.
   - RD&D supporting advanced manufacturing of:
     i. embedded sensors for harsh environments.
     ii. refractory materials for gasification systems.
     iii. ceramic matrix composites for use in hydrogen turbines.

c. In addition, FECM will support crosscutting development, technical assistance, and technical partnerships including:
   - Support for MW-scale demonstrations of integrated energy storage technologies with power plants to accelerate the deployment and adoption of these technologies to help attain net-zero emissions in the power sector by 2035.
   - The Simulation-Based Engineering (SBE) program, which strives for the development and application of new and innovative physics- and chemistry-based models and computational tools at multiple scales (atomistic, device, process, grid and market) to help move the integrated energy systems of the future toward a net-zero carbon economy.
   - Support for development of advanced manufacturing processes such as 3D printing, roll-to-roll, etc. to advance domestic manufacturing capability and create good paying domestic jobs.

- FECM's University Training and Research Program, which enabled numerous undergraduate, master's, and doctoral students to conduct early-stage research in hydrogen and decarbonization technologies, including minority institutions of higher learning (Historically Black Colleges and Universities and Other Minority Institutions).

d. Aligned to the Crosscut Action Areas and the Critical Minerals and Materials crosscut, FECM will work on:
   - Improved extraction of critical minerals and materials from unconventional and secondary sources.
   - Design of novel, environmentally responsible mineral processing technologies to be used with a variety of feedstocks.

4. **National Nuclear Security Administration (NNSA):** The mission of the NNSA's Advanced Manufacturing Development (AMD) Program is to enable a responsive and resilient nuclear security enterprise by rapidly developing and deploying advanced manufacturing solutions to both existing, known problems and developing technologies and capabilities to rapidly recover from unforeseen problems. AMD supports development of models, additive manufacturing, prototyping of machining and development of tooling for electronic printing and material development.
   a. Crosscut Action Area #2 - Foundational Technologies. In FY 2023, AMD will support:
      - Approaches to advance qualification and certification methods to use additively manufactured parts in the active stockpile.
      - Development of material recyclability processes to reuse scrap material and reduce supply chain risk.
      - Conduct of testing to confirm components manufactured with new production methods improve performance margins.

   b. Future anticipated work aligned with the Crosscut includes:
      - Accelerate and transition the use of additive manufacturing as an agile production process for stockpile components.
      - Invest in digital manufacturing to enhance process control diagnostics and supply chain risk mitigation.
      - Support key manufacturing technologies that are replacing obsolete materials and processes on a timeline to support future systems.
      - Leverage scientific knowledge for new qualification and certification methods to enable delivery of additively manufactured components intended for future weapons systems.

5. **Nuclear Energy (NE):** The goal is to maintain U.S. leadership in the development of materials and manufacturing technologies for nuclear energy applications. NE will enable nuclear reactor technology developers by developing materials and manufacturing technologies to produce components that improve safety and reliability and are more cost effective to manufacture.
   a. *Crosscut Action Area #1 - Industrial Innovations:* NE plans to partner and leverage joint capabilities to demonstrate technologies through the production of parts, components and subsystems that have the potential for widespread impact in manufacturing for the nuclear sector. The investment of resources at critical decision points should help overcome technological and regulatory hurdles that could be seen as too risky for the private sector to take on alone. This approach should engage reactor vendors and original equipment

manufacturers, as well as suppliers for products and capabilities with the intent for adoption of the technologies.

b. *Crosscut Action Area #2 – Foundational Technologies:* NE is engaging stakeholders to develop an accelerated qualification framework for certifying advanced materials and manufacturing technologies. The framework will focus initially on 316 stainless steel materials, which are understood in traditional manufacturing processes but are new to advanced manufacturing processes. These materials are a high priority for near-term deployment of advanced reactors and support of the current fleet. In the long-term, NE plans to demonstrate advanced alloy development and manufacturing capabilities that enhance deployment and operations of the existing and advanced reactor fleet.

6. **Science (SC)**: In FY 2023, SC will support efforts for fundamental science leading to transformational manufacturing aligned with all of the *Crosscut Action Areas.* The opportunities for underpinning science for manufacturing crosses many SC activities, including biomanufacturing, next-generation microelectronics fabrication, innovations for accelerator technology, science to transform "traditional" chemical and materials manufacturing, materials for extreme environments, and isotope production and enrichment, to name a few. Central to the discovery and application of transformative science are computational tools and a system-based co-design approach to integration of experiments, predictive theory, and artificial intelligence and machine learning that cross the interfaces among components in manufacturing systems.

   a. *Basic Energy Sciences (BES):* The recent SC BES workshop on Basic Research Needs for Transformative Manufacturing complements prior SC workshops and provides priority research directions that form the basis for this initiative. Critically, new investments in manufacturing science will be enabling for other science and technology initiative areas within DOE, including the Energy Earthshots, with a focus that includes the science for scale-up from initial discoveries to bridge the gap to applied research and commercial application.
   b. *Biological and Environmental Research (BER):* SC BER continues biomanufacturing research that will build on broader biotechnology activities and genome-enabled engineering and design of biomaterials.
   c. *Fusion Energy Sciences (FES):* The 2018 SC Fusion Energy Sciences Advisory Committee (FESAC) report[1] on Transformative Enabling Capabilities for Efficient Advance Toward Fusion Energy highlighted the promise of novel synthesis, manufacturing, and materials design to enable fusion energy systems for the future. FES is pursuing these new manufacturing technologies to enable design and advancement of novel material systems capable of surviving the extreme conditions expected in fusion reactors as well as other applications of materials for extreme environments.
   d. *Isotope R&D and Production (DOE IP):* Advanced manufacturing investments within SC DOE IP form the underpinnings of the next generation of isotope production and processing techniques. Next generation targets and target fabrication techniques developed utilizing multiscale models and tools, coupled with co-design research and methodologies, are critical to enable robust domestic supply chains for critical isotopes used in climate and energy research and applied technologies. Development of modern isotope enrichment technologies will enable advanced manufacturing approaches to enriched materials that can lower operating costs and the spent fuel footprint.
   e. SC will interact with technology offices to ensure close coordination of FY 2023 funding opportunities to ensure maximum impact of funded research on technology challenges.

Research opportunities will include a focus on Established Program to Stimulate Competitive Research (EPSCoR) regions as well as broad outreach to minority serving institutions.

Biotechnology Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY2021 ($ Change)
Advanced Research Projects Agency - Energy	**25,499**	**0**	**TBD**	**TBD**
ARPA-E Projects*	25,499	0	TBD	TBD
Energy Efficiency and Renewable Energy	**59,375**	**59,375**	**57,250**	**-2,125**
Bioenergy Technologies	59,375	59,375	57,250	-2,125
Science	**640,728**	**663,647**	**738,183**	**+97,455**
Advanced Scientific Computing Research	10,000	10,000	10,884	+884
Basic Energy Sciences	228,154	266,330	259,114	+30,960
Biological and Environmental Research	402,574	387,317	468,185	+65,611
NNSA	0	0	20,000	20,000
Defense Nuclear Nonproliferation	0	0	20,000	20,000
Grand Total	**725,602**	**723,022**	**815,433**	**+115,330**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

The challenge to position the United States on an irreversible path to a net-zero economy in 2050 will require advances in every sector. Just as biotechnology is a significant tool in combatting the COVID-19 pandemic, it can also enable global decarbonization efforts across major sectors such as transportation, industry, and agriculture. Biotechnology refers to a wide array of advanced techniques and tools that harness the power of biology, including bioengineering and bioprocessing technologies, to optimize microbes and plants for production of biofuels and bioproducts and enhance the ability of agriculture and forests to help sequester carbon in soils. The goal of this crosscut is to increase the impact of biotechnology on decarbonization through efforts that will ultimately translate benchtop discoveries into commercial-scale bioeconomy applications.

Scientific and commercial achievements in biotechnology underpin the bioeconomy which accounts for five percent of U.S. Gross Domestic Product. DOE has supported major advancements in biotechnology and genome sciences including the sequencing of the human genome and development of genetic editing technologies like CRISPR. To take full advantage of progress made over the last decade in genome sequencing cost and speed, and to accelerate the Nation's capabilities to apply biotechnology to address deep decarbonization challenges, integrated efforts that bring together biological research, data science, high-performance computing, artificial intelligence and machine learning, automation, and process engineering are needed to realize deep decarbonization benefits for transportation, industry, and agriculture. In coordination with these efforts, it is also critical to reduce national security risks associated with biotechnology and biomanufacturing.

Coordination Efforts:

DOE's Biotechnology Working Group is comprised of members from EERE-BETO, SC-BES, SC-BER, SC-ASCR, and ARPA-E. In FY 2021, the working group organized the "Designing for Deep

Decarbonization: Accelerating the U.S. Bioeconomy" workshop. The working group will further engage stakeholders and experts on the challenges and opportunities identified at this workshop.

In addition to the funding offices identified here, various crosscutting offices (including the Office of Economic Impact & Diversity, Office of Policy, the Artificial Intelligence and Technology Office, and the Office of Technology Transitions) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments. The National Nuclear Security Administration also contributes expertise and capabilities that will anticipate and detect threats and strengthen biodefense.

Crosscut Objectives:

- ***Innovation built on strong foundations*:** Exploit and improve on genomic diversity within nature to identify new biological, bioinspired, and biohybrid functions.
- ***Enhance access to tools and facilities:*** Facilitate user access and interoperability between SC user facilities relevant to biotechnology, Bioenergy Research Centers, and the Agile BioFoundry.
- ***Increase range of production of biofuels and bioproducts:*** Conduct research and development (R&D) to increase the variety of sustainable biofuels and bioproducts made from plants and microbes.
- ***Develop advanced modeling and data analytics for biotechnology:*** Create integrative, collaborative, and open access computational platforms for biotechnology, with capabilities in Artificial Intelligence and Machine Learning techniques
- ***Reduce risk by advancing biosafety and biosecurity:*** Assess biotechnology and biomanufacturing risks and develop approaches to reduce risks and integrate security into biotechnology development.

Crosscut Action Areas:

1. **Strengthen Cross-DOE Coordination and Collaboration:** Ensure an integrated approach, including clearly defined "swim lanes" and "relay points," to avoid duplication and increase collaboration, share best practices for management of user facilities and other community resources, workshops and Principal Investigator meetings, community/stakeholder engagement, and data/information sharing.
2. **Support Fundamental and Applied R&D and Technology Transfer*:*** Establish the foundational scientific infrastructure, knowledge base, innovation, and technology transfer to enable dissemination and scale-up for biotechnology.
3. **Develop coordinated "use cases" and collaborations to identify technical and process (workflow) challenges*:*** Establish informal working groups and formal collaborations to regularly assess the state of biotechnology and DOE's readiness to facilitate the entire biotechnology workflow.
4. **Coordinate on Workforce/STEM and Diversity, Equity, and Inclusion:** Collaborate on best practices and accelerate progress towards common goals.

Program Organization:

There are several offices across DOE that work biotechnology and collaborate with one another to achieve the crosscut objectives.

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021 ARPA-E selected and/or obligated $25,499K in Biotechnology funding to projects aligned with the Crosscut through ARPA-E's Supporting Entrepreneurial Energy Discoveries (SEED) Exploratory Topic and Open 2021 programs as well as through Macroalgae Research Inspiring Novel Energy Resources (MARINER). ARPA-E is developing programs for transformational research across a wide range of energy technologies and applications. The assessment process for new programs is now underway and any potential future investments in Biotechnology will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):** EERE's *Bioenergy Technologies Office (BETO)* focuses on developing bioengineering techniques to optimize production of targets (fuels, chemicals, and materials) in microbes. These research, development, and demonstration (RD&D) activities in FY 2023 include:
    a. Agile BioFoundry, a consortium of seven National Laboratories that brings together world-class biotechnology capabilities to target a 50 percent reduction in the time and cost to bring new bio-derived molecules to market by accelerating the Design-Build-Test-Learn cycle.
    b. Biological engineering including enzymatic hydrolysis, fermentation, downstream separations, and catalysis as a part of state of technology pathways which demonstrate transformation of bio-based feedstocks into jet fuels and chemicals.
    c. Biological methods for plastic deconstruction and upcycling including optimization of novel enzymes and organisms to achieve commercial relevance.

3. **Science (SC):** There are multiple programs with the Office of Science that are major contributors to the advancement of the biotechnology crosscut objectives and scientific discovery. In FY 2023, SC programs will focus on new and continued research as described below.
    a. *Advanced Scientific Computing Research (ASCR)* employs high performance computing and the exascale ecosystem to accelerate progress in biotechnology across mission areas and national priorities. Through partnerships and collaborations within the Office of Science, DOE, and related mission agencies (National Institutes of Health (NIH), U.S. Department of Agriculture) ASCR is advancing the foundational research, computational readiness, and high-performance computing (HPC) access for biotechnology applications that underpin predictive capabilities for climate, national preparedness and security, and other DOE missions.
        i. Computational Partnerships supports collaborations with Biological and Environmental Research and NIH to incorporate ASCR research, methods and capabilities into mission critical applications to drive innovation and harness the potential of HPC to provide insights and predictive models that support an array of biotechnology goals.
        ii. Existing partnerships with the National Cancer Institute and NIH incorporate DOE expertise in multiscale modeling, artificial intelligence, data management and workflows, collaborative community driven model development, and HPC with grand challenges in cancer and health to validate existing methods across diverse datasets and applications and to generate new, hybrid methods that accelerate progress in

improving health outcomes and DOE mission critical applications. This includes new efforts to explore the technical readiness and feasibility of digital twin technology to improve cancer treatment outcomes and the development of clinically informed predictive models of radiation impacts on human health across time and length scales.

iii. ASCR is expanding partnerships to include new collaborations with applications focused on emergency response to build an enhanced response capability with state-of-the-art predictive models that leverage the DOE exascale ecosystem and can be rapidly employed when needed.

b. *Basic Energy Sciences (BES)* supports fundamental chemical and materials research to underpin the development of biotechnology. Research supported by BES may also use biotechnological approaches to understand molecular and atomic mechanisms in biochemical and chemical processes and structures which, in turn, may advance new biotechnologies. BES provides tools for characterizing biotechnology-relevant materials and processes through x-ray, neutron, electron beam scattering, and nano-science capabilities.

i. BES biosciences programs support basic research to provide mechanistic understanding of the biochemistry, chemistry, and biophysics of energy capture, conversion, and storage in plants and microbes. Research provides insights into the mechanisms of light harvesting and creation and transport of energy carriers in natural photosynthesis, develops molecular-level understanding of redox and active site protein chemistry controlling energy and molecular conversions, and discovers biochemical and biophysical principles that determine the synthetic pathways to produce biomolecules and structures with specific architectures. These detailed mechanistic studies can enable strategies for biotechnology-based approaches to energy capture and conversion.

ii. BES research on biomolecular materials focuses on the creation of robust, scalable, energy-relevant materials and systems with emergent behavior that work with the extraordinary effectiveness of molecules and processes of the biological world, foundational for biotechnology applications.

iii. Research in catalysis science and solar photochemistry focuses on mechanistic understanding of energy and molecular conversion processes that establish a foundation for development of bio-inspired, biohybrid and biomimetic systems. Future research areas include programmable biomaterials and biocatalysts, neuromorphic computing, and design of chemical processes and integrated systems. Next-generation tools will foster new developments in biotechnology.

iv. Advances at BES scientific user facilities will ensure a broad science and capability base for research at the interface of physical, biological, and computational sciences to understand integrated systems, including those driving or developed through biotechnology.

c. *Biological and Environmental Research (BER)* employs biotechnological approaches such as genome sequencing, proteomics, metabolomics, structural biology, high-resolution imaging and characterization, and integration of information into computational models that can be iteratively tested and validated to advance a predictive understanding of biological systems for DOE mission goals.

i. Genomic Science supports fundamental research on discovery and manipulation of genome structure, regulatory elements and epigenetic controls to understand

genotype to phenotype translations in microbes and plants. These efforts include biosystems design research to explore genomic pathway design and new secure gene-editing and multi-gene stacking techniques for designing new functions into plants and microbes providing a crucial foundation for advancing biotechnology.

ii. Additionally, these efforts seek to gain an understanding of how genomic mechanisms translate to understanding the functioning of plants and soil microbial communities in the environment. This information leads to understanding how plants and microbes impact the cycling and fate of carbon, nutrients, and contaminants in the environment and contribute to more sustainable ecosystems.

iii. Advances in genomic science increasingly require integrative, collaborative, and open access computational platforms to converge on optimized solutions for clean energy production and renewable products. New capabilities in artificial intelligence/machine learning techniques will aid discovery of novel processes and key insights into the functioning of biological systems by examining enormous datasets with powerful analytics to discover new biological principles hidden in complex multivariate data.

iv. BER supports four Bioenergy Research Centers (BRCs) engaged in multidisciplinary genome-enabled biotechnology research to sustainably produce a range of bioenergy and bioproducts from renewable plant biomass. The BRCs seek to identify the genomic underpinnings of complex plant traits in crops with promising bioenergy/bioproduct characteristics, streamline biomass deconstruction processes to funnel plant components into defined process streams, design new pathways in microorganisms to convert plant biomass to a range of fuels, chemicals and products, and develop the needed agronomic understanding of how to manage bioenergy crops for sustainable production on marginal lands laying the scientific foundation for a broader bio-based economy.

v. New quantum-enabled instrumentation for imaging biological processes will be explored in Biomolecular Characterization and Imaging Science for visualizing cellular metabolism non-destructively. Multimodal imaging concepts will also be pursued to create integrative systems to validate hypotheses of cellular function or design of new process.

vi. The Joint Genome Institute (JGI) provides users with high quality genome production and new analysis techniques for complex plant and microbiome samples. Integrative activities with the DOE Systems Biology Knowledgebase will provide new cross-platform capabilities for JGI users and users of the new National Microbiome Data Collaborative providing information on how microbial communities function in a variety of environments.

4. **National Nuclear Security Administration (NNSA):** The NNSA Bioassurance program will contribute to DOE biotechnology efforts through innovations in biosecurity to reduce risk throughout the biotechnology research and development and biomanufacturing lifecycles. The Bioassurance program will anticipate and detect threats and strengthen biodefense. Activities covered under this program will focus on anticipating destabilizing threats through modeling, identifying threat signatures and developing detection technologies, and rapidly developing and validating safeguards and threat mitigation approaches. NNSA will integrate its high-security work with the Department's "open" science work, providing the full spectrum of capabilities essential for a bioassurance program informed by national security expertise drawn from parallel and analogous work on nuclear threats, risks, export controls and licensing, nonproliferation, detection, and verification.

Carbon Dioxide Removal Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**84,478**	**0**	**TBD**	**TBD**
Advanced Research Projects Agency - Energy*	84,478	0	TBD	TBD
Energy Efficiency and Renewable Energy	**88,750**	**13,000**	**26,000**	**-62,750**
Advanced Manufacturing	0	0	10,000	+10,000
Bioenergy Technologies	88,750	10,000	13,000	-75,750
Water Power Technologies	0	3,000	3,000	+3,000
Fossil Energy and Carbon Management	**40,000**	**40,000**	**65,000**	**+25,000**
Carbon Dioxide Removal	40,000	40,000	65,000	+25,000
Science	**35,500**	**36,700**	**170,950**	**+135,450**
Advanced Scientific Computing Research	0	0	25,000	+25,000
Basic Energy Sciences	12,500	13,700	77,950	+65,450
Biological and Environmental Research	23,000	23,000	68,000	+45,000
Grand Total	**248,728**	**89,700**	**261,950**	**+97,700**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

Nearly all climate models that simulate scenarios for reaching net-zero indicate the need for a near-term focus on carbon dioxide removal (CDR) development and deployment (D&D) in addition to carbon reduction efforts including mitigative point source carbon capture and sequestration. Intergovernmental Panel on Climate Change modeling shows that only emissions scenarios including CDR achieve neutrality in 2050.

CDR refers to multiple approaches that capture carbon dioxide (CO_2) directly from the atmosphere and durably store it in geological, biobased and ocean reservoirs or in value-added products to create negative emissions. Negative emission technologies at scale are necessary for achieving national and global net-zero greenhouse gas emission (GHG) goals in the coming decades, removing CO_2 from the accumulated pool in the of carbon from the atmosphere, and avoiding the most critical climate consequences.

In recognition of the necessity of CDR, DOE launched the Carbon Negative shot as its third Energy Earthshot at COP26 in November of 2021. Carbon Negative Shot is a decadal goal to reduce the cost of atmospheric carbon removal to less than $100/net metric ton of CO_2 equivalent (CO_2e). This effort is being deployed to achieve a net-zero carbon economy and eventually remove legacy carbon pollution to help address the climate crisis, with a dedicated focus on doing so in a just and sustainable manner.

Carbon Negative Shot defines four criteria that define goals for each CDR pathway: 1) less than $100/net metric ton CO_2e for both capture and storage of CO_2; 2) robust accounting of full lifecycle emissions (i.e., ensures emissions created from construction to operation of the removal technology are accounted for); 3) high-quality, durable storage with costs demonstrated for monitoring, reporting, and verification for over a period of at least 100 years; and 4) enables necessary gigaton scale removal.

The diverse suite of technologies and approaches in CDR requires integrated investment across the full research, development, demonstration, and deployment (RDD&D) spectrum such that breakthroughs are rapidly transferred and scaled, and that deployment of first-of-its kind technologies quickly informs the next generation of innovation. CDR approaches include, but are not limited to, biomass carbon removal with storage (BiCRS), bioenergy with carbon capture and sequestration (BECCS), direct air capture (DAC) with durable storage (DACS), biological methods to stored products, enhanced mineralization, soil carbon sequestration, improved forest management, and direct ocean capture (DOC) with durable storage (DOCS). Within these approaches, the technology or mechanisms for CO_2 removal are variable, leading to challenges in how to quantify reductions via lifecycle analyses (LCA), and how to accurately define the economics and costs.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, funding from the BIL will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment of carbon dioxide direct air capture, storage, conversion, and transportation. These investments are essential in building out key components of a nascent industry.

Ongoing research, development, and demonstration (RD&D) are needed for other pathways, to enhance scientific understanding of the foundational materials and processes, advance the state of the art, develop accounting methods, monitoring and verification and other activities as described throughout this crosscut narrative.

Coordination Efforts:

In addition to developing and implementing a cross-agency CDR strategy, priorities include joint efforts on information sharing and engagement with external stakeholders, technology experts, and other government agencies. There is close coordination between the DOE's efforts in the CDR crosscut, the interagency CDR Task Force led by DOE, and the international CDR Mission that the U.S. is co-leading as part of Mission Innovation effort on CDR. The CDR crosscut group manages the Carbon Negative Shot.

In addition to the funding offices identified here, various crosscutting offices (including the Office of Economic Impact & Diversity, Office of Policy, the Office of Artificial Intelligence and Technology Office, the Office of International Affairs, and the Office of Technology Transitions) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments.

Crosscut Objectives:

- ***Discover, innovate, and enable the deployment of low-cost and scalable CDR pathways to accelerate removal of carbon dioxide directly from the atmosphere and environment:*** Foster crosscutting fundamental science and applied research and development (R&D) to enable breakthroughs along the carbon removal value chain. Identify and address critical barriers to reducing the costs and energy requirements for CDR systems and materials through targeted research investments. Promote and demonstrate the strategic deployment of diverse CDR systems and strategies.
- ***Engage stakeholders and communicate strategy:*** Host workshops and public meetings to share information. Engage with communities that could participate in or be affected by CDR including sovereign tribal nations, labor groups, and environmental, environmental justice (Justice40), and climate justice organizations.
- ***Address resource and sustainability requirements:*** Assess availability of primary energy, water, and other inputs to ensure holistic, sustainable, low, and negative-life-cycle emissions pathways,

and ensure the stewardship of our communities, natural resources, and the environment. For D&D projects, coupling carbon accounting through LCA and techno-economic analyses are critical for assessing the net amount and timescale of carbon removal alongside associated costs.

Crosscut Action Areas:
The Department of Energy (DOE) Program offices Energy Efficiency and Renewable Energy (EERE), Fossil Energy and Carbon Management (FECM), Science (SC), and Advanced Research Projects Agency-Energy (ARPA-E) will support:

1. **Cost effective capture, conversion, transport, and durable storage:** Issue targeted funding announcements to address scientific and technical challenges preventing widespread deployment of cost-effective CDR technologies, as identified in the Carbon Negative Shot.
2. **Robust Monitoring, Reporting, and Verification (MRV):** Issue targeted R&D funding announcements to advance necessary technologies for measuring, monitoring, and verifying durable carbon storage.
3. **Systems Analysis:** Conduct resource assessments on availability of primary energy, water, and other inputs to ensure holistic, sustainable, low and negative-life-cycle emissions pathways.
4. **Demonstrate and support key infrastructure for CDR:** Leveraging BIL funding related to CDR, demonstrate and validate carbon transport and storage at scale.

Program Organization:

1. **Advanced Research Projects Agency–Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021, ARPA-E selected and/or obligated $84,478K in CDR funding to projects from ARPA-E's Harnessing Emissions into Structures Taking Inputs from the Atmosphere (HESTIA), Supporting Entrepreneurial Energy Discoveries (SEED) Exploratory Topic, and Open 2021 programs. ARPA-E is developing programs for transformational research across a wide range of energy technologies and applications. The assessment process for new programs is now underway and any potential future investments in CDR will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):** Within the EERE there are several programs that support the efforts of the CDR crosscut.
    a. *Advanced Manufacturing Office (AMO):* AMO is developing technology to improve the feasibility of DAC through manufacturing improvements to DAC sorbents and intensified process development that couples DAC with durable storage and using industrial byproducts, such as steel slags and mine tailings, for mineral carbonation to produce products for beneficial use and/or local carbon sequestration.
    b. *Bioenergy Technologies Office (BETO):* BETO supports RDD&D on technologies, systems, and practices to increase carbon removal from biomass, including sustainable agriculture, forest management, and the use of biomass CO_2 from point sources and DAC technologies to improve the productivity of algal biomass. This work includes developing tools and remote sensors for soil carbon monitoring, researching the long-term carbon-drawdown potential of biochar, pursuing landscape design analysis, and investigating the feasibility and carbon

sequestration potential of sustainable BECCS practices, including biomass conversion to advanced fuels and chemicals.

c. *Water Power Technologies Office (WPTO):* WPTO will build on its National Laboratories seed funding program and internal scoping activities to further investigate the role of marine energy in CDR in FY 2022. Investments may include understanding the energy requirements of offshore seaweed farming for CDR with AMO and ARPA-E; building on Pacific Northwest National Laboratory (PNNL)/National Oceanic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory research interests, including ocean observing to assess ocean-based CDR projects, sustainable mariculture for CO_2 offsets, and methods for ocean alkalinity enhancement and CDR in coastal ecosystems; and a host of foundational R&D projects at National Laboratories and universities to understand energy requirements, siting, and energy storage needs of marine-energy powered CDR.

3. **Fossil Energy and Carbon Management (FECM):** FECM focuses on CDR approaches that include chemicals, minerals, and biological pathways. FECM has been working on carbon capture and storage (CCS) projects for almost 20 years and has invested heavily in the development of technologies to capture CO_2 from power plants and industrial sources. More recently, DOE has been applying these technology developments to various approaches, including BECCS and DAC coupled to dedicated storage. The FECM CDR subprogram was a new budget line in the FY 2022 Budget Request and in FY 2023 will support funding on chemical, mineral, and biological concepts. However, it builds upon past CCS efforts which have been funded through FECM's CCS activities, such as past work on DAC, mineralization, co-firing of biomass, and capture technology development. RDD&D activities include:
   a. DAC with durable storage: FECM funds significant DAC RDD&D alongside all carbon storage research at DOE. This includes transformational DAC materials and components, pilot-scale testing, front-end engineering and design (FEED) studies, and large-scale extended tests. FECM is requesting funds for the DAC Test Center at a National Energy Technology Laboratory (NETL) campus.
   b. Biomass waste R&D: R&D on sustainably sourced biomass waste coupled with CCUS which offers an opportunity for near-term deployment of CDR technologies. This includes gasification of waste feedstocks, such as plastics and sustainably sourced biomass waste with CCS.
   c. Mineralization: FECM is continuing to invest in RDD&D for in situ, ex situ, and surficial mineralization opportunities.
   d. Significant RDD&D investments and work for geological CO_2 storage and CO_2 transport. Coupled to CO_2 capture processes, such as bioenergy and DAC, reliable storage on timescales that will positively impact climate are of central focus. For example, reliable storage on the scale of 1000s years is desired, which may include geologic storage deep underground, or the conversion of CO_2 to synthetic aggregates through mineral carbonation (replaces sand and gravel for construction) or plastics.
   e. Program support for Carbon Negative Shot, Mission Innovation Initiative on CDR and/or CDR Task Force.
4. **Science (SC)**: SC provides foundational knowledge and state-of-the-art capabilities in support of crosscut objectives and has supported theoretical and experimental science related to understanding chemical and biological processes, separations, materials, and geochemistry related to carbon capture for many years. Key activities in FY 2023 for CDR include:
   a. Supporting scientific discoveries and major scientific tools to transform our understanding of CO_2 chemistry, gas separation systems, and materials important to CDR technologies.

Research focuses on advancing fundamental knowledge to enable energy-efficient CO_2 capture from dilute sources (e.g., DAC and DOC) and conversion of CO_2 into durable products (e.g., mineralization). In FY 2022, the Office of Basic Energy Sciences (BES) released or plans to release three special funding opportunity announcements (FOA) that included research topics relevant to CDR technologies: Energy Frontier Research Centers, Chemical and Materials Sciences to Advance Clean Energy and Transform Manufacturing and RENEW. Clean energy topics, including CDR, were also called out in the FY 2022 SC Open FOA. In FY 2023, Basic Energy Sciences (BES) will continue to support CDR research that spans from single principal investigators to large teams in BES core programs, to Energy Frontier Research Centers, to Energy Earthshot Research Centers (EERC), described below.

b. In addition, SC operates major x-ray, neutron, nanoscience, genome sequencing, and high-performance computing user facilities that provide advanced synthesis, fabrication, characterization, and computational capabilities that support CDR efforts across the spectrum of basic and applied research.
c. BES also supports research that provides foundational knowledge about critical minerals and materials, such as rare earth elements and platinum group elements, to ensure they remain available or to reduce the dependence on them for CDR technologies as well as other energy technologies (related to the Critical Minerals and Materials Crosscut).
d. Biological and Environmental Research (BER) supports fundamental systems biology research on 1) plants and plant microbiomes to capture atmospheric CO_2 and sequester stabilized forms of carbon in biomass and soil, and 2) algal systems to convert gaseous CO_2 waste streams into a broad range of bioproducts in support of other CDR technologies.
e. Both BES and BER will participate in the initiation of the EERCs, a new modality of research to be launched in FY 2023, bringing together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard or small-group awards. Aligned with both SC and the technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied R&D activities, to bridge the R&D gap. Efforts will focus directly on the interface, ensuring that directed fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied R&D activities. The Carbon Negative Shot will be addressed in this crosscut.

Critical Minerals & Materials Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**13,653**	**44,000**	**TBD**	**TBD**
Advanced Research Projects Agency - Energy*	13,653	44,000	TBD	TBD
Energy Efficiency and Renewable Energy	**104,000**	**106,523**	**208,600**	**+104,600**
Advanced Manufacturing	45,000	45,000	60,000	+15,000
Geothermal Technologies	4,000	50	5,000	+1,000
Hydrogen & Fuel Cell Technologies	25,000	30,000	30,000	+5,000
Solar Energy Technologies	0	0	16,000	+16,000
Vehicle Technologies	30,000	30,000	73,600	+43,600
Wind Energy Technologies	0	1,473	24,000	+24,000
Fossil Energy and Carbon Management	**23,000**	**23,000**	**40,000**	**+17,000**
Mineral Sustainability – Critical Minerals	23,000	23,000	40,000	+17,000
Nuclear Energy	**59,500**	**19,000**	**127,000**	**+67,500**
Nuclear Energy Enabling Technologies	1,000	500	500	-500
Fuel Cycle Research and Development	58,500	18,500	126,500	+68,000
Office of Technology Transitions	**100**	**100**	**100**	**0**
Science	**17,000**	**17,000**	**25,000**	**+8,000**
Basic Energy Sciences	17,000	17,000	25,000	+8,000
Grand Total	**217,253**	**209,623**	**400,700**	**+197,100**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

Critical minerals and materials (CMM) are central for U.S. energy and both economic and national security as they underpin many clean energy technologies, vital manufacturing processes, and a number of key defense applications. Developing reliable, domestic and trusted ally sources, substitutes and processing capacity for these minerals and materials reduces supply risks faced by the United States. Further, there is international competition for these minerals, coupled with disruption potential from geopolitical events and resource nationalization. Reliable, resilient, and secure critical material and mineral supply chains are therefore vital to meeting our economic, national security, and climate goals. These supply chain components include, but are not limited to, rare earth elements (REE) for permanent magnets in electric vehicle (EV) motors and wind turbines; cobalt, lithium, manganese, nickel, and graphite for EV and grid batteries; and platinum group metals in fuel cell catalysts and catalytic convertors. In addition, there are additional key minerals such as copper and uranium, which are vital for clean and low carbon energy, and for resilience considering dynamic and changing global supply chain dynamics.

The development of a sustainable, safe, and robust domestic supply chain for CMM can also create high-paying jobs, support both existing and new manufacturing economies, and aid in a just transition for coal and fossil-based communities. At the same time, development of more diverse and robust mineral

and material supply chains must incorporate engagement and consultation with diverse stakeholder and tribal communities, coupled with deep consideration of and mitigation of the environmental and life cycle impacts of accelerated mineral supply chain growth.

The CMM Crosscut is also working to address key technology portfolio gaps in areas where the Department of Energy (DOE) has less historical focus such as: hard rock (including sedimentary and clay) critical mineral extraction and mining technologies, advanced subsurface technologies, unconventional resource extraction technologies, and robotics and autonomous operation applications in mineral extraction.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment of battery and critical mineral recycling, battery material processing, as well as address critical material innovation, efficiency and alternatives, supply chain research and rare earth elements. These investments are essential in addressing the supply chain and technology needs to support growth in clean energy.

Coordination Efforts:
The CMM Crosscut is coordinated through a crosscutting team and is comprised of representatives from across DOE. DOE investments within the Advanced Research Projects Agency - Energy (ARPA-E), Office of Energy Efficiency and Renewable Energy (EERE), Office of Fossil Energy and Carbon Management (FECM), Office of Nuclear Energy (NE), and Office of Science (SC), support the crosscut objectives. APRA-E, EERE, FECM, and NE support applied research, development, and demonstration (RD&D) across these topics, while SC provides the necessary fundamental research and world-class user facilities necessary to achieve the goals.

Additionally, key facilitating offices support implementation of key portions of these programs. The Office of Technology Transitions (OTT), in coordination with DOE program offices, analyzes, identifies and supports technology commercialization pathways and partnership opportunities. The International Affairs Office (IA) identifies and facilitates opportunities with key foreign and ally partners and serves as a key bridge to other U.S. Government efforts in the global supply chain. The Office of Policy (OP) provides in-depth analysis and identifies policy tools which can accelerate technology use and adoption in support of the clean energy transition. The Office of Legacy Management (LM) manages DOE's Uranium Leasing Program. In addition to the offices identified here, various crosscutting offices (including the Office of Economic Impact & Diversity, Office of Clean Energy Demonstrations, and the Office of Artificial Intelligence and Technology) may contribute staff time and coordinate with the research, development, demonstration and deployment (RDD&D) funding offices to enhance the impact of the Department's investments.

FY 2023 activities include developing and executing RDD&D coordination, budget development, and strategic planning for the crosscut through workshops, reports, and strategy updates. Strategic planning efforts will build upon previous coordination activities directed by Congress, as well as coordination mandated through Executive Order (EO) 13953, *Addressing the Threat to the Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries, and* EO 14017*, America's Supply Chain*. This work includes ongoing DOE efforts within the Office of Policy to develop and maintain domestic supply chains by increasing raw material availability, expanding domestic manufacturing capabilities, supporting formation of and investment in

diverse, secure, and socially responsible foreign supply chains, and enhancing supply chain knowledge and decision making. The CMM crosscut will also coordinate with other priority technology efforts, the most notable and impactful being the Subsurface crosscut, to ensure that key topics and opportunities are not overlooked.

Critical mineral development and access within the U.S. requires close coordination between DOE and other agencies which have key leadership, supporting, or facilitating roles. This includes regulatory (Environmental Protection Agency, Department of Interior (DOI)), international (Department of Commerce (DOC), Department of State, Export-Import Bank, Development Finance Corporation (DFC)), technical (DOI-United States Geological Survey), and commercial facing (DOC, Department of Labor) partners. Interagency collaboration is key to advance and secure sustainable mineral extraction, and to address the issues and challenges posed by future possible resources such as from marine environments.

Crosscut Objectives:

- ***Diversify a domestic and trusted source supply of CMM in a safe, sustainable, and environmentally just way:*** Demonstrate and deploy proven processes for producing, processing and utilizing domestic materials that are cost competitive, minimize environmental impact, increase material stewardship, and ensure workforce safety. Concurrently, advance innovation and new technologies which provide a pathway to lower cost and lower impact mineral access solutions.
- ***Develop safe, responsible, and environmentally just domestic processing and refining capabilities for CMM****:* Develop, demonstrate, and deploy safe, economically competitive, sustainable, and novel technologies for processing and refining CMM.
- ***Develop substitutes for CMM which use earth-abundant materials, are easily and economically processed, and which can have a lessened environmental footprint compared to alternatives:*** Adoption of alternative materials, components, and technologies that minimize or eliminate the use of scarce or difficult-to-access CMM.
- ***Expand and improve the efficient use, recycling and second-life application of CMM:*** Drive solutions to address efficient CMM collection and develop technologies to enable reuse, remanufacture, and efficient recycling for reintroduction into the supply chain.
- ***Develop a high-precision, material-specific understanding of the global supply chain into the future:*** As part of an all-of-government approach, conduct ongoing analyses on criticality, supply/demand, material flow, supply chain risk and uncertainty and state of industry practice. Ensure that this analysis supports actionable options and alternatives to ensure supply chain stability.

Crosscut Action Areas:

1. ***Strengthen Cross-DOE Coordination and Collaboration:*** Ensure an integrated approach to CMM RDD&D activities to include analysis of domestic and trusted ally supplies and processing through workshops, joint funding opportunities, community/stakeholder engagement, and data/information sharing. This requires organizing around the problem vs. a functional or commodity-specific focus.
2. ***Support Fundamental and Applied Research and Development (R&D) and Technology Transfer:*** Establish the foundational scientific infrastructure, knowledge base, innovation, and technology transfer activities to enable DOE to meet the crosscut objectives.

3. ***Launch, Support, and Sustain Demonstration Projects:*** A durable U.S. CMM supply chain requires a carefully crafted bridge between scientific discovery, technology development and industry uptake. Demonstration projects which allow risk reduction and at-scale testing of key technologies is key to a durable and secured supply chain. DOE will leverage BIL activities to support the CMM crosscut.
4. ***Coordinate Broadly on Workforce Development, Science, Technology, Engineering, and Math (STEM) and Diversity, Equity, and Inclusion:*** Collaborate both within the government and with all stakeholders on best practices and accelerate progress towards common goals.

Program Organization:

There are several technology offices which either directly invest in CMM, or which play a vital role in in the critical mineral supply chain.

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021 ARPA-E selected and/or obligated $13,653K in CMM funding to projects from ARPA-E's Supporting Entrepreneurial Energy Discoveries (SEED) Exploratory Topic and Open 2021 programs. In FY 2022 ARPA-E is targeting approximately $44,000K in CMM funding to projects from ARPA-E's Mining Innovations for Negative Emissions Resource Recovery (MINER) program. ARPA-E is developing programs for transformational research across a wide range of energy technologies and applications. The assessment process for new programs is now underway and any potential future investments in CMM will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):**
   a. *Advanced Manufacturing Office (AMO):* Efforts will focus on comprehensive RD&D to reduce supply risk and improve supply resilience for materials and technologies necessary for the clean energy transition (including rare earths, lithium, cobalt, and gallium). These materials are needed for applications such as magnets in EVs and wind turbines, batteries, efficient lighting and semiconductors. Strategies include diversifying supply, developing substitutes, improving reuse/recycling, and more efficient use. Efforts will also focus on pilot and demo projects and testbeds that verify economics of scaled continuous operations in real world conditions. Areas of interest for these projects include highly selective separation, metal reduction, magnet manufacturing, materials recovery from secondary and unconventional sources, material reuse, more efficient use, and balanced coproduction. Lithium-ion extraction projects will improve industrial production of lithium precursors (lithium carbonate and lithium hydroxide) from raw materials sources including (but not limited to) hard rock minerals, brines, geothermal brines, and mine tailings to diversify the domestic sources of lithium.
   b. *Geothermal Technologies (GTO):* Efforts will address technology and process gaps that still exist following the results of the Geothermal Lithium Extraction Prize to generate technical solutions to our Nation's critical minerals supply through geothermal brine and produced water extraction and processing. This may include efforts to scale up technical solutions developed as part of the Geothermal Lithium Extraction Prize to successful demonstration in the Salton Sea area of California. In the Salton Sea alone, there is an estimated annual

lithium resource potential of 600,000 tons, which currently exceeds the annual U.S. demand for lithium.

c. *Hydrogen and Fuel Cell Technologies Office (HFTO):* HFTO supports R&D to reduce Platinum Group Metals (PGM) catalysts for fuel cells and hydrogen production technologies, as well as additional supporting activities to reduce vulnerabilities and build supply chain resilience.

d. *Solar Energy Technologies Office (SETO):* SETO supports the analysis of potential PV deployment limitations related to materials scarcity and the RD&D of materials alternatives, techniques to use materials more efficiently and recycling methods to further utilize existing materials. Critical material considerations will help inform RD&D vectors within the new Solar Manufacturing Accelerator, a collaborative effort with EERE's Advanced Manufacturing Office.

e. *Vehicle Technologies Office (VTO):* Accelerate fundamental research for developing substitutes for graphite by enabling silicon anodes and for developing near term lithium chemistries that require very low or no cobalt. Focus research on lithium battery technologies that eliminate the need for cobalt, significantly reduce or eliminate the need for nickel and graphite such as lithium metal and solid-state battery technologies. Battery recycling R&D will advance the scale-up of bench scale processes and validate processes to meet the goal of utilizing mostly recycled material that matches the performance of virgin material.

f. *Wind Energy Technologies Office (WETO):* Funding for analysis and technology innovation efforts to both understand the vulnerabilities of the wind energy supply chain to critical materials and to mitigate those vulnerabilities by reducing dependence on, and improving recovery of, critical materials within wind energy components.

3. Fossil Energy and Carbon Management (FECM):

a. FY 2023 Key Objectives (Planned): The FY 2023 Budget Request supports further advance production of high purity, commercial grade REEs and other critical minerals, which will form next stage development to broadly enable extraction of REEs and other critical minerals from unconventional feedstocks (such as coal refuse, acid mine drainage, and produced water) towards commercial industry adoption.

b. Funding will also be utilized for Front-End Engineering Design (FEED) studies for an extraction, separation and recovery facility/system that can produce 1-3 metric tons per day of an at least 75% rare earth oxide and/or salt mixed concentrate by weight and assess potential for individual separation and reduction to metal.

c. Funding would be applied to further regional basin projects (the Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Initiative). It will continue to support regional characterization and field activities for unconventional/secondary sources, basin commercialization strategic planning/implementation, environmental remediation value streams, basinal technology development and stakeholder outreach and engagement.

d. Funding would be applied to further Carbon Ore to Products projects to develop synthetic graphite, graphene, and other carbon materials that are critical resources for batteries, electronics, composites, and similar end-uses. This will include technoeconomic analysis and life-cycle analysis, process systems, and market analyses of high value carbon products that will enable critical mineral production from coal-based feedstocks.

e. The development of a sustainable, safe, and robust domestic supply chain for critical minerals and materials can also create jobs and aid in a just transition for coal and fossil-based communities. These communities have expertise that could be transferrable to technology development throughout the supply chain:

i. Upstream unconventional technology and technique development from resource characterization and prediction, through novel extraction from sources such as acid mine drainage, mine refuse, coal ash, and geothermal and produced water brines.
ii. Midstream technology development for environmentally sustainable, efficient, and cost-effective extraction, processing, and refining of resources from unconventional and secondary sources.
iii. Downstream technology development for the transformation of carbon ore to synthetic graphite and graphene for battery anodes as well as graphene for quantum dots for use in solar cells.

4. **Nuclear Energy (NE):** To combat the climate crisis, create American jobs, position the U.S. to compete successfully worldwide, and support national security goals, the Office of Nuclear Energy is taking steps to support a domestic nuclear fuel supply chain including uranium mining, conversion, enrichment, fuel fabrication, and the option of recycling. NE is also developing materials and manufacturing technologies to support advanced reactors and the current fleet of domestic reactors.
    a. In prior years, NE began to identify the critical minerals for the alloys and other applications used by the U.S. nuclear industry for the current fleet and projected for advanced reactors. NE also began supporting domestic uranium mining capabilities through R&D activities to reduce lifecycle costs of uranium production; demonstrating the production of high-assay low enriched uranium (HALEU) using U.S. origin enrichment technology to encourage commercialization by the private sector; and developing advanced recycling technologies as options to improve uranium resource utilization.
    b. Fuel Cycle Research and Development: A HALEU Availability program will support civilian domestic demonstration and commercial use. This program will work to make available small quantities of HALEU from limited DOE uranium inventories and HALEU production in the short term and will work with the private sector in its design and build out of commercial U.S. HALEU production capability in the long term. Additionally, activities for the development and demonstration of different recycling technologies to make available small quantities of HALEU materials will continue, by using the molten salt and hybrid ZIRCEX processes.
    c. Nuclear Energy Enabling Technologies: Perform research on the positive effects of advanced manufacturing techniques to improve use of critical minerals for nuclear energy applications.

5. **Office of Technology Transitions (OTT):** In FY 2022, DOE published the OTT-led report on the "Competitiveness and Commercialization of Energy Technologies, a Supply Chain Deep Dive Assessment," as part of the DOE's Response to EO 14017, "America's Supply Chains." In FY 2023, OTT will continue to collaborate with other DOE offices on the implementation of the framework and methodology described in that report. These activities include:
    a. Conducting market and economic analysis to identify commercialization opportunities across critical material and related supply chains.
    b. Expanding analysis and industry engagement activities to identify and pursue commercialization projects and pathways.

6. **Science (SC):** For many years, SC has supported foundational theoretical and experimental science related to understanding unique chemistry and materials properties associated with

REE, substitution for platinum group element (PGE) catalysts, and novel battery materials and chemistries. New research directions in FY 2023 emphasize the full breadth of the crosscut.

a. SC-supported research has focused on understanding of the role of REEs, PGEs, and other critical elements in the determination of the properties of materials and molecules at length scales ranging from electronic to atomic and microstructural scales, and on advancing geoscience and separation science to enhance the extraction and chemical processing of critical elements.
b. Research will expand understanding of the REE and PGE chemistry, including selective separations from solutions, and dynamics and reactivity at mineral-water interfaces during extraction and recovery.
c. Emphasis will be on integration of the related fields of synthesis, characterization, predictive theory/modeling, and data science to advance understanding of the role of REE, PGE and other critical elements in the determination of the properties of functional materials such as magnets and catalysts, and on the use of such knowledge to reduce, eliminate, or find substitutes for critical materials in energy-relevant technologies.
d. SC operates major x-ray, neutron, nanoscience, and high-performance computing user facilities that provide advanced synthesis, fabrication, characterization, and computational capabilities to this community for basic, applied, and industrial research.

Energy Storage Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**48,281**	**45,000**	**TBD**	**TBD**
Advanced Research Projects Agency - Energy[1]	48,281	45,000	TBD	TBD
Energy Efficiency and Renewable Energy	**344,792**	**311,400**	**496,000**	**+151,208**
Advanced Manufacturing	25,000	30,000	30,000	+5,000
Building Technologies	25,250	7,500	25,000	-250
Geothermal Technologies	6,515	250	12,000	+5,485
Hydrogen and Fuel Cell Technologies	117,000	120,250	123,000	+6,000
Renewable Energy Integration	0	0	64,000	+64,000
Solar Energy Technologies	17,000	10,000	26,800	+9,800
Strategic Programs	1,235	7,000	0	-1,235
Vehicle Technologies	135,000	135,000	181,700	+46,700
Water Power Technologies	15,000	0	27,500	+12,500
Wind Energy Technologies	2,792	1,400	6,000	+3,208
Federal Energy Management Program	**0**	**0**	**1,000**	**+1,000**
Fossil Energy and Carbon Management	**5,000**	**5,000**	**6,000**	**+1,000**
Repurposing Fossil Energy Assets	5,000	5,000	6,000	+1,000
Nuclear Energy	**103,000**	**92,000**	**12,000**	**-91,000**
Crosscutting Technology Development	10,000	10,000	9,000	-1,000
Advanced Reactor Demonstration Program	80,000	80,000	0	-80,000
Light Water Reactor Sustainability	13,000	2,000	3,000	-10,000
Office of Clean Energy Demonstrations	**0**	**0**	**12,500**	**N/A**
Clean Energy Demonstrations	0	0	12,500	N/A
Office of Electricity	**80,000**	**80,000**	**81,000**	**+1,000**
Energy Storage Research	57,000	57,000	81,000	+24,000
20-OE-100 Grid Storage Launchpad[2]	23,000	23,000	0	-23,000
Office of Technology Transitions	**100**	**100**	**100**	**0**
Science[3]	**66,758**	**83,268**	**160,508**	**+93,750**
Basic Energy Sciences	66,758	83,268	160,508	+93,750
Grand Total	**647,931**	**616,768**	**769,108**	**+179,458**

[1] ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

[2] $47 million was provided in the FY 2022 Omnibus appropriation to fully fund the remainder of Grid Storage Launchpad construction.

[3] Science funding includes the Batteries and Energy Storage Energy Innovation Hub, the Fuels from Sunlight Energy Innovation Hubs, the Energy Frontier Research Centers (EFRCs), the Energy Earthshot Research Centers (EERCs), and core research. SC also supports broad research related to hydrogen as an energy storage medium.

Summary:

The DOE Energy Storage crosscut encompasses activities including research, development, and demonstration (RD&D) efforts to accelerate market adoption of transformational energy storage technologies. Energy storage technologies are critical to decarbonizing the energy sector, whether for the power sector, transportation, buildings, or industrial end use. Fully decarbonizing the grid alone is likely to require thousands of gigawatts-hours of new energy storage, incorporating a portfolio of technologies that range in function from immediate response to the ability to discharge continuously for weeks or longer. Existing technologies must be demonstrated and validated for new uses, and new technologies must be developed, proven safe and effective, and commercialized within the next 5-10 years if the United States will achieve its ambitious decarbonization goals.

The Energy Storage Grand Challenge (ESGC) is the coordination mechanism for the Energy Storage crosscut activities. The ESGC goal is to accelerate the development, commercialization, and utilization of next generation energy storage technologies at the scale necessary for the United States to reach its decarbonization goals. This work includes the Long Duration Storage Energy Earthshot, which is a bold target to achieve 90% cost reductions for technologies that can provide 10 hours or longer duration of energy storage within the coming decade. As an Energy Earthshot, Long Duration Storage Shot highlights a top Administration research, development, demonstration, and deployment (RDD&D) focus area where innovation breakthroughs will address the climate crisis and create high-paying clean energy jobs in the United States.

As energy storage can be provided through and enabled by a broad range of technologies – electrochemical, electromechanical, thermal, flexible generation, controllable loads, and power electronics – several DOE offices have the authority and scope to work on different energy storage systems and applications. Given the opportunity space to advance energy storage through a portfolio of technologies, DOE offices are coordinating to target their funding more effectively to the highest priority areas while integrating the RD&D capabilities and expertise across program portfolios.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment of battery and critical mineral recycling, battery material processing, and long duration energy storage. These investments are essential in addressing the supply chain and technology needs to support the storage needs for intermittent renewables and grid reliability.

Coordination Efforts:

The Energy Storage Grand Challenge is co-chaired by the Offices of Electricity (OE) and Energy Efficiency and Renewable Energy (EERE) and includes the Offices of Fossil and Carbon Management (FECM), Nuclear Energy (NE), Science (SC), Technology Transitions (OTT), Clean Energy Demonstrations (OCED), the Federal Energy Management Program and Advanced Research Projects Agency-Energy (ARPA-E) as well as the Loan Programs Office (LPO) as a key participant. The ESGC coordinates activities aligned with the ESGC Roadmap, which was published in December 2020. Plans include holding a Long Duration Storage Shot Summits and workshops, as well as technical assistance and funding opportunities.

In addition to the offices identified here, various crosscutting offices (including the Offices of Economic Impact & Diversity, Policy, and Artificial Intelligence and Technology) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments.

Crosscut Objectives:
There are two crosscutting primary research and development (R&D) objectives:

- ***Long Duration Storage Shot Target***: $0.05/kWh levelized cost of storage for long duration stationary applications, a 90% reduction from 2020 baseline costs by 2030. Achieving this levelized cost target would support the Administration's 2035 and 2050 decarbonization goals and facilitate commercial viability for storage across a wide range of uses, including in:
    - Remote communities, which are frequently disconnected or may not have access to the grid, and
    - Grid-scale applications, where storage can meet load during periods of peak demand and ensure reliability of critical infrastructure, including communications and information technology.
- ***Electric Vehicles (EV) Battery Cells Goal***: Reduce EV battery cell cost by 50 percent to $60/kWh manufactured cost for a battery cell by 2030 for a 300-mile range electric vehicle to achieve cost parity with internal combustion engine vehicles. Advances in battery production for transportation applications are anticipated to continue benefitting production, performance, and safety of similar technologies used in batteries for stationary applications.

These objectives can be met by many technologies, and the more different technologies that meet them, the greater the likelihood that the full range of attributes needed to ensure reliability, flexibility, equity, and resilience in the energy sector will be met.

Crosscut Action Areas: Through ESGC, DOE supports energy storage technologies across the full value chain, from basic and applied research through analysis, demonstration, and full integration into the power and end-use sectors. The program is organized around the following five primary tracks:

1. ***Technology Development:*** accelerates a range of storage technologies to meet the cost and performance goals of specific end use cases. These activities include fundamental breakthroughs in new materials, prototyping at the device scale, system-level validation, and early-stage demonstrations.
2. ***Manufacturing and Supply Chain:*** develops technologies, approaches, and strategies for U.S. manufacturing that support and strengthen U.S. leadership in innovation and continued at-scale manufacturing.
3. ***Technology Transition:*** ensures that DOE's R&D transitions to markets through field validation, demonstration projects, public-private partnerships, bankable business model development, and the dissemination of high-quality market data.
4. ***Policy and Valuation:*** provides data, tools, and analysis to support policy decisions and maximize the value of energy storage.
5. ***Workforce Development:*** educates the workforce, who can then research, develop, design, manufacture, and operate energy storage systems.

Program Organization:

1. **Advanced Research Projects Agency - Energy (ARPA-E):** ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021, ARPA-E selected and/or obligated $48,281K in funding to Energy Storage-related projects through ARPA-E's

Supporting Entrepreneurial Energy Discoveries (SEED) Exploratory Topic and Open 2021 programs as well as Duration Addition to Electricity Storage (DAYS) extension. In FY 2022, ARPA-E is targeting approximately $45,000K in funding to Energy Storage-related projects through ARPA-E's Electric Vehicles program. The assessment process for new programs is now underway and any potential future investments in Energy Storage will be determined for FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE)**: EERE will continue to fund energy storage R&D for both stationary and mobility applications in support of both the Long Duration Storage Energy Earthshot and EV battery cells goal.
   a. *Advanced Manufacturing Office (AMO):* AMO will continue to collaborate with multiple offices, including Office of Electricity (OE), and sister offices in EERE on projects to overcome manufacturing barriers and eliminate gaps in manufacturing capabilities of innovative integrated energy storage systems such as thermal energy storage, long duration energy storage, etc. Additionally, AMO's efforts in industrial decarbonization include exploring opportunities for innovation and impact through incorporating energy storage into manufacturing processes and/or facilities.
   b. *Building Technologies Office (BTO):* BTO will continue its support for energy storage, focusing primarily on thermal energy storage research, more sophisticated controls for storage enabling grid-interactive buildings, deployment of heat pumps with thermal energy storage, and cost reductions of heat pumps with thermal energy storage.
   c. *Geothermal Technologies Office (GTO):* GTO proposes a Reservoir Thermal Energy Storage (RTES) initiative aimed at unlocking the terawatt-scale thermal energy storage of using the Earth as our battery. GTO will conduct new pilots and demonstrations that build on prior years of early-stage research to demonstrate technical feasibility, grid integration, and long-term storage opportunities for renewable energy systems. These projects will consider where geothermal energy storage can be used in combination with other renewable energy generation and energy efficient technologies to create industrial and community energy systems that are fully decarbonized.
   d. *Hydrogen Fuel Cell Technologies Office (HFTO):* HFTO's work in energy storage includes RD&D related to hydrogen production, hydrogen storage, and reversible fuel cell technologies, as well as systems integration RD&D. For example, HFTO funds efforts focused on integrating renewables, nuclear, and other resources with hydrogen production, storage, and end uses across applications as well as infrastructure components. Work also includes support for the National Renewable Energy Lab's Advanced Research on Integrated Energy Systems (ARIES).
   e. *Solar Energy Technologies Office (SETO):* SETO's work in energy storage focuses on thermal energy storage (TES) integrated with concentrating solar-thermal power (CSP) systems, both for electricity generation as well as industrial process heating applications. CSP funding will continue to support high-efficiency, reliable thermal energy storage technologies to support the Energy Storage Grand Challenge and Long Duration Storage Energy Earthshot, with a particular focus on technologies using solid particles as the heat transfer medium, leveraging the SETO funded megawatt-scale Gen3 CSP test facility currently under construction.

f. *Strategic Programs (SP):* SP will continue to support the ESGC Policy & Valuation Track, which provides data, tools, and technical analysis that help policymakers and other energy system decision-makers maximize the value of energy storage.
g. *Vehicle Technologies Office (VTO):* VTO's Battery R&D activity supports early-stage R&D of high-energy and high-power battery materials, cells, and battery development that can enable industry to significantly reduce the cost, weight, volume, and charge time of plug-in electric vehicle batteries.
h. *Water Power Technologies Office (WPTO):* WPTO, through the HydroWIRES initiative, will provide funding for hydropower hybrid demonstrations, a comprehensive Hydropower Futures Study to quantify emission and cost reductions enabled by increased hydropower flexibility and new pumped storage hydropower (PSH) development, and expansion of the PSH Valuation Guidebook to include non-power value.
i. *Wind Energy Technologies Office (WETO*): WETO supports the energy storage crosscut through multi-office collaboration in hybrid system design, hardware, control, and demonstration to hybrid systems involving combinations of technologies such as wind, hydropower, solar, battery storage, or hydrogen.

3. **Federal Energy Management Program (FEMP)**: FEMP focuses on key services that help agencies meet energy- and water-reduction requirements and goals. With more than 350,000 energy-utilizing buildings and 600,000 vehicles, the federal government is the nation's largest energy consumer. Energy used in buildings and facilities represents about 40% of the total site-delivered energy use of the federal government, with vehicle and equipment energy use accounting for 60%. FEMP will provide technical assistance to Federal agencies to integrate energy storage technologies into their decarbonization and climate adaption strategies.

4. **Fossil Energy and Carbon Management (FECM)**: To achieve ESGC objectives, FECM's Repurposing Fossil Energy Assets program focuses on the integration of long-duration energy storage technologies with a variety of fossil assets, including co-locating energy storage with some strategic fossil assets, which provides many benefits including improved asset flexibility and efficiency, improved grid reliability, and reduced greenhouse gas emissions.

   Additionally, energy storage enables many heavily decarbonized use cases; for example, the integration of hydrogen energy storage systems with hydrogen turbine power production. In FY 2021, FECM selected 29 energy storage projects at a range of host sites across the U.S. that will be down selected to advance a few promising projects up the Technology Readiness Level scale. In FY 2023, FECM proposes $9 million for pilot-scale field testing of integrated grid scale (>10MWh) long duration energy storage systems with fossil assets to demonstrate progress toward commercialization, assess technical and commercial viability, and enable widespread deployment. FECM will continue to focus on advancing energy storage concepts that can leverage abandoned or under-utilized fossil assets, including repurposing coal power plants with thermal energy storage and repurposing oil and gas infrastructure for geologic H_2 storage.

5. **Nuclear Energy (NE)**: NE supports R&D to enable flexible plant operation while utilizing the full capacity of a nuclear plant, including coproduction of hydrogen, to enhance the flexibility of the plant. The quick response time of electrolysis allows the system to balance electricity demand by quickly increasing or decreasing hydrogen production. If more power is needed, stored hydrogen can also be used in heat engines to provide additional electrical generation. NE is also modeling and developing thermal extraction, storage, and distribution systems for providing

both industrial process heat, as well as energy storage for the grid, where peak power turbines can be used to convert the stored thermal energy into electricity. NE is assessing thermal storage with various types of reactors, to include the current light water reactors and advanced reactors with various operating temperatures ranging from 300 to 900 degrees Celsius.

In FY 2023, NE will support activities in:

a. Energy system modeling and simulation to develop a modeling framework for economic dispatch optimization of integrated energy systems;
b. Energy distribution R&D to characterize and verify performance of thermal energy distribution systems;
c. Energy storage R&D to evaluate performance, reliability, and cost for thermal energy storage systems; and
d. Energy conversion R&D to assess thermal storage capacity and efficiency of energy conversion with heat pump cycles, chemical systems, and turbomachinery.

6. **Office of Clean Energy Demonstrations:** As part of OCED's management of the oversight and execution of the Advanced Reactor Demonstration Program demonstration projects, OCED will support the development of the Natrium sodium-cooled fast reactor demonstration. This project will incorporate a molten salt thermal storage system capable of boosting electrical output from 345 MW to a peak of 500 MW for 5.5 hours. While BIL provided significant funding that will support this cost-shared award, annual appropriations are necessary for DOE to fully fund the likely federal contribution for later phases of the project. To that end, while responsibility for these projects was transferred to OCED in FY 2022, the FY 2022 Enacted included $30 million in the Office of Nuclear Energy budget for this award.

7. **Office of Electricity (OE)**: OE's role in the Energy Storage crosscut focuses on grid-scale energy storage. The OE Energy Storage program leads a national effort to ensure a more flexible, resilient, and equitable North American power grid through increased deployment of bi-directional electrical energy storage. Through FY 2023, OE plans to continue to invest in new battery technologies that utilize low-cost, abundant, and safe materials, such as aqueous soluble organics; zinc-manganese dioxide; and sodium. OE also supports power conversion and balance of plant technologies, which account for an increasing proportion of storage system costs. OE will also continue to reinforce the importance of energy storage safety through new sensing and mitigation technologies, system testing, codes and standards development, and public outreach. OE has continued to refine and validate open-source software tools and analytical models for optimal value, sizing, and location, based on field deployments. OE also conducts and will continue in FY 2023 to conduct extensive outreach and capacity building for regulators, communities, and other key decisionmakers.

   Using FY 2022 and prior appropriations, OE is funding the construction of the Grid Storage Launchpad (GSL), a major facility for validation, acceleration, and collaboration of next generation storage materials. FY 2023 energy storage research funding includes support for an inaugural cohort of fellows to be hosted at dedicated spaces within the GSL after it begins operation. Post-graduate level academics, entrepreneurs, or other high-potential innovators with early-stage concepts for new storage technologies will accelerate storage development by leveraging GSL's advanced capabilities, such as: *in operando* characterization (atomic-level monitoring of batteries as they charge and discharge), cell pack fabrication, and kW-scale testing.

The Rapid Operational Validation Initiative (ROVI) is another effort to facilitate commercial deployment of storage at scale by integrating analytical methods with field data collected from other ESGC demonstration and manufacturing activities to deliver usable projections. ROVI implements the "Testing and Validation" portion of the Energy Storage System Research, Development, and Deployment Program mandated by sec. 3201(b) of the Energy Act of 2020. In FY 2023, OE seeks to develop methodologies that would enable investment-grade performance projections at twice the speed of combined real time field/lab testing and modeling (for instance, 1 year of testing provides 2 years of projections).

8. **Office of Technology Transitions (OTT)**: OTT leads the Technology Transition track for ESGC and leverages that role to conduct coordinated market and economic analyses to pursue energy storage commercialization opportunities. Prior efforts include publication of the Energy Storage Market Report and analysis of energy storage for remote and underserved communities. In FY 2023, OTT efforts will include market and economic analysis to identify and pursue technology commercialization opportunities and coordination of energy storage-related technology transfer activities across the DOE lab complex.

9. **Science (SC)**: SC supports foundational, crosscutting, fundamental energy storage research, including the Joint Center for Energy Storage Research (JCESR) Energy Innovation Hub and Energy Frontier Research Centers (EFRCs), that underpin the technology offices activities. In FY 2023, after 10 years of support for JCESR, the Batteries and Energy Storage Hub program will be openly recompeted. Core research activities through FY 2023 include crosscutting science that is relevant to electrochemical energy storage as well as hydrogen and fuel cells. Included in the hydrogen portion of the crosscut is the Fuels from Sunlight Energy Innovation Hub program and EFRCs related to hydrogen research. The research emphasizes understanding of phenomena and discoveries of new materials and chemistries for these technologies.

   In FY 2023, the Request includes support for a new research modality, the Energy Earthshot Research Centers (EERCs), which will work toward the stretch goals of the DOE Energy Earthshots and will provide a solid bridge between SC and the Energy Technology Offices. Through strong alignment with the technology offices, EERCs will address key research challenges at the interface between currently supported basic and applied R&D activities to bridge the R&D gap.

   In addition, research grants and National Laboratory research will continue to support postdoctoral, graduate, and undergraduate research activities. Other programs include support of graduate student internships at National Laboratories, as well as Small Business Innovation Research topics in membranes for electrochemical systems. SC user facilities will continue to host broad community research and industrial users who advance energy storage technologies.

Energy-Water Crosscut

Funding by Appropriation and Program Control ($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**7,671**	**0**	**TBD**	**TBD**
Advanced Research Projects Agency - Energy*	7,671	0	TBD	TBD
Energy Efficiency and Renewable Energy	**84,885**	**84,885**	**80,750**	**+4,135**
Advanced Manufacturing	45,000	45,000	40,000	-5,000
Bioenergy Technologies	5,750	5,750	15,000	+9,250
Solar Energy Technologies	0	0	750	+750
Water Power Technologies	34,135	34,135	25,000	-9,135
Fossil Energy and Carbon Management	**4,000**	**4,000**	**8,000**	**+4,000**
Nuclear Energy	**2,000**	**2,000**	**2,500**	**+500**
Reactor Concepts RD&D	0	0	1,000	+1,000
Fuel Cycle Research and Development	2,000	2,000	1,500	-500
Science	**8,500**	**8,500**	**17,000**	**+8,500**
Basic Energy Sciences	8,500	8,500	12,000	+3,500
Biological and Environmental Research	0	0	5,000	+5,000
Weatherization and Intergovernmental Programs	**500**	**500**	**500**	**0**
Grand Total	**107,556**	**99,885**	**108,750**	**+17,135**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

The Energy-Water crosscut is a DOE-led activity focusing on advancing transformational technology and innovation to meet the global need for safe, secure, and affordable water while maintaining an environmentally responsible water life cycle. Water is critical to human health, economic growth, and agricultural productivity and is intimately tied to the energy sector because the production of useable water requires energy and the production of energy requires water. The United States has historically benefitted from access to low-cost water supplies, but changes in freshwater supplies due to climate change and population growth are threatening U.S. economic competitiveness and water security. Until recently, the United States has had an abundance of fresh water sources that are relatively cheap and easy to treat for various end users – municipalities, utilities/power, industrial, agriculture, and resource extraction.

This large-scale, centralized water infrastructure is challenged by new pressures due to climate change, increased competition for water resources, an aging water infrastructure, and regulatory hurdles. This is forcing water users across the United States, especially those experiencing extreme drought, aridification, and water stress, to look toward non-traditional water sources (e.g., brackish groundwater, seawater, wastewater). Improvements in water and energy efficiency and resiliency are being sought in both our water and energy systems. Efforts to integrate renewables and to recover and reuse valuable

co-products from wastewater (i.e., fertilizer, hydrogen, biofuels, biopower, biochemicals, critical materials, and water reuse) are underway. An immediate opportunity lies ahead, as the U.S. is poised to invest billions in the Nation's infrastructure for long overdue repairs to water and energy systems through forward-looking investments that enhance environmental justice, equity, resiliency, cybersecurity, and climate preparedness. DOE has a significant role to bridge this by investing in research, development, and demonstration (RD&D) that enables an energy-water infrastructure that is more sustainable, climate adaptive, and equitable for the 21st century and beyond.

Coordination Efforts:
The Energy-Water activities are being coordinated by the Office of the Undersecretary for Science and Innovation, with leadership from each of the Offices involved. The Energy-Water crosscut provides RD&D, technology, climate modeling and analysis, assessment tools, technical support to manufacturers and wastewater treatment facilities, informed policy, planning and financing tools, and workforce development to replace America's outdated and deteriorating water infrastructure across municipalities, industry, utilities, agriculture, and resource extraction (i.e., oil and gas, mining), integrated with the rebuilding of the energy infrastructure.

The Offices of Energy Efficiency and Renewable Energy (EERE), Fossil Energy and Carbon Management (FECM), Science (SC), the Advanced Research Projects Agency-Energy (ARPA-E), Nuclear Energy (NE) and Weatherization and Intergovernmental Programs (WIP) participate in the Energy-Water crosscut. Numerous activities across DOE have focused on different aspects of these issues, such as: the Advanced Manufacturing Office's Energy-Water Desalination Hub (led by the National Alliance for Water Innovation(NAWI)) and the Better Plants program; the Solar Energy Technologies Office Solar Thermal Desalination research and development (R&D) and Prizes; the Water Power Technologies Office Waves to Water Prize and Water Resilience; FECM's produced water RD&D and analysis; and SC's 2017 Basic Research Needs Workshop and report for energy and water. DOE's strong innovation role is needed to develop technologies that address both opportunities and risks inherent in the integration of energy and water systems to strengthen their connected resiliency, reliability, and efficiency. As an example, DOE is addressing the energy and costs associated with treating non-traditional water sources that contain higher salinity and other constituents, while exploiting opportunities to recover water for reuse as well as valuable co-products, thus reducing the overall carbon footprint of water and wastewater systems.

In addition to the funding offices identified here, various crosscutting offices (including the Office of Economic Impact & Diversity, Office of Policy, the Artificial Intelligence and Technology Office, and the Office of Technology Transitions) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments.

In 2021, DOE led a Congressional Report on the Energy-Water-Food nexus. In FY 2022 and ongoing in FY 2023, EERE will have a dedicated staff to lead regular coordination meetings across DOE and with other agencies. This internal DOE and interagency RD&D collaboration improves our Nation's and community-level energy, water, and food security; improves water resiliency and water quality in our watersheds; provides for modernization of irrigation systems; reduces the energy and water intensity across all sectors of our economy; and provides local economic development opportunities. Particularly, this institutional alignment of RD&D offers new economic markets that can provide both urban and rural areas with profitable and sustainable options for growth.

DOE through EERE is also responsive to new Statutory Requirements from the Energy Act of 2020, SEC. 1010. ENERGY AND WATER FOR SUSTAINABILITY. 10 (a) NEXUS OF ENERGY AND WATER FOR SUSTAINABILITY for establishing a new joint DOE and Department of Interior (DOI) office, interagency coordination, and a strategic plan for RD&D investments across the federal landscape that will be developed and released in 2022.

The Office of Science activities that advance climate modeling are coordinated through the U.S. Global Change Research Program, an interagency effort under the Office of Science and Technology Policy (OSTP).

Crosscut Objectives:

- ***Inform Investment Decisions:*** Advance Earth system modeling, simulation, and analysis tools essential for informing energy infrastructure investment decisions that have the potential for large-scale deployment and in turn benefit national security and environmental justice.
- ***Drive innovation for Water Remediation:*** Develop projects that lead to water remediation associated with produced water from fossil extraction in addition to water produced as a result of large-scale geologic storage of CO_2.
- ***Enable a Diverse, Safe, and Secure Water Supply:*** Conduct RD&D, modeling, and analysis leading to a portfolio of technologies that enable pipe parity for 90% of nontraditional water sources. A nontraditional water supply achieves pipe parity when the key metrics (i.e. cost, energy performance, environmental externalities process adaptability, reliability, sustainability, etc.) of supplying water from the nontraditional source is equivalent to that of the next available option.
- ***Provide Technical Assistance for Energy-Water Efficiency:*** Partner with stakeholders across the country to make water and wastewater treatment more energy- and water-efficient by providing robust technical assistance and tools as well as facilitating the sharing of best practices. This effort also includes building out a workforce that is well trained, diverse, and inclusive to meet the needs of a more sustainable and secure 21st century energy-water infrastructure and beyond.
- ***Increase Viable Resource Recovery and Water Reuse*:** Develop technology to convert wastewater into a renewable power source (biopower, biofuels, hydrogen, renewable natural gas) or a recycled feedstock (recovered biochemical, fertilizers, critical materials, and reusable water) - ultimately decarbonizing our water/wastewater treatment and creating recycled feedstock.
- ***Develop Resilient Energy-Water Systems:*** Leverage climate, hydrologic, and grid modelling activities from across the participating Offices as well as alternative opportunities for hydropower development to understand and quantify the resilience challenges and opportunities for integrated energy-water systems in the face of climate change.

Crosscut Action Areas: DOE program offices will:

1. ***Advance Understanding of the Earth's Water Cycle:*** Develop the physical, biogeochemical, and dynamical underpinning of fully coupled climate and Earth System Models (ESMs), in coordination with other Federal efforts, leading to an advanced understanding of the Earth's water cycle. The research specifically focuses on quantifying and reducing the uncertainties in these system models, based on more advanced process representations, sophisticated software, robust couplers, diagnostics, performance metrics, and advanced data analytics.

2. ***Develop Science and Technologies for Desalination:*** Continue to support ongoing RD&D and analysis activities to be closely coordinated across DOE offices and other agencies such as Environmental Protection Agency, DOI, and U.S. Department of Agriculture, who were involved in roadmaps developed in 2021. The science of separations and membranes funded in SC will feed into the technology-focused aims of applied programs.
3. ***Provide Tools and Training for Water Efficiency:*** Enable an increase in technical assistance for water efficiency to provide tools and training for water efficiency improvements and sharing of best practices at existing facilities.
4. ***Develop Resilient Energy-Water Systems***: Continue to build and ramp up climate change and hydrologic modelling work as well as develop integrating models built for water and grid purposes. Leverage ongoing work related to quantification of resilience benefits from integration and development opportunities as they relate to hydropower infrastructure.

Program Organization:

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. ARPA-E selected and/or obligated funding to Energy-Water-related projects through ARPA-E's Open 2021 program. For example, Open 2021 projects support research and development on "Systems Two Phase Cooling" and "Helical Turbulator for Robust Nucleate Boiling Cold Plate." The assessment process for new programs is underway and any potential future investments in Energy-Water will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):** EERE will continue to focus on energy water nexus activities including:
    a. *Advanced Manufacturing Office (AMO):* AMO activities include:
        - The Energy-Water Desalination Hub (i.e., NAWI) will continue to build its alliance and perform meaningful R&D on desalination technologies.
        - Advanced water resource recovery systems and decarbonization through development of new water/wastewater treatment systems.
        - Technical assistance programs such as Better Plants, Innovative Technology Validations, and Combined Heat and Power as well as Small Business Innovation Research/Small Business Technology Transfer, Lab Embedded Entrepreneurship Program (LEEP), HPC4Manufacturing, Technology Commercialization Fund, Energy Icorps, and National Laboratory annual operating plans for modeling and analysis.
        - Additional work will be developed through the strategic plan for the Nexus of Energy Water Sustainability (NEWS) interagency RD&D strategy plan, as required by the Energy Act 2020, Section 1010.
    b. *Bioenergy Technologies Office (BETO):* DOE's Bioenergy Technologies Office (BETO) supports RD&D on strategies to manage wet wastes, including municipal wastewater, food waste, and manures. BETO is continuing to support technology demonstrations that can effectively manage manures and other wet agricultural wastes to support rural economies and reduce greenhouse gas emissions—fugitive methane in particular—from these wastes. BETO also supports community-based technical assistance to identify

waste management solutions in rural and urban areas and will support joint office partnerships in FY 2023 to improve wastewater treatment in urban communities.

c. *Solar Energy Technologies Offices (SETO):* SETO funded activities in FY 2022 and FY 2023 primarily consist of market and technology analyses to help support the development and identification of promising solar thermal desalination systems and markets. This supports the two ongoing rounds of the Solar Desalination Prize, funded in FY 2019-FY 2021, which are working on developing pilot tests of innovative technologies.

d. *Water Power Technologies Office (WPTO):* WPTO activities include:
   - The Marine Energy program has funded the Waves To Water (W2W) Prize from FY 2019-FY 2021 with prize culmination during FY 2022 followed by the development of long-term duration and reliability testing of wave powered system designs and sub-assemblies. FY 2023 will continue this work, at a reduced level from FY 2022.
   - Irrigation Modernization research is being conducted to better understand innovative modernization scenarios, through the development of IrrigationViz – a design decision support tool to help irrigation district managers consider multiple modernization scenarios which will eventually lead to a larger physical demonstration program.
   - Hydrology and climate activities include the Grid Modernization and Laboratory Consortium Water Risk project, which examines the impacts and risk to grid operations due to varying climate and hydrologic drivers and different infrastructure futures. WPTO will develop initiatives that will enhance long-term data collection at basin scales to enhance water and energy resiliency planning.
   - WPTO is investigating alternative opportunity contexts for development of low-impact hydropower where the primary goal of the project is to identify and exploit the water, environmental, and/or social benefits that communities have prioritized for themselves and provide technical assistance to communities to promote these values.
   - WPTO is examining how water risk and resilience propagates through the electric grid and vice versa. Work includes developing case studies and models to support and be responsive to utilities and communities.

3. **Fossil Energy and Carbon Management (FECM):** In FY 2023, FECM will focus on the following areas and activities:
   a. Produced water research on multipronged approaches for characterizing constituents and managing the cleaning of water as part of the broader effort to transform produced and extracted water from a waste to a resource. FECM partners with the Water De-Salination Hub and with research universities engaged in the study of characterizing, cleaning, treating, and managing produced water to develop and assess commercially viable technology though public private partnerships with the energy industry to achieve these goals. Additionally, FECM will continue work to develop and advance technologies that can economically treat produced water for beneficial re-use, protect water resources, reduce water use, and address induced seismicity related to underground injection of produced water.

b. NAWI – FECM/National Energy Technology Laboratory (NETL) provided input and support in developing NAWI's roadmap. Additionally, NETL serves as a subcontractor to a current NAWI award.

4. **Nuclear Energy (NE):** NE supports early stage, cost-shared R&D that enables technological advances in uranium mining, conversion, and transportation capabilities in the United States as well as conducting evaluations and assessments related to these areas. In FY 2021, DOE released a public funding opportunity announcement (FOA) to request proposals for R&D that reduce water usage and/or improve the extraction efficiency associated with uranium production. Mining sites are often located in underserved communities and locations with limited water resources. Improvements to mining technology spurred by R&D may enable local economic opportunities while reducing the amount of water used during uranium production. In FY 2022 and FY 2023, NE will fund cost-shared R&D for uranium mining and processing technologies that reduce water usage and/or improve extraction efficiency and resource utilization for uranium production. The Reactor Concepts RD&D's Light Water Reactor Sustainability program will also support preliminary R&D to investigate opportunities to improve the existing fleet of nuclear reactor's cooling water usage.

5. **Science (SC):** SC provides foundational knowledge and state-of-the-art capabilities in support of crosscut objectives and has supported theoretical and experimental science related to understanding chemical and biological processes, separations, materials, and geochemistry related to energy-water research for many years.
    a. *Basic Energy Sciences (BES):* For BES, the research focus in this area is identified in the 2017 Basic Research Needs (BRN) workshop for Energy and Water. Priority research directions identified in the workshop report include the prediction and control of molecular-to-macroscopic properties and behavior of complex, multicomponent fluids; mechanistic understanding and control of interfaces and transport in complex and extreme environments; the codesign of dynamic interactions between materials and reactive fluids for unprecedented tunability of purification, transformation, and transport processes in energy-water systems; and revolutionary advances in approaches to quantify, sense, predict, and manipulate coupled physical, chemical, and biological processes in subsurface environments. In 2018, BES made 3 new awards for Energy Frontier Research Centers to advance priority research directions identified in the 2017 BRN workshop. This area remains a priority for Energy Frontier Research Centers (EFRCs) in FY 2022 with a re-competition of awards made in FY 2018. Support for the Energy-Water Nexus crosscut will continue through the EFRCs in FY 2023.
    b. *Biological and Environmental Research (BER):* Presently, BER research contributes to reducing the greatest uncertainties in model predictions, e.g., involving clouds and aerosols. In the last decade, DOE research has made considerable advances in increasing the reliability and predictive capabilities of these models using applied mathematics, access to DOE's fastest computers, and systematic comparisons with observational data to improve confidence in model predictions and thus the ability to use the model predictions to develop climate resilient infrastructure, including the Nation's energy infrastructure.
        i. Specifically, the current research will begin to incorporate artificial intelligence and machine learning capabilities and enable more sophisticated research based on higher model resolution, and the new version will add advanced capabilities for exploring changing water cycles on watershed and coastal hydrological systems

down to spatial scales of 3 km. Additional core research to underpin emerging and future Earthshots will also be initiated.

ii. Overall, BER's research focuses on quantifying and reducing the uncertainties in these system models (including the Earth's water cycle), based on more advanced process representations, sophisticated software, robust couplers, diagnostics, performance metrics, and advanced data analytics. Priority model components include the ocean, sea-ice, land-ice, atmosphere, terrestrial ecosystems, and human activities.

Grid Modernization Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**18,363**	**0**	**TBD**	**TBD**
Advanced Research Projects Agency – Energy*	18,363	0	TBD	TBD
Cybersecurity, Energy Security and Emergency Response	**96,000**	**96,000**	**125,000**	**+29,000**
Energy Efficiency and Renewable Energy	**188,950**	**139,213**	**267,000**	**+78,050**
Advanced Manufacturing	2,000	0	0	-2,000
Building Technologies	49,300	19,725	20,000	-29,300
Hydrogen and Fuel Cell Technologies	46,000	28,000	17,000	-29,000
Renewable Energy Integration	0	0	57,000	+57,000
Solar Energy Technologies	53,000	53,000	83,500	+30,500
Vehicle Technologies	18,000	18,000	20,000	+2,000
Water Power Technologies	15,000	13,850	27,500	+12,500
Wind Energy Technologies	5,650	6,638	42,000	+36,350
Fossil Energy and Carbon Management	**3,726**	**3,726**	**5,000**	**+1,274**
Hydrogen with Carbon Management	2,075	2,075	0	-2,075
Crosscutting Research	1,513	1,513	0	-1,513
Point-Source Carbon Capture	138	138	0	-138
TBD	0	0	5,000	+5,000
Grid Deployment Office	**0**	**0**	**84,700**	**+84,700**
Grid Planning & Development	0	0	16,200	+16,200
Grid Technical Assistance	0	0	29,500	+29,500
Wholesale Market Technical Assistance & Grants	0	0	19,000	+19,000
Interregional & Offshore Transmission Planning	0	0	20,000	+20,000
Nuclear Energy	**298,000**	**287,000**	**52,000**	**-246,000**
Crosscutting Technology Development	10,000	10,000	9,000	-1,000
Light Water Reactor Sustainability	13,000	2,000	3,000	-10,000
Advanced SMR RD&D	115,000	115,000	40,000	-75,000
Advanced Reactor Demonstration Program	160,000	160,000	0	-160,000
Office of Clean Energy Demonstrations	**0**	**0**	**175,052**	**+175,052**
Energy Demonstrations	0	0	150,052	+150,052
Advanced Reactor Demonstrations	0	0	25,000	+25,000
Office of Electricity	**193,720**	**193,720**	**279,800**	**+86,080**
Transmission Reliability & Resilience	48,220	48,220	37,300	-10,920
Energy Delivery Grid Operations Technology	0	0	39,000	+39,000
Resilient Distribution Systems	50,000	50,000	50,000	0
Cyber Resilient & Secure Utility Communications Networks	0	0	20,000	+20,000
Energy Storage Research	57,000	57,000	81,000	+24,000
20-OE-100 Grid Storage Launchpad	23,000	23,000	0	-23,000

Transformer Resilience & Advanced Components	7,500	7,500	22,500	+15,000
Applied Grid Transformation Solutions	0	0	30,000	+30,000
DCEI Energy Mission Assurance	1,000	1,000	0	-1,000
Transmission Permitting and Technical Assistance	7,000	7,000	0	-7,000
Grand Total	**798,759**	**719,659**	**988,552**	**+208,156**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

The DOE Grid Modernization crosscut encompasses activities focused on research, development, demonstration, and deployment (RDD&D) to ensure an affordable, resilient, flexible, secure, sustainable, equitable, and reliable grid. The portfolio of work helps integrate all sources of electricity, improve the security of our Nation's grid, solve challenges of energy storage and distributed generation, and provide a critical platform for U.S. competitiveness and innovation in a global energy economy. These efforts directly enable this Administration's goals to achieve a 50-52% reduction in greenhouse emissions by 2030, zero emissions grid by 2035, and a net-zero greenhouse gas emissions economy by 2050.

Through the Grid Modernization crosscut, DOE coordinates activities across the Offices of Electricity (OE), Energy Efficiency and Renewable Energy (EERE), Fossil Energy and Carbon Management (FECM), Grid Deployment Office (GDO), Nuclear Energy (NE), Clean Energy Demonstrations, Cybersecurity, Energy Security, and Emergency Response (CESER), and Advanced Research Projects Agency-Energy (ARPA-E).

The Grid Modernization crosscut assesses and advances regional and national grid modernization efforts, technology and market developments, and institutional barriers affecting generation, transmission, distribution, and end-use technologies. It incorporates and regularly iterates on the most updated data, analyses, and projects from across a number of DOE offices.

The Grid Modernization Initiative (GMI) is core partnership of OE, EERE, FECM, NE and CESER to drive the crosscut and to co-fund foundational research through competitive opportunities as well as work with the National Laboratories, especially through the Grid Modernization Laboratory Consortium (GMLC).

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment of: cybersecurity and cyber resilience for the energy sector and rural and municipal utilities; advanced nuclear reactor demonstration; energy storage and system reliability work; smart grid investments and programs to assess risks, prevent outages and facilitate transmission. These investments are essential in addressing the supply chain and technology needs to support growth in clean energy and the grid.

Coordination Efforts:

The Grid Modernization crosscut coordinates across six priority research pillars that will enable the Administration's decarbonization goals. The six pillars are: devices and integrated systems; operations; planning; markets, policies, and regulations; resilient and secure systems; and flexible generation and load.

In addition to the offices identified above others (including the Office of Economic Impact & Diversity, Office of Policy, Office of Technology Transitions, Loan Programs Office, and the Artificial Intelligence and Technology Office) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments.

Crosscut Objectives:

The Grid Modernization crosscut works to advance high priority objectives concerning the complex U.S. grid system.

- ***Operating a Decarbonized Grid:*** Develop and advance new procedures and underlying technologies required for the operation of a national-level, decarbonized grid by 2035.
- ***Addressing Infrastructure Needs and Interdependencies:*** Address challenges and identify new opportunities for the improvement of the electricity grid and interdependent infrastructure, such as natural gas pipelines and communications.
- ***Preparing for Evolving Uncertainties:*** Support and inform careful planning and monitoring of all assets and a more robust risk-assessment process for potential failures, including to all societal income levels, to improve resilience against all malicious threats, natural disasters, climate change impacts, and other systemic risks such as human error or dependence on other critical systems.
- ***Accommodating Diverse Markets, Policies, and Business Models:*** Address analytical gaps to allow for data-driven decisions by policymakers and develop new business models as well as market and policy approaches that work effectively with an evolving grid.

Crosscut Action Areas:

DOE program offices will:

1. ***Accelerate Innovation, Demonstration, and Deployment of Tools and Technologies:*** Fund cost-shared RDD&D to accelerate the pace of technological innovation, especially where market fragmentation impedes the ability of individual entities to capture the value of research investments.
2. ***Provide Direct Technical Assistance Utilizing World-Class Capabilities:*** Provide technical assistance to public and private sector grid related entities, drawing upon unique technical capabilities of the National Laboratories and DOE program offices.
3. ***Support Private Sector Innovation Investments:*** Catalyze private sector innovation through the expertise within DOE and its National Laboratories, working in collaboration with other key stakeholders to help establish the technological foundation for grid modernization.
4. ***Invest in Regionally-Focused Partnerships and Initiatives:*** Address unique regional issues to deliver collaborative partnerships and initiatives that are tailored to regional needs as well as able to deliver national benefits.
5. ***Support Peer-to-Peer Information Exchange:*** Convene technical experts, synthesize, and help communicate across DOE and to external stakeholders, without being prescriptive.

Program Organization:

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, the Advanced Research Projects Agency – Energy (ARPA-E) catalyzes transformational energy technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact energy projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021, ARPA-E selected and/or obligated $18,363K in grid modernization funding to projects through the ARPA-E Grid Optimization (GO) Competition and

Open 2021 programs. The assessment process for new programs is now underway and any potential future investments in Grid Modernization will be determined in FY 2023.

2. **Cybersecurity, Energy Security and Emergency Response (CESER):** CESER integrates cybersecurity activities across DOE and coordinates with other DOE offices to ensure cybersecurity is built in across different R&D programs. CESER leverages DOE's National Laboratories to advance the goal of securely modernizing the Nation's electric grid. All of CESER's cybersecurity risk management tools and technologies funding is included in the GMI. For FY 2023, this includes developing cyber situational awareness and analytics including the newly announced DOE Electricity Industrial Control Systems (ICS) effort; cradle to grave supply chain cybersecurity, including programs like Cybersecurity Testing for Industrial Control Systems (CyTRICS) and digital subcomponent enumeration, and mitigation efforts; developing tools, guidance, and practices that help energy organizations' understanding and management of cybersecurity risk; cyber resilience through cyber engineering by way of programs such as the Consequence-driven Cyber-informed Engineering (CCE); and collaborations with universities to support workforce development and to stimulate innovation by students to address cyber risks to energy infrastructure.

3. **Fossil Energy and Carbon Management (FECM):** FECM ensures that the perspective for fossil generation and fuel security is reflected in the Department's grid efforts. In FY 2023, FECM will continue to fund four FECM projects involving three of the GMI topic areas: 1) Design and Optimize Infrastructure for Tightly Coupled Hybrid Systems that focuses on incorporating advanced power plant technologies into existing model frameworks; 2) Near-Term Reliability and Resiliency will look at reliability issues due to changing generations of energy sources over the next ten years in electricity regions across the country; 3) Blockchain for Optimized Security and Energy Management (BLOSEM) involves DOE's National Energy Technology Laboratory and the use of blockchain to secure energy systems; 4) Digital Twin Reinforcement Learning focuses on artificial intelligence to detect new and previously unknown cyber threats.

4. **Energy Efficiency and Renewable Energy (EERE):**
   a. *Building Technologies Office (BTO):* BTO's RDD&D on advanced and grid-interactive technologies, such as controls, interoperability, and energy storage, will partner with industry stakeholders to develop and deploy grid-interactive efficient buildings related systems, capable of connecting with the power grid in new and increasingly adaptive manners to help with overall energy system efficiency, reliability, resilience, environmental performance, and energy affordability. These capabilities are an integral and necessary part of a decarbonized power system that maximizes use of renewable resources and can significantly reduce energy use at times when this provides a valuable option for utilities and their customers.
   b. *Hydrogen and Fuel Cell Technologies Office (HFTO):* HFTO funds RD&D in energy storage and grid integration (including the National Renewable Energy Laboratory's Advanced Research on Integrated Energy Systems (ARIES) and R&D on reversible fuel cell technologies. In addition, HFTO's portfolio includes systems development and integration, including hybrid energy systems such as wind/offshore-wind to hydrogen, and microgrids for underserved communities, along with supporting analysis.
   c. *Vehicle Technologies Office (VTO):* VTO will continue laboratory and industry-led projects to develop secure vehicle-grid connection and communication technologies, as well as high power grid-tied charging systems.

d. *Wind Energy Technology Office (WETO):* WETO will prioritize RD&D in offshore transmission analysis and technology advancement, grid reliability and resilience, wind control and cybersecurity research, and crosscutting demonstrations in grid-enhancing technologies and hybrid energy systems. This body of work will align with the Renewable Energy Grid Integration Action Plan, developed to align grid activities across EERE and OE to enable a just transition to a grid that supports a decarbonized power system by 2035 and a zero-emission economy by 2050, all while maintaining the reliability, affordability, security, and resilience of the energy system.
e. *Solar Energy Technologies Office (SETO):* SETO will support analysis and RDD&D of grid integration technologies at the bulk power and distribution system levels to allow reliable, resilient, and secure grid planning and operation with increasing amounts of solar, energy storage, hybrid systems, and other inverter-based assets.
f. *Renewable Energy Integration (REI):* REI will expand power system planning and operations support to communities looking to deploy larger amounts of renewable energy, provide analysis-based technical assistance to power system operators and regulators, demonstrate expanded provision of reliability services from wind and solar generation, and support the integration of renewable generation into heavy-duty electric truck corridor demonstrations.
g. *Water Power Technologies Office (WPTO):* WPTO, through the HydroWIRES initiative, will provide funding for hydropower hybrid demonstrations through a comprehensive Hydropower Futures Study to quantify emission and cost reductions enabled by increased hydropower flexibility and new PSH development, and expansion of the PSH Valuation Guidebook to include non-power values.

5. **Grid Deployment Office (GDO):** GDO catalyzes development of new and upgraded high-capacity electric transmission lines nationwide and deployment of transmission and distribution technologies to improve the resilience of our Nation's electric infrastructure. Massive deployment of renewable energy and build out of transmission infrastructure is necessary for 100% clean electricity by 2035 and net-zero emissions economy-wide by 2050. GDO works in strong partnership with energy sector stakeholders on a variety of grid initiatives to achieve a clean, reliable, resilient, and equitable grid.

   All of GDO activities fall under the grid modernization crosscut. In FY 2023, GDO will accelerate the planning and development of transmission through the National Transmission Planning Study and interregional transmission plans; provide grid technical assistance activities to enable policy and investment decisions; assist regions and states in improving or establishing wholesale electricity markets; and help develop offshore wind transmission infrastructure.

6. **Nuclear Energy (NE):** In FY 2023, NE will continue to support targeted research with industry, universities, and National Laboratories through competitive funding opportunities and directed research, such as improved simulation methods to better understand how new capabilities change the way nuclear plants interact with the electrical grid and quantify the dynamic response rates of the plants that are equipped with integrated energy systems (IES). NE plans to perform probabilistic analysis to evaluate IES performance in extreme weather scenarios when variable resources may be unavailable. Additionally, NE will conduct regional studies on IESs that include thermal energy storage systems and on their co-product markets and optimal storage use. NE also plans to support a study of U.S. electricity markets to assess whether they are incentivizing the investments necessary to ensure reliable supply, and if not, what mechanisms

could be introduced to ensure that the value each generation's source provides to the grid is reflected in market prices.

7. **Office of Clean Energy Demonstrations (OCED):** OCED will initiate a new competition in FY 2023 to support commercial-scale demonstrations related to the integration of renewable and distributed energy systems. The goal of this new investment area is to support demonstrations that de-risk controlling flexible loads from renewable energy, energy storage, electric vehicle (EV) charging, and other facilities into the U.S. transmission and distribution grids. This may include support for demonstrations of innovative hybrid generation systems, as well as the utilization of energy storage technologies, EV charging, controllable loads from buildings and industrial facilities, and other approaches for cost effective integration of renewable energy, as well as the demonstration of operational flexibility, consumer behavior changes, and grid services provision.

   Additionally, OCED will provide additional funding via annual appropriations for additional project management and technical oversight of the two Advanced Reactor Demonstration Program demonstrations: the TerraPower Natrium sodium fast reactor and the X-energy Xe-100 high-temperature gas reactor previously funded via NE. Sustained support for these demonstrations are a key component of DOE's strategy to meet Administration's goals of 100 percent clean energy generation by 2035 and net-zero emissions by 2050**.**

8. **Office of Electricity (OE)**: Grid modernization is a critical aspect of all OE programs, therefore the entire OE program, except OE Program Direction funding, is included in the GMI. In FY 2023, OE plans to continue pursuing research for technologies to improve grid reliability, resilience, efficiency, flexibility, and functionality that are built from inception to automatically detect, reject, and withstand cyber incidents, regardless of the threat to the electricity delivery system. OE will also continue to develop core analytic, assessment, and engineering capabilities that can evolve as the technology and policy needs mature to support decision making involving complex interdependencies among energy infrastructure systems, such as between electricity and natural gas systems.

   OE plans to continue support for private sector innovation investment in data platforms and advanced communications/control designs, regional and national deployment through cooperative agreements, and is completing construction of the Grid Storage Launchpad with FY 2022 funding to consolidate existing materials research and new characterization and testing capabilities focused on grid scale energy storage research.

Hydrogen Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**34,342**	**0**	**TBD**	**TBD**
Advanced Research Projects Agency – Energy*	34,342	0	TBD	TBD
Energy Efficiency and Renewable Energy	**155,900**	**166,500**	**217,500**	**+61,600**
Advanced Manufacturing	5,000	10,000	20,000	15,000
Hydrogen & Fuel Cell Technologies	150,000	150,000	186,000	+36,000
Solar Energy Technologies	0	5,100	7,500	+7,500
Water Power Technologies	0	0	1,000	+1,000
Wind Energy Technologies	900	1,400	3,000	+2,100
Fossil Energy and Carbon Management	**88,700**	**88,700**	**116,000**	**+27,300**
Advanced Turbines	27,000	27,000	27,000	0
Gasification Systems	19,000	19,000	26,000	+7,000
Solid Oxide Fuel Cells	30,000	30,000	5,000	-25,000
Simulation-Based Engineering	500	500	6,000	+5,500
Point Source Carbon Capture	5,500	5,500	20,000	+14,500
Energy Storage Grand Challenge	5,000	5,000	6,000	+1,000
Natural Gas Decarbonization and Hydrogen Technologies	1,700	1,700	26,000	+24,300
Nuclear Energy	**23,000**	**12,000**	**12,000**	**-11,000**
Crosscutting Technology Development	10,000	10,000	9,000	-1,000
Light Water Reactor Sustainability	13,000	2,000	3,000	-10,000
Office of Technology Transitions	**0**	**0**	**100**	**+100**
Science	**17,000**	**17,386**	**60,400**	**+43,400**
Basic Energy Sciences	17,000	17,386	60,400	+43,400
Grand Total	**318,942**	**284,586**	**406,000**	**+121,400**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

The DOE Hydrogen crosscut encompasses activities across multiple offices in DOE that sponsor research, development, demonstration, and deployment (RDD&D) to foster innovations and develop widely available, net-zero emission, cost-competitive technologies for the production, storage, and delivery of hydrogen, and for its end use as a chemical feedstock or fuel. Hydrogen is a versatile energy carrier that can be produced with net-zero greenhouse gas emissions by using diverse domestic resources including renewables, nuclear, and fossil fuels with carbon capture and storage. Accordingly, hydrogen is an enabling piece of DOE's portfolio of solutions to achieve an abundant, reliable, and affordable supply of clean energy to meet our climate goals and maintain our prosperity throughout the 21st century and beyond.

Crosscut activities will focus on enabling clean hydrogen for hard-to-decarbonize applications in industry and heavy-duty transport, as well as in power generation and energy storage. A crosscutting team comprising DOE program offices of Energy Efficiency and Renewable Energy (EERE), Fossil Energy and Carbon Management (FECM), Science (SC), Nuclear Energy (NE), Technology Transitions (OTT), and the Advanced Research Projects Agency-Energy (ARPA-E) coordinates these activities, including the Hydrogen Energy Earthshot, which is a highly ambitious production cost target to reach $1 for 1 kg of clean hydrogen in one decade. The Hydrogen Energy Earthshot is one of the Department's top RDD&D focus areas where innovation breakthroughs are needed to address the climate crisis and create high-paying domestic jobs in clean energy.

Hydrogen as an energy carrier can be produced using diverse domestic resources and can be used in a wide range of end-use sectors, and as such, several DOE offices are involved in developing different hydrogen production and delivery methods as well as application spaces. By integrating those efforts, each office benefits from joint analyses and assessments and therefore more effectively targets their funding to the highest priority areas and avoids duplication of efforts.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment for clean hydrogen hubs, clean hydrogen electrolysis and clean hydrogen manufacturing and recycling. These investments are essential in addressing the supply chain and technology needs to support growth in clean energy.

Coordination Efforts:

The Hydrogen crosscut coordinates activities aligned with the DOE Hydrogen Program Plan, which outlines key activities and a matrix of roles and responsibilities across the pipeline of hydrogen production, delivery, storage, and end use RDD&D efforts. The team meets regularly to coordinate the DOE Hydrogen Program strategy. The offices also meet monthly at a technical level across relevant DOE offices to share status, progress, and gaps, as well as meet monthly with other agencies involved in hydrogen activities. Plans also include Hydrogen Shot Summits and workshops, a joint Annual Merit Review and Peer Evaluation Meeting, a Basic Energy Sciences Roundtable to address research gaps, joint regional analysis, lifecycle emissions and supply chain assessments, and joint proposal peer reviews for solicitations.

In addition to the funding offices identified here, various crosscutting offices (including the Offices of Economic Impact & Diversity, Policy, and Artificial Intelligence and Technology) may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments. Coordination with the Office of Clean Energy Demonstrations will be essential to maximize BIL related hydrogen provisions going forward.

Crosscut Objectives:

The Hydrogen crosscut team works to achieve objectives identified through Hydrogen Shot and the DOE Hydrogen Program Plan.

- ***Achieve Hydrogen Production Goals:*** Conduct research, development, and demonstration (RD&D) to achieve $1/kg clean hydrogen cost target in one decade per the Hydrogen Shot target.
- ***Enable Market Competitive End Uses and Hydrogen Infrastructure:*** Enable viable end uses for hydrogen in hard-to-decarbonize sectors (e.g., steel/chemicals manufacturing, heavy-duty

transport, power generation/storage) through RDD&D and by addressing institutional barriers such as safety, codes, and standards.

- ***Address Resource and Sustainability Requirements:*** Assess availability of primary energy, water, materials, and other inputs to ensure holistic, sustainable, net-zero life-cycle emissions pathways, and ensure stewardship of our communities and the environment.
- ***Innovate:*** Foster fundamental science and applied research and development (R&D) to enable breakthroughs along the value chain of hydrogen technologies including fuel cells, electrolyzers, turbines, and end uses.

Crosscut Action Areas: Through the Hydrogen crosscut, DOE program offices EERE, FECM, SC, NE, OTT, ARPA-E, and the Office of Clean Energy Demonstrations (OCED), will:

1. ***Strengthen Cross-DOE Coordination and Collaboration:*** Ensure an integrated approach to RDD&D hydrogen activities to include analysis of complex and integrated systems, workshops, joint funding opportunities, and Principal Investigator meetings, community/stakeholder engagement, and data/information sharing.
2. ***Support Fundamental and Applied R&D and Technology Transfer:*** Establish the foundational scientific infrastructure, knowledge base, innovation, and technology transfer activities to enable DOE to meet the crosscut objectives.
3. ***Launch Demonstration Projects:*** Establish Hydrogen Hubs and demonstration projects, aligned with the Hydrogen Shot and the H2@Scale initiative, and use data to guide future RD&D.
4. ***Conduct Systems Analysis:*** Conduct life cycle, resource, regional, and techno-economic analyses to guide the portfolio and strategy.
5. ***Promote Hydrogen Safety Sharing:*** Share best practices and resources and make hydrogen safety a priority in our activities and projects.
6. ***Coordinate on Workforce/STEM and Diversity, Equity, and Inclusion:*** Collaborate on best practices and accelerate progress towards common goals.

Program Organization:

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021, ARPA-E selected and/or obligated $34,342K in hydrogen-related funding to projects through ARPA-E's Renewable Energy to Fuels' Utilization of Energy-dense Liquids Integration and Testing (REFUEL+IT) and Open programs. The assessment process for new programs is now underway and any potential future investments in Hydrogen will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):** EERE programs will collaborate to maximize impact in FY 2023:
   a. *Advanced Manufacturing Office (AMO):* AMO will invest in developing and deploying hydrogen and fuel cell technologies to advance the economic use of low-carbon hydrogen for industrial processes, including high temperature electrolyzer manufacturing R&D.
   b. Hydrogen and Fuel Cells Technologies Office (HFTO): EERE's entire HFTO activities are included in this crosscutting investment. Efforts supported include hydrogen production, delivery/infrastructure, storage, fuel cells, and end uses, including systems development and integration, as well as safety, codes, standards, and workforce development.

c. *Solar Energy Technologies Office (SETO):* SETO supports the RD&D of concentrating solar thermal power systems that can be used for hydrogen production or in conjunction with hydrogen as a chemical feedstock for decarbonized industrial processes.
d. *Water Power Technologies Office (WPTO):* As part of the HydroWIRES funding opportunity, WPTO will support the demonstration of hybrid energy storage multi-resource configurations such as floating photovoltaics and hydrogen storage.
e. *Wind Energy Technologies Office (WETO):* WETO supports the hydrogen crosscut through multi-office collaboration in hybrid system design, hardware, control, and demonstration to hybrid systems involving combinations of technologies such as wind, hydropower, solar, battery storage, or hydrogen.

3. **Fossil Energy and Carbon Management (FECM)**: FECM focuses primarily on hydrogen production from carbon-based or fossil resources, coupled to carbon capture and storage (CCS) to achieve carbon-neutral hydrogen, as well as large scale power generation using turbines or solid oxide fuel cells (SOFC) and large scale/geological hydrogen storage. FECM has invested considerable resources to support the development of gasification systems with pre-combustion carbon capture for producing clean hydrogen as a feedstock for fuel as well as hydrogen turbines and fuel cells for electricity generation.

   In FY 2023, FECM plans include lifecycle cost and technoeconomic analyses for co-gasification of wastes (i.e., legacy coal waste, plastics, sustainably sourced biomass); building a gasification test facility; development of fundamental combustion knowledge for other carbon-free fuels such as ammonia; development of modular heat engines that can be used to decarbonize energy and industry ecosystems; investment in field-testing of 10–25-kW SOFC systems running on both natural gas and hydrogen in a real environment at third-party data center locations.

   Within the Office of Resource Sustainability, efforts will focus on technologies for carbon-neutral hydrogen production from stranded methane sources, as well as hydrogen (and ammonia) transportation, and geologic storage technologies that leverage existing natural gas infrastructure as well as supporting analytical tools and models. Hydrogen research will focus on cutting edge, next-generation conversion technologies, blending hydrogen with natural gas, and leveraging existing transportation and storage infrastructure to handle high volume fractions of hydrogen.

4. **Nuclear Energy (NE):** NE focuses on enabling hydrogen production from nuclear power, including the existing fleet of reactors and advanced reactors. In FY 2022, NE continues to negotiate two projects selected with EERE Hydrogen Fuel Technology Office (HFTO) for hydrogen production demonstration at nuclear power plants.

   In FY 2023, NE will continue to:
   a. Advance technical feasibility, economic potential, and license considerations to validate the feasibility and business case for producing hydrogen at nuclear power plants in different regions of the country;
   b. Perform R&D on the physics and control of thermal delivery systems that couple nuclear reactors to high-temperature steam electrolysis at increasing scale;
   a. Develop full-scope nuclear plant simulators to help develop operating concepts and human factors that will enable nuclear power plants to dispatch energy safely and efficiently to the

hydrogen plant when switching to full production of electricity for the grid according to real-time market signals; and

b. Demonstrate industrial/chemical hydrogen applications using hydrogen produced with heat and electricity from existing nuclear reactors (in collaboration with EERE).

5. **Office of Technology Transitions (OTT):** OTT will continue to collaborate with DOE offices to:
   a. Conduct market and economic analysis to identify commercialization opportunities, risks, and challenges across the RDD&D continuum.
   b. Expand analysis and industry engagement activities to identify and pursue commercialization projects and pathways.

6. **Science (SC):** *Basic Energy Sciences (BES)* provides foundational knowledge and state-of-the-art capabilities in support of the Hydrogen Crosscut objectives and continues to support theoretical and experimental science related to understanding hydrogen technologies and materials that will continue through FY 2023. In FY 2023, the Request includes support for a new research modality, the Energy Earthshot Research Centers (EERCs), which will work toward the stretch goals of the DOE Energy Earthshots and will provide a solid bridge between SC and the Energy Technology Offices. Through strong alignment with the technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities to bridge the R&D gap.

   Key activities include supporting scientific discoveries and major scientific tools to transform our understanding of hydrogen-related technologies including hydrogen storage, production, utilization, and conversion. SC operates major x-ray, neutron, nanoscience, and high-performance computing user facilities that provide advanced synthesis, fabrication, characterization, and computational capabilities to this community for basic, applied, and industrial research.

   SC research enables breakthrough advances to hydrogen production beyond conventional approaches such as electrolysis; related work is conducted by the Fuels from Sunlight Hub program and the Energy Frontier Research Centers, which complement the technology-specific RD&D supported by DOE's applied energy offices and provides foundational knowledge that can bring advances to many areas of technology development.

   Further, SC enables advances in synthesis, catalysis, modeling, artificial intelligence/machine learning, analytical instrumentation at user facilities, high-performance computing, and bio-inspired approaches. Key basic research focus areas include: novel materials for hydrogen storage, membranes for separations, purification, ion transport, novel materials, chemical processes for production and use of hydrogen such as design of nanoscale catalysts, bio-inspired materials and processes, and solar hydrogen production. SC increases understanding of the role of critical elements such as rare earth elements and platinum group metals used in catalysts to reduce their use and dependence on such materials in coordination with the Critical Minerals and Materials Crosscut.

Industrial Decarbonization Crosscut

Funding by Appropriation and Program Control
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**103,164**	**0**	**TBD**	**TBD**
Advanced Research Projects Agency - Energy*	103,164	0	TBD	TBD
Energy Efficiency and Renewable Energy	**388,006**	**388,006**	**639,390**	**+251,384**
Advanced Manufacturing	165,506	165,506	315,700	+150,194
Bioenergy Technologies	105,500	105,500	109,000	+3,500
Hydrogen and Fuel Cell Technologies	117,000	117,000	176,150	+59,150
Solar Energy Technologies	0	0	32,675	+32,675
Strategic Programs	0	0	5,865	+5,865
Fossil Energy and Carbon Management	**251,600**	**251,600**	**235,000**	**-16,600**
Hydrogen with Carbon Management	63,300	63,300	31,500	-31,800
Point-Source Carbon Capture	86,300	86,300	81,500	-4,800
Carbon Transport and Storage	79,000	79,000	122,000	+43,000
Carbon Dioxide Conversion	23,000	23,000	0	-23,000
Nuclear Energy	**36,000**	**28,500**	**44,000**	**+8,000**
Advanced Reactor Technologies	8,500	8,500	16,000	+7,500
Crosscutting Technology Development	10,000	10,000	9,000	-1,000
Light Water Reactor Sustainability	13,000	2,000	3,000	-10,000
National Reactor Innovation Center	4,500	8,000	16,000	+11,500
Office of Technology Transitions	**0**	**0**	**100**	**+100**
Science	**13,700**	**30,700**	**88,700**	**+75,000**
Basic Energy Sciences	13,700	30,700	88,700	+75,000
Grand Total	**792,470**	**698,806**	**1,007,190**	**+317,884**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

The Decarbonizing Industry crosscut engages multiple offices across DOE to foster innovations and enables scale up of cost-competitive, low-emissions technologies to achieve the DOE goal of decarbonizing energy intensive and high greenhouse gas (GHG)-emitting industries to achieve net-zero greenhouse gas emissions, economy-wide, by no later than 2050. The crosscut leverages research, development, demonstration and deployment (RDD&D) across the pillars of industrial decarbonization: energy efficiency; electrification; low carbon fuels, feedstocks and energy sources; and carbon capture and storage (CCS).

The U.S. industrial sector is considered a hard-to-decarbonize sector of the energy economy, due in part to the diversity of energy inputs into a wide array of heterogeneous industrial processes and operations. In 2020, the industrial sector accounted for 33% of the nation's primary energy use and 30% of energy-

related carbon dioxide (CO_2) emissions[1] with refining, chemicals, iron and steel, cement, and food products representing the top energy-consuming sectors.

Given the technologies and systems interdependencies across the decarbonization pillars, crosscut activities will be an enabling piece of DOE's portfolio of solutions to achieve a net zero carbon economy by 2050, with the potential to contribute to a reduction of 400 million metric tons of CO_2 of industrial emissions by 2050 in the most energy and emissions intensive industrial subsectors. Additionally, industrial decarbonization investments can improve manufacturing productivity, develop innovative products, and meet expanding societal needs while enabling jobs and maintaining our prosperity throughout the 21st Century and beyond.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of technology development, demonstration, scale-up, and deployment for industrial emissions reduction, industrial research and assessments, support state manufacturing and advanced energy manufacturing and recycling. These investments are essential in addressing the supply chain and technology needs to decarbonize industry.

Coordination Efforts:

The Industrial Decarbonization crosscut is coordinated with regular meetings across representatives from Energy Efficiency and Renewable Energy, Fossil Energy and Carbon Management, Science, Nuclear Energy, Office of Technology Transitions and Advanced Research Projects Agency - Energy, with focused discussions on industry. FY 2023 activities include developing and executing research, development, demonstration, and deployment (RDD&D) coordination, budget development, and strategic planning for the crosscut that is informed by the Industrial Decarbonization Roadmap, a Congressionally directed report.

In addition to the offices identified here, other technology offices such as Office of Electricity, Office of Clean Energy Demonstrations, Office of Cybersecurity, Energy Security and Emergency Response and other crosscutting offices such as Office of Economic Impact & Diversity, Office of Policy, Artificial Intelligence and Technology Office, and Loan Programs Office may contribute staff time and coordinate with the RDD&D funding offices to enhance the impact of the Department's investments.

Crosscut Objectives:

Given the reliance on carbon and variation of energy sources, uses, and product mixes, it will be critical to proactively pursue multiple decarbonization approaches in parallel, which include the following:

- ***Address Energy Efficiency:*** Conduct RDD&D to enable energy efficiency in hard-to-decarbonize sectors ranging from energy intensive unit operations (e.g., process heating) to facilities/systems operations. This includes, for example, waste heat recovery and flexible combined heat & power (CHP) approaches that have the potential to significantly reduce energy consumption and associated GHG emissions in the near term, and that will also be able to transition to fully clean (zero carbon-emitting) energy sources in the mid- to long-term (i.e., ensure that unintended fossil fuel lock-in does not occur).
- ***Decarbonize Operations:*** Fossil fuel energy use in operations, as well as some processes inherent to manufacturing (e.g., cement production, fermentation of biofuels) generate CO_2. In

[1] EIA (Energy Information Administration), Annual Energy Outlook 2021 with Projections to 2050. 2021. https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf.

addition to utilizing zero carbon generation electricity, carbon capture, and sequestration (CCS) can reduce emissions at the source. RDD&D focuses on technologies that can improve capture performance; generate lower carbon intensive products (i.e., ethanol, H_2, cement) convert CO_2 into valuable products, in some cases, products that can augment those produced in the industrial sector such as cement and curing to concrete; and safely store CO_2 in geologic formations. Viable CCS and CO_2 conversion pathways need both a value proposition as well as assessment of the availability of primary energy, water, and other inputs to ensure holistic, sustainable, low-life cycle emissions pathways, and ensure stewardship of our communities and the environment.

- ***Transition Energy Sources:*** RDD&D focuses on hydrogen, low carbon fuels and feedstocks, solar thermal, and electrification so they can be cost-effectively used to reduce energy and emission intensity. Low-carbon and sustainably sourced biomass feedstocks may also offer an effective alternative to replace current petroleum-based feedstocks for a variety of high-volume chemical products leading to significant GHG emissions reductions.
- ***Innovate Alternate Pathways and New Technologies:*** The current predominantly linear production system of materials extraction to manufacturing to product use to disposal does not optimize around energy or GHG emissions; circular economy approaches, and reverse supply chain may provide entirely new opportunities for energy/emissions improvements in concert with new economic opportunities for transformative material and resource utilization. Opportunities exist to foster fundamental science and applied R&D aligned with other crosscuts and DOE priorities such as advanced manufacturing including biomanufacturing; circularity for critical materials, plastics, and water; as well as entirely new pathways for carbon dioxide removal (CDR) approaches via reaction of CO_2 with alkaline by-products or waste (e.g., mine tailings) to produce synthetic aggregates, which can serve as replacements for sand and gravel.

Crosscut Action Areas:

The Industrial Decarbonation crosscut will:

1. ***Strengthen Cross-DOE Coordination and Collaboration:*** Ensure an integrated approach including clearly defined "swim lanes" and "relay points," integrated systems analysis, workshops and Principal Investigator meetings, community/stakeholder engagement, and data/information sharing.
2. ***Support Fundamental and Applied R&D and Technology Transfer:*** Establish the foundational scientific infrastructure, knowledge base, innovation, and technology transfer to enable DOE to meet program goals.
3. ***Conduct Front-end Engineering Design Studies and Launch Demonstration Projects:*** Conduct front-end engineering design (FEED) studies as way to build confidence in technical and cost performance of subsequent full-scale builds. Establish Decarbonizing Industry demonstration projects in priority areas aligned with pre-demonstration stage DOE investments and use data to guide future RDD&D.
4. ***Conduct Systems Analysis:*** Conduct life cycle, resource, regional, and techno-economic analyses to guide the portfolio and strategy.
5. ***Promote Information and Data Sharing:*** Share best practices and resources to accelerate progress across the Technology Readiness Level (TRL) value chain.
6. ***Coordinate on Workforce/STEM and Diversity, Equity, and Inclusion:*** Collaborate on best practices and accelerate progress towards common goals.

Program Organization:

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. In FY 2021, ARPA-E funded Decarbonizing Industry / projects related to Sulfur Hexaflouride (SF6)-Free Routes for Electrical Equipment, Harnessing Emissions into Structures Taking Inputs from the Atmosphere (HESTIA), and Open 2021 programs. ARPA-E is developing programs for transformational research across a wide range of energy technologies and applications. The assessment process for new programs is now underway and any potential future investments in Decarbonizing Industry will be determined in FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):** In FY 2023, EERE will support Industrial Decarbonization through applied research, development, and demonstration that pursues all pathways to decarbonization.
   a. *Advanced Manufacturing Office (AMO):* AMO broadly covers approaches to decarbonize industry with a strong focus on lowering GHG emissions through energy and materials efficiency, industrial electrification, and transformative uses of low-carbon fuels, feedstocks, and energy sources. Representative research, development, and demonstration (RD&D) topics include process intensification, electrochemistry-driven materials transformations, electrified and intensified thermal processes as well as low thermal budget processes, material efficiency and circular economy approaches, smart and sustainable manufacturing, and strategic energy management. Programs are rolled out through public-private partnerships (e.g., Institutes and Hubs); AMO will support RD&D projects (to develop and demonstrate the next generation of targeted technologies that will address high GHG-emitting industrial subsectors, as well cross-cutting technologies that will have impact across multiple industrial subsectors); partnerships with industry to address direct and indirect emissions from their processes, facilities and operations; and creative approaches to develop the workforce and next generation of innovators.
   b. *Bioenergy Technologies Office (BETO):* BETO supports industrial decarbonization through the development of alternative feedstocks, and energy efficient conversion processes to produce fuels, chemicals, and materials. BETO's alternative feedstocks R&D focuses on technologies to produce sustainable, cost-effective, conversion-ready feedstocks, including biomass and wastes, such as CO_2. BETO also supports RD&D conversion technologies that can utilize these alternative feedstocks to replace traditional manufacturing processes and fossil-derived chemicals with leap-frog technologies that use significantly less energy inputs and reduce GHG emissions.
   c. *Hydrogen and Fuel Cell Technologies Office (HFTO):* HFTO funds RD&D to enable affordable carbon-free hydrogen to address hard-to-decarbonize applications across sectors. Within the hard-to-decarbonize industrial and chemical processes, HFTO supports RD&D focused on demonstrating the ability of clean hydrogen as a feedstock (ammonia production) or as a direct reducing agent (i.e., steel production). Efforts may also include demonstrating clean hydrogen as a heat source for processes like steel and cement production.
   d. *Solar Energy Technologies Office (SETO):* SETO supports the RD&D of industrial processes driven by solar thermal energy. This activity includes both low-temperature systems focused on low-cost embodiments of existing technologies, and the development of components and system designs for high-temperature systems that are difficult to decarbonize through electrification. Low temperature systems, in the range of 100 to 300 °C target a levelized cost of heat (LCOH) of 1 cent per kWh-thermal or lower, which would constitute at least a 50 percent decrease in

current LCOH. High temperature systems work includes the development of solar thermal pathways for the carbon-emission-free production of energy-intensive chemicals, commodities, and fuels, like ammonia, steel, cement, and hydrogen.

e. *Strategic Programs (SP):* SP analyzes crosscutting issues that affect EERE technologies, such as integration of EERE technologies into the energy system, changing demand for energy, and efficient use of limited resources to enable the transition to a net-zero carbon emission economy.

3. Fossil Energy and Carbon Management (FECM): In FY 2023, FECM will support the Decarbonizing Industry crosscut in several ways, including:

a. RDD&D on CCUS including technical feasibility, economic potential, and siting/systems considerations to co-locate large industrial facilities with CCUS availability.
b. RDD&D on the production of hydrogen with CCUS from fossil resources/wastes (such as plastics and co-production using biomass, where available).
c. RDD&D on turbines that can utilize hydrogen, ammonia, and other low carbon fuels for power generation to be used in industrial applications, as well as hybrid and integrated systems to maximize efficiency.
d. Reversible solid oxide fuel cells/solid oxide electrolyzer cells, focused on natural gas and co-producing hydrogen, in coordination with EERE's HFTO.
e. Large scale transport and geological energy storage, including hydrogen or hydrogen carriers such as ammonia at scale to support bulk power generation.
f. R&D on integrating DAC systems with industrial facilities to leverage waste heat opportunities.
g. R&D on installation of Bioenergy with Carbon Capture and Storage (BECCS) and Biomass Carbon Removal and Storage (BiCRS) systems at industrial facilities.

5. **Nuclear Energy (NE):** In FY 2023, NE will support industrial decarbonization in several ways, including:

a. Developing the methods for thermal extraction, storage and distribution; as well as operations and control systems for direct use of heat generated from the existing light water reactor fleet.
b. Developing architectural and engineering models and investor-grade reports to detail the opportunities for providing clean thermal and electrical energy for industrial applications with the existing light water reactor fleet (e.g., hydrogen, ammonia, metals, chemicals, and fuels).
c. Development of site integration methods and practices for collocating microreactors and small modular reactors with distributed industrial applications for use of both clean heat and clean electrical power from nuclear energy (e.g., refineries, chemical plants, mineral processing, data centers).
d. Development of reactor technologies that produce high grade heat (500 C to 900 °C) suitable for use in most chemical and industrial processes.
e. Cost analysis of advanced reactor technologies to identify pathways for cost reduction and the economic viability for integration of advanced reactors with industrial applications.
f. Feasibility studies for upgrading lower temperature (300 °C) heat sources with heat pumps.
g. Exploring opportunities to use low-cost, clean nuclear heat for broad-spectrum material recycling processes.
h. Using nuclear energy source to improve the yield of bio-refineries.

4. Office of Technology Transitions (OTT): OTT will continue to collaborate with DOE offices to:

a. Conduct market and economic analysis to identify commercialization opportunities, risks and challenges across the RDD&D continuum.
b. Expand analysis and industry engagement activities to identify and pursue commercialization projects and pathways.

5. **Science (SC):** Basic Energy Sciences provides foundational knowledge and state-of-the-art capabilities in support of crosscut objectives, including theoretical and experimental science related to understanding opportunities for decarbonizing industry. The research to support this crosscut is also discussed in the Critical Materials and Minerals, and Advanced Manufacturing crosscut narratives. In FY 2023, SC will support the Industrial Decarbonization crosscut in several ways, including:
   a. Support scientific discoveries and major scientific tools to transform our understanding of materials and conversion processes related to chemicals, low carbon fuels (including hydrogen), and manufacturing processes. SC operates major x-ray, neutron, nanoscience, and high-performance computing user facilities that provide advanced synthesis, fabrication, characterization, and computational capabilities to this community for basic, applied, and industrial research.
   b. Enable advances in synthesis, catalysis, modeling, artificial intelligence/machine learning, analytical instrumentation at user facilities, high-performance computing, and bio-inspired approaches. Key basic research focus areas include: novel materials for low carbon fuels/feedstocks (e.g., hydrogen in coordination with the Hydrogen crosscut), membranes for separations, design of catalysts at the nanoscale, co-design for manufacturing (combining disciplines and computation for a “whole systems” approach), and synthesis science for scale-up from initial discoveries to bridge the gap to applied research and commercial application.
   c. Increase understanding of the use of critical materials in manufacturing processes and reducing the dependence on such materials in coordination with the Critical Minerals Crosscut.
   d. Enable advances in biomanufacturing, to replace or improve performance relative to petroleum-derived products.

Subsurface Energy Innovation Crosscut

Funding by Appropriation and Program Control
($ Thousands)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 CR Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)
Advanced Research Projects Agency - Energy	**15,712**	**44,000**	**TBD**	**TBD**
Advanced Research Projects Agency – Energy*	15,712	44,000	TBD	TBD
Energy Efficiency and Renewable Energy	**106,000**	**106,000**	**202,000**	**+96,000**
Geothermal Technologies Office	106,000	106,000	202,000	+96,000
Fossil Energy and Carbon Management	**11,500**	**11,500**	**13,000**	**+1,500**
Carbon Management	10,000	10,000	10,000	0
Resource Sustainability	1,500	1,500	3,000	+1,500
Science	**10,715**	**11,017**	**17,378**	**+6,663**
Advanced Scientific Computing Research	5,715	6,017	4,378	-1,337
Basic Energy Sciences	5,000	5,000	13,000	+8,000
Grand Total	**143,927**	**172,517**	**232,378**	**+104,163**

*ARPA-E funding is determined annually based on programs developed through office and stakeholder priorities. Therefore, funding for FY 2023 is not available at this time.

Summary:

Subsurface clean energy applications hold massive untapped potential for solving the climate crisis. However, our ability to assess, access, and monitor the subsurface quickly and economically is insufficient to mitigate financial and environmental risk for deployment. Common risk drivers include *a)* uncertainty in subsurface resource properties; *b)* inability to monitor reservoir dynamics that can trigger seismicity and/or leakage; and *c)* prohibitive costs and timelines to access subsurface resources. The Subsurface Energy Innovation (SEI) Crosscut funds research, development, demonstration, and deployment (RDD&D) to improve the accuracy, precision, and speed with which subsurface resources can be assessed, accessed, and monitored. Such advancements will allow the technologies listed below to become market-competitive, scalable, and permanent clean energy solutions, and create tens of thousands of good-paying jobs:

- *Geothermal energy*, which requires dramatic cost reductions in Enhanced Geothermal System (EGS) capability to increase its footprint beyond 0.5 percent of U.S. electricity generation;
- *Geologic carbon storage*, currently happening at 0.1 percent of the rate necessary to meet our climate goals;
- *Geologic hydrogen storage*, currently only feasible in unique and rare geologic features;
- *Sustainable critical mineral extraction*, necessary to reduce high American import reliance; and
- *Geologic hydrogen sourcing*, a new and potentially cost-effective, zero-emission source of hydrogen.

SEI Crosscut activities reduce the uncertainty and cost burden facing these technologies through the production and application of tools, data products, and workstreams that improve our observational, decision-making, and operational capabilities. Such activities require advancements across fundamental science, and applied RDD&D. The SEI Crosscut will leverage the integration of state-of-the-art High-

Performance Computing (HPC) resources, Artificial Intelligence (AI), Machine Learning (ML), and simulation capabilities with applied technology workstreams necessary to build subsurface simulation and interpretation visualization, prediction, and decision-making tools.

Bipartisan Infrastructure Law (BIL) – In FY 2023, in addition to the annual appropriations request, BIL funding will support the initial stages of planning and execution of demonstration of enhanced geothermal systems and carbon storage validation and testing projects. These investments are essential in addressing the supply chain and technology needs to support growth in clean energy.

Coordination Efforts:

The Department of Energy (DOE) houses the entire range of technological expertise across the RDD&D chain required for innovation in the subsurface for clean energy advancement including: Office of Science (SC) Basic Energy Sciences and Advanced Scientific Computing Research Offices, Energy Efficiency and Renewable Energy (EERE)'s Geothermal Technologies Office (GTO), Advanced Research Projects Agency - Energy (ARPA-E), Fossil Energy and Carbon Management (FECM) with the Artificial Intelligence and Technology Office (AITO) providing technical support and staff time.

In addition to developing and implementing a cross-agency subsurface RDD&D Strategy, priorities include joint efforts on information sharing and engagement with external stakeholders and technology experts. Additionally, the SEI Crosscut will prioritize the establishment of new partnerships and maintenance of existing partnerships with other Federal agencies, such as the Department of Interior and the United States Geological Survey (USGS), the National Science Foundation, and the National Aeronautics and Space Administration.

Crosscut Objectives:

- ***Significantly improve our understanding of the nation's deep subsurface resources:*** Recent advancements in geophysical data acquisition and HPC can drive significant improvements in our current ability to assess the subsurface properties and integration of already-collected subsurface data from previously drilled or orphaned wells, abandoned mines, and other legacy projects, which can greatly improve the current understanding of subsurface properties. The SEI Crosscut will develop the understanding of the phenomena, tools, methods, and data products necessary for rapid, accurate assessment of the deep subsurface at the meter scale. RDD&D activities include the development of new sensors and telemetry systems, the interpretation of signals using HPC, the development of methods and understanding to integrate and interpret subsurface properties from disparate data sources, and the creation of publicly available, high-resolution subsurface resource datasets.
- ***Monitor subsurface engineering activity, and make operational decisions, in real time:*** The geological engineering required to deploy subsurface clean energy applications can drive changes to the original subsurface environment. Such changes can lead to operational and/or environmental risks that can jeopardize project success and widespread technology adoption. These risks can be avoided, however, through operational decision-making informed by accurate, continuous, real-time monitoring of subsurface operations. SEI Crosscut efforts drive improvements in all the technological components of this objective, including data acquisition and processing, operational decision-making workflows informed through AI, and responsive subsurface engineering hardware.

- ***Access the deep subsurface quickly and economically:*** Subsurface clean energy technologies require the deployment of precise drilling techniques that allow for the targeted exploitation of a resource. Many of these techniques, such as horizontal and directional drilling, have been successfully demonstrated in the domestic oil and gas sector. SEI Crosscut efforts drive both the creation of drilling equipment and methods and the effective and efficient technology transfer of the state-of-the-art within the oil and gas, mining, aerospace, and other relevant industries. Such efforts will include original RDD&D to improve drilling speed, bit materials, casing materials, and well completion technologies as well as externally focused workshops, public meetings, and information requests to foster technological collaboration with the private sector.
- ***Engineer the subsurface to optimize benefit and minimize risk***: To expand subsurface clean energy technologies to the scale that will be required in the coming decades, technologies that will allow for the manipulation and the engineering of the subsurface will be needed. Such technologies may include stimulation or other permeability enhancements, methods to plug leaks or otherwise reduce permeability, methods to manipulate reactivity or surface tension, pressure control through a combination of injection and production, and approaches to enable in situ mining/extraction of critical minerals or materials. SEI crosscut efforts will include the development and in situ testing of such technologies in a variety of geologies and subsurface conditions.
- ***Drive job transition opportunities for fossil community workers:*** Aggressive growth in subsurface clean energy applications could provide job transition opportunities for nearly 100,000 American workers with relevant technical skillsets who have been trained in the fossil fuel extraction industry.

Crosscut Action Areas: DOE's EERE, FECM, SC, ARPA-E, and AITO work collaboratively to:

1. ***Conduct guiding quantitative technological analyses:*** engage in cross-office strategic analysis to identify technical objectives and resources required to meet Administration clean energy goals pertaining to subsurface clean energy applications.
2. ***Expand cross-DOE RDD&D coordination informed by quantitative analysis:*** develop cross-office information requests, roundtables, and funding opportunities designed to achieve technical objectives identified from analyses.
3. ***Collaboratively engage with industry to promote technology transfer:*** develop both public and targeted workshops, roundtables, and forums to facilitate opportunities for experts in industry to ensure DOE programming is aligned with the industry state-of-the-art, and foster synergies where available.
4. ***Collaboratively engage with the oil and gas workforce to promote a just transition:*** engage in public-facing outreach to promote workforce development activities designed to increase the size of the subsurface clean energy workforce.
5. ***Guide responsible and trustworthy infrastructure, autonomy, and AI outcomes:*** engage in cross-office strategic analysis to establish scenario-based benchmarks and develop test and evaluation criteria to mitigate biases and risks.
6. ***Support infrastructure development that allows sharing of data, AI/ML models, algorithms, results, and lessons learned across offices:*** Establish an AI Integrated Development Environment strategy and actionable planning team that facilitates interoffice collaboration leading to an

integrated platform that provides users secure and streamlined access to high-quality data, models, tools, and computing power.

Program Organization:

1. **Advanced Research Projects Agency - Energy (ARPA-E):** As defined by its authorization under the America COMPETES Act, ARPA-E catalyzes transformational technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact projects that are too risky to attract private sector investment but could significantly advance the ways to generate, store, distribute and use energy. ARPA-E selected and/or obligated funding to Subsurface projects through ARPA-E's Open 2021 program. For example, Open 2021 projects support research and development on "Repurposing Infrastructure for Gravity Storage Using Underground Potential Energy" and "Electro-Hydraulic Fracturing for Enhanced Geothermal Systems." In FY 2022, ARPA-E is targeting funding to Subsurface projects through ARPA-E's Mining Innovations for Negative Emissions Resource Recovery (MINER) program. ARPA-E is developing programs for transformational research across a wide range of energy technologies and applications. The assessment process for new programs is now underway and any potential future investments in Subsurface will be determined FY 2023.

2. **Energy Efficiency and Renewable Energy (EERE):**
   Geothermal Technologies Office (GTO): In FY 2023 GTO will support Crosscut objectives through focused RD&D on exploration, characterization, reservoir monitoring, and drilling-based verification of advanced exploration technologies and methods. Exploration and characterization activities will focus on improving targeting the breadth of geothermal resources across temperature ranges and applications through improvements in multi-physics inversion methods and incorporation of machine learning models. GTO has partnered with USGS to perform large scale airborne geophysical surveys that support more focused future exploration activities. Additionally, broad data collection efforts will enable a significant increase in the discovery of hidden geothermal systems.

   Subsurface accessibility will focus on RD&D directed at lowering the time to drill geothermal wells and decrease the costs of required materials and equipment. Activities will include efforts to adopt data driven workflows to increase the efficiency of geothermal drilling, adapting applicable technologies proven in the oil and gas well construction industry, directly addressing primary causes of "non-productive time", and the implementation of RD&D programs to reduce the materials costs associated with geothermal well development. Numerous drilling-related investigators are entering their final stages of activities and the development of well completion technologies, equipment, and workflows related to reservoir stimulation will continue to be an RD&D focus. The development and deployment of surface and subsurface reservoir monitoring technologies focusing on microseismic, electrical, and optical methods will continue.

   Funding will also support data, modeling, and analysis activities that underpin the Department's RD&D portfolio. These efforts quantitatively assess the full value of geothermal electricity generation to the grid, development of real time analysis tools that leverage geothermal data, and the development of a pathway to improved permitting timelines, which are critical to increased geothermal deployment. Crosscutting activities such as machine learning, advanced

manufacturing, and a focus on technology commercialization will support the program in its focus on the energy transition.

3. **Office of Fossil Energy and Carbon Management (FECM):**
FECM supports the FY 2023 SEI Crosscut objectives through extensive expertise and capability related to the characterization, management, and extraction of subsurface resources, such as critical mineral (CM) extraction, as well as geologic storage of hydrogen and CO_2. FECM launched the Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) initiative designed to address the upstream and midstream CM supply chain and downstream manufacturing of high-value, nonfuel, carbon-based products (CBP), to accelerate the realization of full potential for carbon ores and CM within the U.S basins. FY 2023 activities in this area include novel monitoring technologies, including geochemical and biological approaches, will help characterize mineral resources.

   FECM activities in FY 2023 will capitalize on and integrate recent advances in geochemical, wellbore integrity, and fluid-structure interaction modeling derived from decades of field experience with underground gas storage in the oil and gas industry to drive greater uptake and acceptance of underground hydrogen storage (UHS). Such activities will allow for UHS operators to both dynamically track and adaptively manage UHS reservoirs to ensure existing barriers, such as induced seismicity and sulfate-reducing bacteria, are mitigated. Extensive outreach to and cooperation with the public and regulatory bodies are central to FECM UHS activities and are key to widespread application of the technology.

   In FY 2023, the FECM Carbon Transport and Storage Program is supporting the Science-Informed Machine Learning to Accelerate Real-Time (SMART) decision making to enable real-time performance monitoring of CO_2 storage, with more intuitive visualization capabilities, and a rapid virtual learning environment to assess performance scenarios. SMART has launched its second phase, in which ML-driven technologies shown to be promising in phase 1 will be developed for field deployment and testing. Multiple National Laboratories will also embark on developing sensors, downhole power systems, and telemetry technologies to add to the data streams that will enable SMART's ML-driven processes. These activities will drive the integration of SMART capabilities into operational commercial scale CO_2 storage projects, spurring adoption by industry as a lower cost paradigm for safely operating CO_2 storage projects.

4. **Science (SC):** SC provides foundational knowledge and state-of-the-art capabilities in support of crosscut objectives, such as novel computational algorithms in material properties and fluid flow data analysis and management, high performance computation, and subsurface material characterization.
   a. *Advanced Scientific Computational Resources (ASCR):* ASCR provides state-of-the-art HPC facilities as well as R&D that develops physics-informed deep learning techniques to address long-standing subsurface challenges. ASCR's investment in the Subsurface project involves understanding and predicting the behavior of hundreds of thousands of deep wells drilled to characterize reservoirs. The Subsurface project, funded through ASCR's Exascale Computing Project (ECP), is developing a high-resolution reservoir simulator, integrating the complex

multiphysics processes occurring from kilometer to micron scales to study and prevent well bore failure for CO_2 sequestration in saline reservoirs. This project focuses on the science challenge of overcoming the failure of a wellbore for CO_2 sequestration in saline reservoirs, with consideration of a wellbore segment of up to 100 meters and times up to 1 year. In addition, ECP's Earthquake Simulation (EQSIM) project is creating an end-to-end capability to simulate earthquakes from the initiation of a fault rupture to surface ground motions and ultimately to infrastructure response.

b. *Basic Energy Sciences (BES):* BES supports computational/theoretical and experimental science aimed at understanding geomechanically, chemical, hydrological, and interfacial chemical and materials behavior that provides the foundational knowledge to advance subsurface energy technologies through awards to universities and DOE National Laboratories. Specific areas of research that support the SEI Crosscut goals include:
   i. Mineral dissolution, nucleation, and phase equilibria in confined and interfacial environments, including characterization at the molecular level with x-ray/neutron sources and advanced computational chemistry.
   ii. The individual and collective dynamical properties, structures, and characteristic microseismic signatures of interacting fracture systems, integrating modeling, laboratory, and field observations.
   iii. Leverage of the unique capabilities at SC scientific user facilities, such as x-ray light sources (for high-resolution imaging of the time-dependence of geochemical/mechanical interactions in rock samples) and leadership class (exascale) computing (for predictive modeling of processes across scales and ML simulations of massive data sets to connect data to the underlying processes).

Funding in FY 2023 will focus on connecting subsurface data to underlying geophysical processes. Research will support efforts to understand how geophysical signals – such as those measured as ultrasound/thermoacoustic emissions (active) and acoustic (passive) emissions in the laboratory, and seismic signals in the field – arise from geophysical processes that transfer stress and dynamically open and close fractures. The goal is to understand these processes so that they can be predicted and ultimately controlled.

Safeguards and Security
Crosscut

Program Mission

The Safeguards and Security (S&S) program at headquarters and each DOE field site protects against theft, diversion, sabotage, espionage, unauthorized access, compromise, and other hostile acts which may cause damage to national security, program continuity, the health and safety of employees, the public or the environment. The 'crosscut' summarizes the S&S programs that are distributed through the budget volumes. Each program's S&S components are described in the budget justifications for:

- Science
- Weapons Activities
- Defense Nuclear Nonproliferation
- Naval Reactors
- Defense Environmental Cleanup
- Nuclear Energy
- Energy Efficiency and Renewable Energy
- Fossil Energy R&D
- Strategic Petroleum Reserve
- Legacy Management
- Loans Program Office
- Enterprise Assessments
- Environment, Health, Safety and Security
- Energy Information Administration
- Specialized Security Activities
- NNSA Federal Salaries and Expenses
- Chief Financial Officer
- Chief Information Officer

Program Overview

The budget for the direct funded S&S programs is organized to ensure consistency in program and budget execution and ensure management, direction, tracking and monitoring of security costs throughout the Department. Each program budget provides visibility for S&S issues to help management ensure effective and efficient S&S program implementation. Figure 1 shows comparable overall funding for S&S in the FY 2021 Enacted, FY 2022 Annualized CR and the FY 2023 Request.

Figure 1: Overall DOE S&S Funding

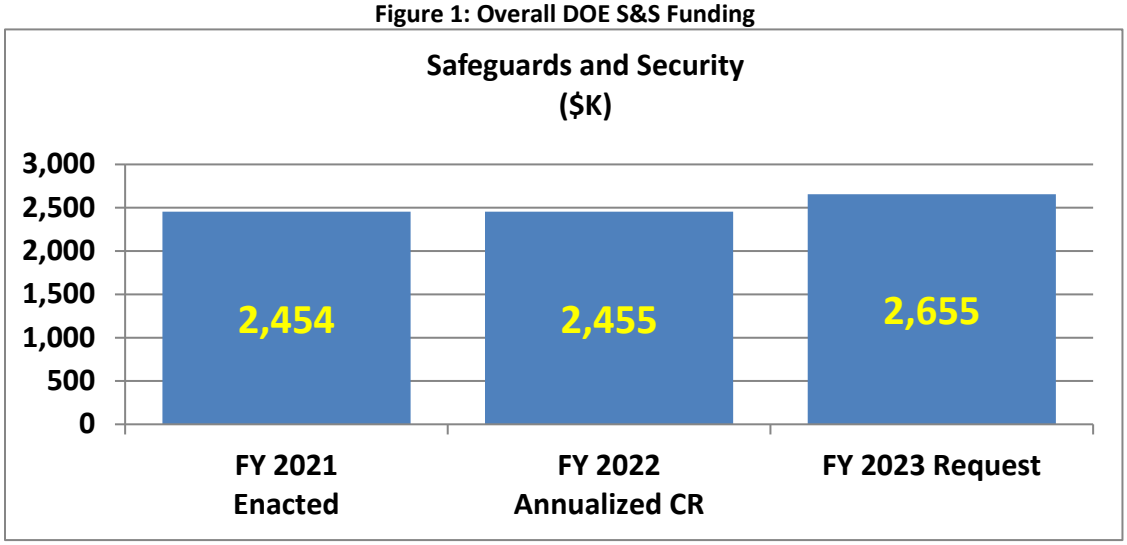

Table 1: Functional Components of S&S

The S&S crosscut budget is comprised of the functional components shown in the following table.

Protective Forces	Provides for the protection of special nuclear materials, information, employees, and government property from theft, diversion, sabotage, and malicious destruction.
Physical Security Systems	Addresses access control and interior/exterior intrusion detection systems.
Information Security	Ensures that individuals protect classified matter and sensitive unclassified matter and establishes protection systems that require degrees of protection for each classification level.
Cybersecurity	Assures protection of IT resources and networks, to include modernizing cybersecurity defenses by protecting federal networks, improving information-sharing between the U.S. government and the private sector on cyber issues, and strengthening the United States' ability to respond to incidents when they occur.
Personnel Security	Supports activities associated with the access authorization program.
Material Control and Accountability	Provides assurance that the nuclear materials used and/or stored at DOE facilities are always properly controlled and accounted for.
Program Management	Assures a framework for efficient and effective security operations.
Security Investigations	Provides for background investigations for access authorizations.
Transportation Security	Provides secure transportation of nuclear materials.
Security Infrastructure/ Construction	Provides for update and repair of security-related infrastructure and construction for that purpose.
Specialized Security Activities	Provides highly specialized analyses in support of national security objectives.

Table 2 shows S&S funding by program cost elements; and Table 3 by functional cost elements. Subsequent sections break out each functional element of safeguards and security by program.

Highlights:
In FY 2023, the Department's overall S&S investment (field and HQ) is $2.7 billion, an increase of +$200.4 million, or 8.2%, above the FY 2021 Enacted level.

By functional element, DOE is making strategic investments in Cybersecurity (+$31 million, or +6.8%), Protective Forces (+$89.2 million, or +11.5%), Physical Security Systems (+$43.7 million, or 25.6%), there are decreases in security infrastructure/construction (-$3.0 million, or -5.8%) and Program Management (-9.5 million, or -6.4%).

By program, there are significant increases from FY 2021 Enacted to FY 2023 Request for Weapons Activities (+$76 million, or +5.6%) for additional security requirements associated with mission growth across the nuclear security enterprise, including plutonium pit production and preparation for operation of the Uranium Processing Facility at the Y-12 National Security Complex. Additionally, there are notable increases in the Office of Science (+$68.5 million, or +56.6%) Fossil Energy & Carbon Management (+$3.9 million, or +34.1%) and the Office of the Chief Information Officer (+$20.6 million or +28.6%) primarily for investments in cybersecurity in response to Executive Order 14028, Improving the Nation's Cybersecurity.

Table 2: S&S Funding by Program ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Safeguards and Security (S&S) by Program					
Chief Financial Officer	1,410	1,410	3,500	2,090	148.2%
Chief Information Officer	71,800	71,800	92,361	20,561	28.6%
Defense Environmental Cleanup	320,771	320,771	309,573	-11,198	-3.5%
Defense Nuclear Nonproliferation	294	336	350	56	19.0%
Energy Efficiency and Renewable Energy	12,950	12,950	15,450	2,500	19.3%
Energy Information Administration	920	1,105	1,405	485	52.7%
Enterprise Assessments	9,505	9,505	9,535	30	0.3%
Environment, Health, Safety and Security	73,614	73,614	80,430	6,816	9.3%
Federal Salaries and Expenses	2,816	2,872	2,917	101	3.6%
Fossil Energy & Carbon Management	11,304	11,304	15,154	3,850	34.1%
Legacy Management	2,433	2,433	2,675	242	9.9%
Naval Reactors	1,157	1,157	1,141	-16	-1.4%
Nuclear Energy	149,800	149,800	156,600	6,800	4.5%
Science	121,000	121,000	189,510	68,510	56.6%
Specialized Security Activities	283,500	283,500	306,067	22,567	8.0%
Strategic Petroleum Reserve	25,262	25,262	26,325	1,063	4.2%
Title 17: Loan Guarantee Program	388	338	353	-35	-9.0%
Weapons Activities	1,365,551	1,365,600	1,441,531	75,980	5.6%
Total, Program S&S	**2,454,475**	**2,454,757**	**2,654,877**	**200,402**	**8.2%**

Table 3: S&S Funding by Functional Cost Element ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
S&S by Functional Cost Element					
Cybersecurity	457,358	456,879	488,365	31,007	6.8%
Headquarters S&S	283,500	283,500	306,067	22,567	8.0%
Information Security	81,680	83,180	92,031	10,351	12.7%
Material Control and Accountability	46,836	47,707	60,941	14,105	30.1%
Personnel Security	81,269	76,379	86,085	4,816	5.9%
Physical Security Systems	170,354	171,854	214,014	43,660	25.6%
Program Management	148,711	147,693	139,171	-9,540	-6.4%
Protective Forces	774,599	788,250	863,815	89,216	11.5%
Security Infrastructure	51,506	40,506	48,512	-2,994	-5.8%
Security Investigations	9,763	9,910	9,578	-185	-1.9%
Transportation Security	348,899	348,899	346,298	-2,601	-0.7%
Total, Functional S&S	**2,454,475**	**2,454,757**	**2,654,877**	**200,402**	**8.2%**

Protective Forces
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Protective Forces					
Defense Environmental Cleanup	188,572	188,572	192,648	4,076	2.2%
Energy Efficiency and Renewable Energy	3,215	3,215	3,600	385	12.0%
Environment, Health, Safety and Security	33,303	33,303	40,000	6,697	20.1%
Fossil Energy & Carbon Management	3,072	3,072	3,164	92	3.0%
Legacy Management	649	649	670	21	3.2%
Nuclear Energy	71,705	85,356	88,497	16,792	23.4%
Science	44,200	44,200	50,000	5,800	13.1%
Strategic Petroleum Reserve	19,113	19,113	19,690	577	3.0%
Weapons Activities	410,770	410,770	465,546	54,776	13.3%
Total, Protective Forces	**774,599**	**788,250**	**863,815**	**89,216**	**11.5%**

Mission

The Protective Forces element of field and headquarters S&S provides funding to protect the Department's critical assets, which include nuclear weapons in DOE custody, nuclear weapons components, special nuclear materials, classified information, and DOE facilities against a spectrum of threats, including terrorist activity, sabotage, espionage, theft, diversion, loss, or unauthorized use.

Protective Force programs throughout the complex provide for personnel salaries, wages, and benefits for personnel; management and supervision; and well-maintained and logically deployed equipment and facilities to ensure effective performance of assigned functions and tasks under normal and emergency conditions.

Protective Forces programs include the conduct of access control and security response operations; the physical protection of special nuclear material, classified matter and information, and government property; emergency response forces and tactical assistance during events as well as an on-scene security commander; random patrols; coordination with local law enforcement and protective force elements aimed at providing effective response to emergency situations; random prohibited article inspections; security alarm monitoring and dispatch services; the collection and destruction of classified matter; and testing of the protective force to respond to various event scenarios.

Protective Forces programs maintain a Special Response Team capability to provide resolution of incidents that require effective and timely response with force options that exceed the capability of front-line protective force personnel. This includes prevention, recapture and recovery operations involving the use of special weapons systems and tactics to prevent access to special nuclear material or effect recovery from unauthorized control.

Highlight:

- For Weapons Activities, increase reflects additional security requirements associated with growth across the nuclear security enterprise, in particular the plutonium pit production mission at Los Alamos National Laboratory.

Physical Security Systems
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Physical Security Systems					
Defense Environmental Cleanup	28,504	28,504	28,600	96	0.3%
Energy Efficiency and Renewable Energy	815	815	925	110	13.5%
Environment, Health, Safety and Security	7,379	7,379	6,238	-1,141	-15.5%
Fossil Energy & Carbon Management	1,195	1,195	171	-1,024	-85.7%
Legacy Management	120	120	127	7	5.8%
Nuclear Energy	10,075	11,575	12,203	2,128	21.1%
Science	20,180	20,180	34,260	14,080	69.8%
Strategic Petroleum Reserve	1,051	1,051	1,141	90	8.6%
Weapons Activities	101,035	101,035	130,349	29,314	29.0%
Total, Physical Security Systems	**170,354**	**171,854**	**214,014**	**43,660**	**25.6%**

Mission

The Physical Security Systems element of field and headquarters S&S provides for the physical protection of special nuclear material and equipment, sensitive information, Departmental property, and unclassified facilities. Included are buildings, fences, barriers, lighting, sensors, surveillance devices, entry control devices, access control systems, explosive detection systems, power systems and other real property and hardware designed for or affecting security. This hardware and equipment are operated and used to support the protection of DOE property and other interests of national security.

Security Systems programs support DOE-wide efforts required to conduct performance assurance testing. These programs also ensure that security alarm systems are operational and functioning in accordance with applicable DOE requirements. Physical Security System programs are also responsible for two subprograms: (1) a barriers, secure storage, and lock program to restrict, limit, delay or deny entry into a designated area; and (2) an entry control and access program that provides positive identification of personnel requiring access to facilities and initial access to facilities in general, ensuring that persons entering or leaving facilities are authorized, and do not introduce prohibited articles into or remove Government property from Departmental facilities.

The budget estimates include all access control administrative activity involving production, accountability and destruction of access authorization badges and firearms credentials. They also include systems components and tamper-safe oversight by monitoring and responding to alarms, determining access, and securing all alarmed structures on site. In addition, this element provides for handling all radio communications for the protection of the facilities.

Highlight:

- For Science, the increase will support the first stages of implementation of HSPD-12 for uncleared long-term contractor personnel and the associated modernization of personnel access control systems. These systems also mitigate active shooter and workplace violence, as well as providing control and compartmentalization of classified matter, intellectual property, sensitive information, and hazardous materials.
- For Weapons Activities, the increase is associated with mission growth across the nuclear security enterprise (NSE) including pit production and UPF preparation efforts.

Information Security
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Information Security					
Defense Environmental Cleanup	5,911	5,911	5,447	-464	-7.8%
Energy Efficiency and Renewable Energy	515	515	575	60	11.7%
Environment, Health, Safety and Security	13,679	13,679	13,679	0	0.0%
Fossil Energy & Carbon Management	319	319	163	-156	-48.9%
Legacy Management	71	71	72	1	1.4%
Nuclear Energy	4,674	6,174	5,016	342	7.3%
Science	4,420	4,420	5,010	590	13.3%
Strategic Petroleum Reserve	231	231	238	7	3.0%
Weapons Activities	51,860	51,860	61,831	9,971	19.2%
Total, Information Security	**81,680**	**83,180**	**92,031**	**10,351**	**12.7%**

Mission

The Information Security element of field and headquarters S&S ensures that material and documents that may contain sensitive and classified information are accurately and consistently identified, properly reviewed for content, appropriately marked, and protected from unauthorized disclosure, and ultimately destroyed in an approved manner.

Information Security programs provides for plans, policies, procedures, and training to ensure that all employees are aware of the requirements for the identification, review, classification, declassification, marking, protection and proper disposal of sensitive information and classified material. In addition, operational security considerations are used to preclude inadvertent compromise of classified material.

Highlight:

For Weapons Activities, the increase in Information Security is associated with mission growth including pit production and UPF preparation efforts.

Cybersecurity

Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Field Cybersecurity*					
Science	37,520	37,520	81,260	43,740	116.6%
Weapons Activities (NNSA)[a]	251,472	251,472	215,451	-36,021	-14.32%
Defense Environmental Cleanup	41,460	41,460	30,299	-11,161	-26.9%
Nuclear Energy	20,476	19,812	23,916	3,440	16.8%
Energy Efficiency and Renewable Energy	7,200	7,200	9,200	2,000	27.8%
Fossil Energy & Carbon Management	5,022	4,772	9,678	4,656	92.7%
Strategic Petroleum Reserve	2,664	2,664	3,144	480	18.0%
Legacy Management	1,183	1,183	1,383	200	16.9%
Total, Cybersecurity	**366,997**	**366,083**	**374,331**	**7,334**	**2.0%**

*Cybersecurity amounts shown do not include Working Capital Fund or Energy Information Technology System contributions

Cybersecurity (including Headquarters Offices)					
Field Cybersecurity	**366,997**	**366,083**	**374,331**	**7,334**	**2.0%**
Headquarters Cybersecurity	**90,361**	**90,796**	**114,034**	**23,673**	**26.2%**
Fossil Energy & Carbon Management (HQ only)	920	1,170	1,300	380	41.3%
Loan Program Office	288	288	303	15	5.2%
Enterprise Assessments	9,335	9,335	9,335	0	0.0%
Energy Information Administration	920	1,105	1,405	485	52.7%
Environment, Health, Safety and Security	5,688	5,688	5,830	142	2.5%
Chief Financial Officer	1,410	1,410	3,500	2,090	148.2%
Chief Information Officer	71,800	71,800	92,361	20,561	28.6%
Total, Cybersecurity (Field & HQ)	**457,358**	**456,879**	**428,365**	**31,007**	**6.8%**

Mission

The Cybersecurity element of field and headquarters S&S improves the nation's cybersecurity and protects the federal government networks, in line with Executive Order 14028, Improving the Nation's Cybersecurity. Recent cybersecurity incidents such as SolarWinds, Microsoft Exchange, and the Colonial Pipeline incident are a sobering reminder that U.S. public and private sector entities increasingly face sophisticated malicious cyber activity from both nation-state actors and cyber criminals. These incidents share commonalities, including insufficient cybersecurity defenses that leave public and private sector entities more vulnerable to incidents.

In FY 2023, the Department of Energy is making significant contributions toward modernizing cybersecurity defenses by protecting federal networks, improving information-sharing between the U.S. government and the private sector on cyber issues, and strengthening the United States' ability to respond to incidents when they occur. Investments in Cybersecurity at the Department will focus on the following key areas, as identified in EO 14028:

- Remove Barriers to Threat Information Sharing Between Government and the Private Sector. Ensure that IT Service Providers can share information with the government and require them to share certain breach information. Removing any contractual barriers and requiring providers to share breach information that could impact Government networks is necessary to enable more effective defenses of Federal departments, including DOE, and to improve the Nation's cybersecurity.

- Modernize and Implement Stronger Cybersecurity Standards. Help move DOE enterprise to secure cloud services and a zero-trust architecture, and mandate deployment of multifactor authentication and encryption within a specific time period. Outdated security models and unencrypted data have led to compromises of systems in the

[a] The reduction in Weapons Activities cybersecurity funding reflects a reclassification of certain initiatives from the Cybersecurity program to the Information Technology subprogram to better display pure cybersecurity funding.

public and private sectors. DOE will increase its adoption of security best practices, by accelerating movement to a zero-trust security model and secure cloud services, and consistently deploying foundational security tools such as multifactor authentication and encryption.

- Improve Software Supply Chain Security. Continue to mature and expand the Information and Communication Technology Supply Chain Risk Management Program to improve the security of software and hardware. Too much of our hardware and critical software is shipped with significant vulnerabilities that our adversaries exploit.

- Improve Investigative and Remediation Capabilities. Improve cybersecurity threat hunting and response through improved logging and data analytics. Create cybersecurity event log and data retention requirements for DOE enterprise. Modernized perimeter sensors, improved data storage and search capabilities will improve the organization's ability to detect intrusions, mitigate those in progress, and determine the extent of an incident after the fact.

The amounts given here are program funds and do not include security elements that are within software applications developed for the Department's programmatic or administrative purposes, whether directly or indirectly funded. They do include IT Security and Compliance entries within the IT Investment portfolio. Highlights of cybersecurity activities can be found within the individual program budget requests.

Field Cybersecurity Highlights:

- Increase for Science 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 and to strengthen protection at federal and M&O sites in the areas of: Cyber Threat Intelligence, Incident Response, Incident Recovery, Novel Security Techniques, Infrastructure Refresh, Industrial Control System Protection, Continuous Diagnostics and Mitigation, and Controlled Unclassified Information Protection. Additionally, the Request will continue implementation of Executive Order 14028 requirements at both federal and Management & Operating contract sites.

Headquarters (HQ) Cybersecurity Highlights:

- Increase for Chief Information Officer reflects dedicated cyber reserve fund for the entire DOE complex to address requirements of Executive Order 14028 Improving the Nation's Cybersecurity.

Personnel Security
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Personnel Security					
Defense Environmental Cleanup	12,647	12,647	11,792	-855	-6.8%
Energy Efficiency and Renewable Energy	215	215	240	25	11.6%
Environment, Health, Safety and Security	6,442	6,442	6,192	-250	-3.9%
Fossil Energy & Carbon Management	285	285	358	73	25.6%
Legacy Management	75	75	76	1	1.3%
Nuclear Energy	9,554	4,714	5,593	-3,961	-41.5%
Science	5,500	5,500	8,480	2,980	54.2%
Strategic Petroleum Reserve	661	661	561	-100	-15.1%
Title 17: Loan Guarantee Program	100	50	50	-50	-50.0%
Weapons Activities	45,790	45,790	52,743	6,953	15.2%
Total, Personnel Security	**81,269**	**76,379**	**86,085**	**4,816**	**5.9%**

Mission

The Personnel Security element of field and headquarters S&S supports the access authorization program and ensures security sensitivity through security briefings such as the initial refresher and termination briefings, re-orientations, computer-based training, special workshops and classes, publications, closed circuit television programs, signs, posters, and special event days. Support for the access authorization program includes: (1) personnel security assurance program, adjudications, screening, and analysis of personnel security cases for determining eligibility for access authorizations, administrative reviews, and handling of Freedom of Information Act and Privacy Act requests related to security access authorizations; (2) security awareness and education; and (3) activities associated with classified and unclassified visits and assignments by foreign nationals.

Highlights:

- For Weapons Activities, the increase reflects additional security requirements associated with mission growth across the nuclear security enterprise, in particular the plutonium pit production mission at Los Alamos National Laboratory and UPF preparation efforts.
- For Science, the increase will provide additional FTEs to support the increased HSPD-12 access authorization functions and the increased functions for the increased processing and vetting of foreign nationals.
- For Nuclear Energy, decrease reflects the implementation of full cost recovery for security clearance activities by requesting program organizations.

Material Control and Accountability
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Material Control and Accountability					
Defense Environmental Cleanup	7,176	7,176	6,735	-441	-6.1%
Nuclear Energy	5,505	6,376	5,825	320	5.8%
Science	2,465	2,465	2,800	335	13.6%
Weapons Activities	31,690	31,690	45,581	13,891	43.8%
Total, Material Control and Accountability	**46,836**	**47,707**	**60,941**	**14,105**	**30.1%**

Mission

The Material Control and Accountability (MC&A) element of field S&S provides assurance that nuclear materials are properly controlled and always accounted for. MC&A provides evidence that all nuclear materials are accounted for appropriately and that theft, diversion, or operational loss has not occurred. MC&A also supports weapons production, nuclear nonproliferation, nuclear materials operations, facility closure, and nuclear critical safety by determining and documenting the amounts of nuclear materials in weapons and packaged items. MC&A administration includes the following: (1) assessing the levels of protection, control and accounting required for the types and quantities of materials at each facility; (2) documenting facility plans for nuclear materials control and accounting; (3) assigning authorities and responsibilities for MC&A functions; (4) ensuring that facility MC&A personnel are trained and qualified to perform their responsibilities; (5) establishing programs to report occurrences such as nuclear material theft, the loss of control or inability to account for nuclear materials, or evidence of malevolent acts; (6) conducting performance testing of required program elements; and (7) establishing facility programs to conduct and document internal assessments of their operations and MC&A programs.

Highlight:

- For Weapons Activities, the increase is associated with mission growth across NNSA's NSE, including for pit production and UPF preparation efforts.

Program Management
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Program Management*					
Defense Environmental Cleanup	25,742	25,742	26,231	489	1.9%
Energy Efficiency and Renewable Energy	820	820	720	-100	-12.2%
Environment, Health, Safety and Security	5,940	5,940	7,591	1,651	27.8%
Fossil Energy & Carbon Management	491	491	320	-171	-34.8%
Legacy Management	335	335	347	12	3.6%
Nuclear Energy	11,193	10,175	11,450	257	2.3%
Science	6,715	6,715	7,700	985	14.7%
Strategic Petroleum Reserve	1,542	1,542	1,551	9	0.6%
Weapons Activities	95,933	95,933	83,261	-12,672	-13.2%
Total, Program Management	**148,711**	**147,693**	**139,171**	**-9,540**	**-6.4%**

* In Weapons Activities, titled, *Security Program Operations and Planning.*

Mission

The Program Management element of field and headquarters S&S develops the framework for efficient and effective security operations. This includes the development and updating of S&S plans, conducting vulnerability assessments to determine if assets are at risk, modeling to ensure the plans and operations meet mission objectives, identifying assets that need protection, developing local threat assessments and participating in the S&S quality panel process and security education. In addition, these programs ensure that plans are developed and revised in accordance with DOE requirements, professional and technical training is administered, and Departmental S&S goals and objectives are implemented complex wide.

The programs develop S&S plans or other applicable security plans and implement S&S requirements, conduct surveys to determine whether S&S requirements have been implemented, respond to national and local threats, and perform a vulnerability analysis that measures the risk of S&S assets. Program Management includes participation in the quality panel process, which raises issues from the field to the headquarters managers and ensures that the staff is properly educated in security matters.

Highlight:

- For Weapons Activities, the decrease is due to use of estimated available uncosted uncommitted funding, inclusive of SPP recoveries offset by an increase in requirements associated with growth across the nuclear security enterprise (NSE), including plutonium pit production and UPF preparation efforts.

Security Investigations
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Security Investigations*					
Defense Environmental Cleanup	1,656	1,656	1,464	-192	-11.6%
Defense Nuclear Nonproliferation	294	336	350	56	19.0%
Energy Efficiency and Renewable Energy	170	170	190	20	11.8%
Enterprise Assessments	170	170	200	30	17.6%
Environment, Health, Safety and Security	1,183	1,183	900	-283	-23.9%
Federal Salaries and Expenses	2,816	2,872	2,917	101	3.6%
Naval Reactors	1,157	1,157	1,141	-16	-1.4%
Weapons Activities	2,317	2,366	2,416	99	4.3%
Total, Security Investigations	**9,763**	**9,910**	**9,578**	**-185**	**-1.9%**

*NE and SC Security Investigations costs for Federal Employees are subsumed within Personnel Security.

Mission

The Security Investigations element of field and headquarters S&S funds background investigations associated with providing access authorizations (security clearances) to DOE Federal and contract personnel who, in the performance of their official duties, require access to classified information or certain quantities of special nuclear material. Background investigations are required by Section 145 of the Atomic Energy Act of 1954, as amended, and Executive Order 12968, Access to Classified Information. The investigations are performed, and access authorizations granted based on 10 C.F.R. 710, Criteria and Procedures for Determining Eligibility for Access to Classified Matter or Special Nuclear Material. Funding provides for initial single scope background investigations, periodic reinvestigations, and initial and reinvestigation national agency checks.

Highlight:

- No major changes in Security Investigations funding from FY 2021 Enacted to the FY 2023 Request.

Transportation Security
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Transportation Security					
Defense Environmental Cleanup	215	215	965	750	348.8%
Weapons Activities	348,684	348,684	345,333	-3,351	-1.0%
Total, Transportation Security	**348,899**	**348,899**	**346,298**	**-2,601**	**-0.7%**

Mission

Transportation security provides for the secure transport of weapons, weapons components, and nuclear materials to support Stockpile Management and consolidation and disposition of nuclear material within the complex; to meet DOE, DOD, and other customer requirements. This functional component of S&S is funded primarily within NNSA's Secure Transportation Asset (STA) Program.

STA provides safe and secure shipments for Weapons Activities and other Department elements requiring this capability. The STA program supports Departmental initiatives to convert weapons-grade material for use or disposal. STA supports other DOE programs, including Environmental Management; and others, including the National Aeronautics and Space Administration, and international shipments in cooperation with Canada, the United Kingdom, and France.

Highlight:

- For Weapons Activities, the decrease reflects the procurement of a replacement aircraft in FY 2021, offset by increases for the Mobile Guardian Transporter (MGT) and for Program Direction.

Security Infrastructure/Construction
Funding Schedule ($K)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	$ Change FY23 vs. FY21	% Change FY23 vs. FY21
Security Infrastructure/Construction					
Defense Environmental Cleanup	8,888	8,888	5,392	-3,496	-39.3%
Nuclear Energy	16,618	5,618	4,100	-12,518	-75.3%
Weapons Activities	26,000	26,000	39,020	13,020	50.1%
Total, Security Infrastructure/Construction	**51,506**	**40,506**	**48,512**	**-2,994**	**-5.8%**

Mission

Security Infrastructure provides critical security infrastructure investments and protection enhancements necessary to ensure adequate protection of DOE sites and personnel.

Highlights:

- For Weapons Activities, the increase reflects SIRP projects to be executed that include sensor, camera, lighting, and communication refreshes, and smaller capital equipment projects.
- For Nuclear Energy, decrease reflects the required project funds for Phase IIB offset by the completion of the consolidated training facility at the Central Facilities Area.

Research and Development Crosscut

(dollars in thousands)

R&D and Related Equipment and Construction	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Basic Research	5,540,345	5,646,297	6,319,228	+778,883	+14%
Applied Research	5,649,489	5,704,772	6,834,055	+1,184,566	+21%
Development	3,714,950	3,730,247	5,392,865	+1,677,915	+45%
Subtotal, Research and Development	**14,904,784**	**15,081,316**	**18,546,147**	**+3,641,363**	**+24%**
R&D Related Construction	2,044,279	1,910,067	1,930,039	-114,241	-5.6%
R&D Related Equipment	-828,954	1,889,956	1,481,372	+2,310,326	-279%
Subtotal, R&D and Related Facilities	**1,215,325**	**3,800,023**	**3,411,411**	**+2,196,085**	**+181%**
Total, R&D and Related Equipment and Construction	**16,120,109**	**18,881,339**	**21,957,558**	**+5,837,449**	**+36%**

Summary

The FY 2023 Request includes an overall increase of $5.8 billion (or 36 percent) in Research and Development (R&D) and Related Equipment and Construction compared with FY 2021 Enacted. The increase in Development of $1.7 billion (or 45 percent) reflects the emphasis on moving R&D efforts through the technology transfer chain to meet the "build back better" goal.

The Department has identified challenging goals in the effort to avoid the worst effects of anthropogenic climate change and mitigate the effects of changes that can no longer be avoided. These goals towards decarbonization across all segments of the economy will be managed across the Department through crosscutting activities, enabling synergies that can be developed only through the collaboration and coordination of multiple Department offices. Each R&D related crosscut is described in its own section in the budget justification and new crosscuts have been added in response to the Administration goal of a carbon free economy by 2050 through a concerted effort in transportation, agriculture, industry, and electric power generation. Each DOE office has contributions to the overall success of our R&D efforts. These are summarized as follows.

Office of Science (SC) 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; and basic research for advancement in new energy technologies. The SC FY 2023 Request increases investments in Administration priorities including basic research on climate change and clean energy, artificial intelligence (AI) and machine learning (ML), and biopreparedness. SC's Reaching a New Energy Sciences Workforce (RENEW) initiative doubles to expand targeted efforts to increase participation and retention of underrepresented groups in SC research activities. SC initiates three new research initiatives to include Energy Earthshots; Funding for Accelerated, Inclusive Research (FAIR); and Accelerate Innovations in Emerging Technologies (Accelerate). The Request also supports ongoing investments in priority areas including microelectronics, critical materials, quantum information science (QIS), exascale computing, fundamental science to transform manufacturing, and accelerator science and technology. These initiatives position SC to address new research opportunities through more collaborative, cross-program efforts.

The SC portfolio has two principal thrusts: direct support of scientific research and direct support of the design, development, construction, and operation of unique, open-access scientific user facilities. The SC basic research portfolio includes extramural grants and contracts supporting nearly 29,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. The portfolio of 28 scientific user facilities serves nearly 34,000 users per year. SC programs invest in foundational science, including basic research for the advancement of clean energy, to transform our understanding of nature and strengthen the connection between advances in fundamental science and technology innovation.

Energy Efficiency and Renewable Energy (EERE) accelerates the research, development, demonstration, and deployment (RDD&D) of technologies and solutions to equitably transition America to net-zero greenhouse gas emissions economy-wide by no later than 2050, creating good paying jobs, and ensuring the clean energy economy benefits all Americans, especially

workers and communities impacted by the energy transition and those historically underserved by the energy system and overburdened by pollution. To achieve this mission, EERE is increasing investment in the integration of clean energy technologies that are ready to be demonstrated and deployed, as well as R&D activities that advance early-stage technologies with a clear path to deployment. EERE's FY 2023 investment strategy focuses on investments in five priority areas central to the U.S. greenhouse gas profile: decarbonizing the electricity sector; decarbonizing transportation across all modes: air, sea, rail, and road; decarbonizing energy-intensive industries; reducing the carbon footprint of buildings; and decarbonizing the agriculture sector, including a focus on the energy-water nexus**.** The Request prioritizes increased investments in these priority areas critical to reduce emissions in the near term drastically, while investing in research to ensure American leadership and competitiveness in advanced clean energy technology.

Office of Cybersecurity, Energy Security, and Emergency Response (CESER) seeks to accelerate and expand efforts to strengthen the nation's energy sector against cyber threats and mitigate vulnerabilities. CESER's R&D investments aim to bolster critical infrastructure capabilities by developing game-changing cybersecurity risk management tools, technologies, methodologies, and guidance that aid the energy sector in securing energy infrastructure for the present and future. These tools and technologies will help energy industry identify, protect, detect, respond, and recover in the face of increasingly advanced cyber threats. CESER has instituted coordination and integration of cybersecurity requirements in research and development efforts across DOE's science and energy programs, building cybersecurity into the energy delivery system components. CESER will supplement these efforts with development, demonstration and deployment of crosscutting tools leveraging emerging technologies and techniques such as machine learning, underlying data from cyber-physical systems, and quantum information sciences. CESER has also expanded its scope to include RD&D to address risks to the energy sector from non-cyber hazards such as physical attack and impacts of climate change, e.g., increased wildfires and severe hurricanes. CESER will develop tools that help with risk characterization and analysis and enable early detection and mitigation of these risks.

Office of Electricity (OE) supports R&D for new technologies to strengthen, transform, and improve electricity delivery infrastructure so consumers have access to resilient, secure, and clean sources of electricity. OE provides solutions to technical, market, institutional, and operational failures that go beyond any one utility's ability to solve. OE works to ensure that our Nation's electricity delivery system can accommodate all the changes at generation and load sides of the grid and ensure reliable, resilient, and secure operations of the decarbonized electric grid.

Nuclear Energy (NE) supports efforts to move to new and innovative advanced reactors, small modular reactors, and microreactors from the conceptual and development stages into the commercial energy sector. NE executes its mission through investments in early-stage research and development efforts with the national laboratories, U.S. universities, and industry technical organizations, as well as through partnerships with the U.S. industry and commercial stakeholders to develop and demonstrate advanced reactor technologies and designs. NE focuses on three major mission areas: the nation's existing reactors, the development of advanced nuclear reactor concepts, and fuel cycle technologies. Investments in these areas leverage the tremendous innovation capacity of the United States' National Laboratories, universities, and advanced reactor developers to transform America's power sector. Safe and secure nuclear energy delivers carbon-free power continuously, with high reliability, over long periods of time. NE will leverage creative funding mechanisms - such as prizes, competitions, technical assistance, and programs targeted to small businesses; thereby enabling the commercialization of climate change and clean energy innovations that will activate job creation, expanding other public impact outcomes, and yielding a more geographically diverse and impactful research portfolio.

Fossil Energy and Carbon Management (FECM) supports increased funding for a revitalized perspective on fossil energy that advances carbon reduction and mitigation in sectors and applications that are difficult to decarbonize, including the industrial sector, with technologies and methods such as carbon capture and storage, hydrogen, and direct air capture—all while ensuring that overburdened communities are protected from increases in cumulative pollution. The Request will fund DOE's role in supporting the new Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization. The FECM Request will help fulfill President Biden's 'build back better' objective in a way that supports communities left behind, workers translating their skills to new positions in various areas, such as, building carbon capture and hydrogen systems on existing industrial and power plant facilities, and reinforcing existing pipelines to minimize methane emissions. FECM's Request, its new name indicative of a new approach responsive to its research imperatives, shows increases for Point-Source Carbon Capture, Carbon Dioxide Conversion, Carbon Transport and Storage, and Carbon Dioxide Removal.

Research and Development Crosscut

Advanced Research Projects Agency – Energy (ARPA-E) supports the delivery of innovative, investable opportunities to the commercial sector. ARPA-E will continue to deliver value to the U.S. economy with continued emphasis on maintaining a diverse portfolio of projects. The Department proposes to expand ARPA-E's scope to include R&D on climate adaptation and resilience innovations. This will enable work beyond the energy technology-focused projects necessary to meet the Administration's goals to adapt and strengthen resilience from the most devastating impacts of climate change.
ARPA-E projects cover a broad range of advanced technology topics, with a growing focus on additional scale-up of the most promising projects that have demonstrated success in technical development, project management, and definition of commercial pathways. ARPA-E executes its budget through funding opportunity announcements that address applications that are not represented in its present portfolio and develops new opportunities opened by the outcomes of previous programs.

Office of Clean Energy Demonstrations (OCED) supports activities to accelerate and prove the design, construction, and operation of high-impact demonstration projects, at or near a commercial-scale, with the purpose of generating publicly available technical, economic, and environmental performance data essential to developers, financiers, regulators, policymakers, utilities, manufacturers, end users and other stakeholders. OCED investments are part of a clear progression and transition between the research, development, and laboratory and pilot-scale demonstration projects within DOE technology offices and initial full and commercial-scale deployments supported by the private sector or other programs, such as the Loan Programs Office, ensuring coherent strategies for advancing and deploying clean energy technologies and systems. Funding decisions are made to support scalable outcomes that lead to commercialization and deployment. In FY 2023, OCED will initiate a new competition in FY 2023 to support commercial-scale projects that demonstrate technologies, or the manufacturing of technologies that integrate renewable and distributed energy systems with broader energy networks. The goal of this new investment area is to support demonstrations that de-risk technologies needed to manage variable generation; control flexible loads; and integrate energy storage electric vehicle (EV) charging, and other facilities into the U.S. transmission and distribution grids.

National Nuclear Security Administration contributes directly and crucially to U.S. nuclear security R&D by supporting key investments in science and technology innovation that support the stewardship of the nuclear weapons stockpile, modernize the nuclear security enterprise, protect the United States from weapons of mass destruction threats, enable science-based certification of the stockpile, and provide the U.S. Navy with nuclear reactors that meet complex evolving requirements.

Administrative and Support Functions: The Department's funding estimates of R&D activities include those administrative and support functions that are necessary to the success of the R&D programs consistent with government-wide and international reporting practices. These include program direction, safeguards and security, and infrastructure costs. The following table details funding of R&D in the budget by categories; basic, applied, development, equipment, and related construction; and program office.

Research and Development Crosscut

(dollars in thousands)

Basic Research	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Cybersecurity, Energy Security, and Emergency Response	5,139	2,250	0	-5,139	-60%
Defense Nuclear Nonproliferation	158,215	157,596	179,084	+20,869	+13%
Electricity	14,146	14,146	15,185	+1,039	+7%
Science	5,362,845	5,472,305	6,124,959	+762,114	+14%
Subtotal, Basic Research	**5,540,345**	**5,680,297**	**6,373,043**	**+828,883**	**+15%**

(dollars in thousands)

Applied Research	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Advanced Research Projects Agency--Energy	213,500	213,500	350,075	+136,575	+64%
Bonneville Power Administration Fund	2,000	1,000	1,000	-1,000	-50%
Cybersecurity, Energy Security, & Emergency Response	48,120	32,237		-48,120	-100%
Defense Environmental Cleanup (EM)	11,500	11,500	8,214	-3,286	-29%
Defense Nuclear Nonproliferation	195,197	164,212	203,806	+8,609	+4%
Electricity	56,453	56,453	86,119	+29,666	+53%
Energy Efficiency and Renewable Energy	676,784	676,784	1,046,682	+369,898	+55%
Fossil Energy and Carbon Management	691,633	691,633	841,230	+149,597	+22%
Global Clean Energy Manufacturing	-	-	20,000	+20,000	N/A
Nuclear Energy	770,756	770,756	1,096,648	+325,892	+42%
Weapons Activities	2,983,546	3,086,697	3,180,281	+196,735	+7%
Subtotal, Applied Research	**5,649,489**	**5,704,772**	**6,834,055**	**+1,184,566**	**+21%**

(dollars in thousands)

Development	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Advanced Research Projects Agency--Energy	213,500	213,500	350,075	+136,575	+64%
Bonneville Power Administration Fund	1,000	1,000	1,000	-	N/A
Cybersecurity, Energy Security, & Emergency Response	11,664	26,990	220,000	+208,336	+1,786%
Defense Environmental Cleanup (EM)	23,500	23,500	16,786	-6,714	-29%
Defense Nuclear Nonproliferation	114,819	105,325	124,835	+10,016	+9%
Electricity	75,587	75,587	84,588	+9,001	+12%
Energy Efficiency and Renewable Energy	1,378,725	1,378,725	2,106,555	+727,830	+53%
Global Clean Energy Manufacturing	-	-	34,000	+34,000	N/A
Naval Reactors	1,140,270	1,140,270	1,312,770	+172,500	+15%
Nuclear Energy	258,926	258,926	338,365	+79,439	+31%
Office of Clean Energy Demonstrations	-	-	167,000	+167,000	N/A
Weapons Activities	496,959	506,424	636,891	+139,932	+28%
Subtotal, Development	**3,714,950**	**3,730,247**	**5,392,865**	**+1,677,915**	**+45%**

Research and Development Crosscut

(dollars in thousands)

R&D Construction	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Electricity	25,137	25,137	-	-25,137	-100%
Defense Nuclear Nonproliferation	24,481	24,481	26,164	+1,682	+7%
Energy Efficiency and Renewable Energy	40,000	61,000	119,000	+79,000	+198%
Manufacturing and Energy Supply Chains	-	-	18,000	+18,000	N/A
Naval Reactors	330,000	330,000	455,265	+125,265	+38%
Nuclear Energy	37,000	37,000	7,300	-29,700	-80%
Science	1,343,109	1,187,956	1,221,513	-121,596	-9%
Weapons Activities	244,552	244,493	82,797	-161,756	-66%
Subtotal, R&D Related Facilities	**2,044,279**	**1,910,067**	**1,930,039**	**-114,241**	**-5.6%**

(dollars in thousands)

R&D Equipment	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Advanced Technology Vehicles Manufacturing Loan Program Account	-1,893,000	-	-	+1,893,000	-100%
Bonneville Power Administration Fund	267,000	267,000	267,000	-	N/A
Construction, Rehabilitation, Operation & Maintenance, Western Area Power Administration	5,000	3,000	9,000	+4,000	+80%
Construction, Rehabilitation, Office of Nuclear Energy	37,000	37,000	7,300	-29,700	-80%
Defense Nuclear Nonproliferation	24,500	24,500	26,164	+1,664	+7%
Energy Efficiency and Renewable Energy	-	39,000	-	-	N/A
Federal Energy Management Program	-	-	117,000	+117,000	N/A
Fossil Energy and Carbon Management	29,000	29,000	25,000	-4,000	-14%
Naval Reactors	1,000	1,000	25,100	+24,100	2,410%
Operation and Maintenance, Southwestern Power Administration	10,000	10,000	11,000	+1,000	+10%
Title 17 Innovative Technology Loan Guarantee Program	-96,000	22,000	150,000	+246,000	-256%
Transmission Facilitation Fund	-	380,000	-	-	N/A
Science	238,706	239,739	246,988	+8,282	+3%
Weapons Activities	547,840	437,717	396,820	-151,020	-28%
Western Area Power Administration, Borrowing Authority, Recovery Act	-	400,000	200,000	+200,000	N/A
Subtotal, Major Equipment	**-828,954**	**1,889,956**	**1,481,372**	**+2,310,326**	**-279%**

Research and Development Crosscut

(dollars in thousands)

R&D and Related Equipment & Construction	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs FY 2021	% Change
Advanced Technology Vehicles Manufacturing Loan Program Account	-1,893,000	-	-	+1,893,000	-100%
Advanced Research Projects Agency--Energy	427,000	427,000	700,150	+273,150	64%
Bonneville Power Administration Fund	270,000	269,000	269,000	-1,000	-0.4%
Construction, Rehabilitation, Operation & Maintenance, Western Area Power Administration	5,000	3,000	9,000	+4,000	+80%
Construction, Rehabilitation, Office of Nuclear Energy	37,000	37,000	7,300	-29,700	-80%
Cybersecurity, Energy Security, & Emergency Response	64,923	61,477	220,000	+155,077	+239%
Defense Environmental Cleanup (EM)	35,000	35,000	25,000	(10,000)	-29%
Defense Nuclear Nonproliferation	517,212	476,114	560,053	+42,840	+8%
Electricity	171,323	171,323	185,892	+14,569	+9%
Energy Efficiency and Renewable Energy	2,095,509	2,155,509	3,272,237	+1,176,728	+56%
Federal Energy Management Program	-	-	117,000	+117,000	N/A
Fossil Energy and Carbon Management	720,633	720,633	866,230	+145,597	+20%
Global Clean Energy Manufacturing	-	-	54,000	+54,000	N/A
Manufacturing and Energy Supply Chains	-	-	18,000	+18,000	N/A
Naval Reactors	1,471,270	1,471,270	1,793,135	+321,865	+22%
Nuclear Energy	1,066,682	1,066,682	1,442,313	+375,631	+35%
Office of Clean Energy Demonstrations	-	-	167,000	+167,000	N/A
Operation and Maintenance, Southwestern Power Administration	10,000	10,000	11,000	+1,000	+10%
Title 17 Innovative Technology Loan Guarantee Program	-96,000	22,000	150,000	+246,000	-256%
Transmission Facilitation Fund	-	380,000	-	-	N/A
Science	6,944,660	6,900,000	7,593,460	+648,800	+9%
Weapons Activities	4,272,898	4,275,331	4,296,789	+23,892	+1%
Western Area Power Administration, Borrowing Authority, Recovery Act	-	400,000	200,000	+200,000	N/A
R&D and Related Equipment & Construction	**16,120,109**	**18,881,339**	**21,957,558**	**+5,837,449**	**+36%**

Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR)

(dollars in thousands)

SBIR/STTR	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 vs. FY 2021	% Change
Advanced Research Projects Agency-Energy	14,308	14,308	23,470	+9,162	+64%
Cybersecurity, Energy Security & Emergency Management	1,077	1,276	912	-165	-15%
Defense Environmental Cleanup	1,278	1,278	1,022	-256	-20%
Defense Nuclear Nonproliferation	13,202	13,975	14,705	+1,503	+11%
Electricity	4,646	4,646	6,151	+1,505	+32%
Energy Efficiency and Renewable Energy	80,472	68,102	102,180	+21,708	+27%
Fossil Energy and Carbon Management	15,226	15,226	19,733	+4,507	+30%
Nuclear Energy	18,893	18,893	25,679	+6,786	+36%
Office of Clean Energy Demonstrations	0	0	6,096	+6,096	N/A
Science	181,980	187,982	207,774	+25,794	14%
Total, SBIR/STTR	**331,082**	**325,686**	**407,722**	**76,640**	+23%

The Department of Energy manages two separate Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) programs, one administered by the Office of Science and the other by the Advanced Research Projects Agency – Energy. The Office of Science has managed the DOE SBIR and STTR programs for the Department since the SBIR program was created in 1982 and the STTR program was created in 1992. The ARPA-E SBIR/STTR programs were created in FY 2012 to manage ARPA-E's SBIR & STTR allocations independently.

The SBIR/STTR Reauthorization Act of 2011 reauthorized the SBIR and STTR programs and provided for annual increases phased in over six years. The Act directs DOE to expend not less than the percentages specified for nonexempt extramural R&D. The percentages are 3.2% for SBIR and 0.45% for STTR programs, a total of 3.65% assessed for all contributing programs. The above table shows only the total by program with the precise splits by program determined in execution. By statute, "amounts obligated for Atomic Energy Defense Programs solely for Weapons Activities or for Naval Reactor Programs" are exempt [15 USC 638(e)(1)].

DOE SBIR/STTR Programs Office

The SBIR/STTR Programs Office works collaboratively with nine participating R&D program offices to administer the programs: the Office of Science; Cybersecurity, Energy Security and Energy Preparedness; Environmental Management (Defense Environmental Cleanup); Defense Nuclear Nonproliferation (within the National Nuclear Security Administration); Electricity; Energy Efficiency and Renewable Energy; Fossil Energy and Carbon Management; Nuclear Energy; and Clean Energy Demonstrations. Each office makes awards commensurate with its allocation and collaborates with other offices during execution, as necessary.

The participating programs are responsible for topic selection, reviewer assignment, award selection, and project oversight. Each program office considers its high priority research needs and program mission, as well as the Department's goals for the program in developing research topics. The specific research topics selected for the SBIR and STTR programs are developed by the Department's technical program managers.

The SBIR/STTR Programs Office is responsible for issuing topics and solicitations, managing the peer review and award selection process, working with the Office of Science Office of Acquisition and Assistance to award SBIR/STTR Phase I and Phase II grants, issuing annual reports to the U. S. Small Business Administration, performing outreach, and setting overall policy for the Department regarding the two programs.

In the implementation of SBIR/STTR, DOE assesses each program office at the minimum required percentages for both SBIR and STTR to meet expenditure requirements. DOE's current methodology is to vary the allocations such that each office will make the same total SBIR and STTR contribution, but the amounts given to SBIR and STTR will be adjusted to provide executable amounts, while in total DOE will meet the expenditure requirements for both SBIR and STTR.

ARPA-E SBIR/STTR Program

ARPA-E executes its SBIR/STTR programs separate from the DOE-wide SBIR/STTR program. The ARPA-E SBIR/STTR program employ the same rigorous merit review, accelerated contracting, funding, and active project management as all other ARPA-E programs. The ARPA-E SBIR/STTR Program focuses on targeted, mission-relevant areas where the agency believes that small business provides the best opportunity for innovative technology development.

Contractor Pensions and Other Postretirement Benefits

This section of the budget provides projected costs of contractor defined benefit (DB) pension plan contributions and other postretirement benefit reimbursements. The DB pension plan contributions are provided in Section I below for FY 2021 through FY 2023 by plan. The section also shows the allocations of those contributions to the following Department of Energy (DOE) Departmental Elements:[a]

- National Nuclear Security Administration (NNSA)
- Office of Environmental Management (EM)
- Office of Science (SC)
- Office of Energy Efficiency and Renewable Energy (EERE)
- Office of Nuclear Energy (NE)

Information regarding projected reimbursements for other postretirement benefits (primarily medical) is provided in Section II below.

Contractors that manage and operate DOE's laboratories, weapons plants, and execute environmental cleanup projects at various government-owned sites and facilities are contractually required by DOE to assume sponsorship of the existing contractor DB pension plans and other postretirement benefit plans for incumbent employees. DOE reimburses the costs of the contractors' contributions to DB pension plans and the benefits paid from other postretirement benefit plans. These costs are typically allocated as indirect costs, though DOE does directly pay the costs of some legacy plans.[b]

Due to the timing of the required annual valuation for the contractor DB pension plans, the actual amount of the contractors' annual contributions to these DB pension plans that DOE will reimburse each fiscal year will not generally be known until after budget development. Budgetary line items that include DOE reimbursement of contractor contributions to DB pension plans assume an indirect rate anticipated to be sufficient to meet reimbursement requirements. In the case of plans covering contractor employees whose costs are reimbursed by various programs, the allocation of contributions among NNSA, the Program Offices, and Reimbursable Work is done based on each site's best estimate of the allocation of work based on current and anticipated work for the various parties that the site serves.[c]

The American Rescue Plan Act (ARPA) and the Infrastructure Investment and Jobs Act (IIJA) became law in March and November 2021, respectively, and included several changes which affect the funding of qualified single employer and multiple employer defined benefit plans. In general, the provisions of the new legislation affecting multiemployer plans will not affect the two multiemployer pension plans which are included in this report. The provisions also do not impact the State plans included in this report. However, the changes affecting single and multiple employer plans will significantly reduce expected minimum required contributions in the future. The changes associated with ARPA and IIJA are included based on the best estimates of contractors in January 2022.

[a] Tables include projected contributions from "Reimbursable Work" and "Other" entities (e.g., DOE departmental administration, classified programs, etc.). Reimbursable Work also includes the costs associated with the Naval Reactors contractor's plans covered by its contract with the Department of the Navy.

[b] The NNSA legacy University of California (UC) plans and the East Tennessee Technology Park Pension Plan for Grandfathered Employees rely on direct costs. For fiscal years starting in FY 2022, NNSA and EM plan to directly fund the reimbursement of the unfunded liability of the Savannah River Nuclear Solutions, LLC Multiple Employer Pension Plan.

[c] These allocations were provided by the contractors to the DOE in January 2022 and represent contractors' expectation of work for these years.

Section I - Contractor DB Pension Plan Contributions[d]

DOE reimburses contractors for pension contributions at levels that are at least equal to the minimum required contribution (MRC) by the Employee Retirement Income Security Act (ERISA), as amended by ARPA and IIJA. The MRC is determined on a plan year basis. Only two of the contractor plans have a plan year that coincides with the federal fiscal year and, therefore, the majority of fiscal year pension allocations are spread across two plan years. At a minimum, plan sponsors of single or multiple employer plans [e] in which the plan assets were less than liabilities in the prior year must make quarterly contributions during the plan year with the first contribution due 3½ months after the beginning of the plan year and any outstanding amount due 8½ months after the plan year ends.

Contractors develop long-term projections of future asset investment returns that affect estimates of future MRCs for each plan. Asset returns that are higher or lower than the projected long-term investment returns affect future MRCs, though the provisions of ERISA ensure that these effects are somewhat smoothed by allowing recognition over a two (single/multiple) or a five-year period (multiemployer/state). In calendar year 2021, market returns were generally positive and equaled or exceeded most contractors' expected asset return for 2021. The actual investment returns in calendar year 2021 will predominantly affect MRCs beginning in Fiscal Year 2023 though there could be some impact in FY 2022 depending on the funded status of the plan. DOE evaluated the impact of the actual calendar year 2021 investment returns on the individual DB plans as part of its annual pension plan review process. The FY 2022 contribution amounts reflect the better than expected asset return.

Reimbursement of contractor costs in excess of the MRC requires specific approval. Reimbursements requested in excess of the MRC are reviewed by the cognizant program office, the Office of the Chief Financial Officer, the Office of Management, and the Office of the General Counsel through an annual pension management plan process. Table 1 provides information related to plans where funding in excess of the MRC was requested during FY 2021, and it includes the MRC, the contribution approved, and the actual amount contributed during FY 2021. In FY 2021, requests by contractors for reimbursement of contributions in excess of the MRC for 18 plans were approved. Contributions in excess of the MRC were approved primarily to minimize volatility for future payments and mitigate increases in future contribution requirements.

Table 1: FY 2021 Contributions in Excess of the MRC ($K)

Plan	Program Office	FY 2021 Congressional Budget Justification	FY 2021 Estimated Minimum Required Contribution	Preliminary Additional Amount Requested in Year of Execution	Amount Reported in September 2021	Final FY 2021 Amount Approved and Contributed
East Tennessee Technology Park Pension Plan for Grandfathered Employees	EM	16,359	11,695	17,680	29,375	29,375
Pension Plan for Eligible Bettis Employees and Retirees	NNSA	30,500	-	30,500	30,500	30,500
Pension Plan of the Pacific Northwest Laboratories, Battelle Memorial Institute	Science	45,000	-	45,000	45,000	45,000
Retirement Program for Employees of Consolidated Nuclear Security, LLC at the U. S. Department of Energy Facilities at Oak Ridge, Tennessee	NNSA	64,500	39,800	12,200	52,000	52,000
Idaho National Laboratory Employee Retirement Plan	NE	50,000	-	60,000	60,000	60,000

[d] DOE has reimbursed contributions for 32 funded DB pension plans and 13 non-qualified DB pension plans in FY 2021. Non-qualified plans have no assets and are funded on a pay-as-you-go basis.

[e] A single employer plan is a plan sponsored by only one employer; a multiple employer plan is a plan sponsored by 2 or more unrelated employers and not maintained pursuant to a collective bargaining agreement; a multiemployer plan is a plan maintained pursuant to a collective bargaining agreement between an employee organization and more than one employer.

Plan	Program Office	FY 2021 Congressional Budget Justification	FY 2021 Estimated Minimum Required Contribution	Preliminary Additional Amount Requested in Year of Execution	Amount Reported in September 2021	Final FY 2021 Amount Approved and Contributed
Salaried Employee Pension Plan for KAPL Employees and Retirees	NNSA	30,500	-	30,500	30,500	30,500
Pension Plan for KAPL Employees in Participating Bargaining Units	NNSA	3,400	-	3,400	3,400	3,400
Triad Defined Benefit Pension Plan (TCP1)	NNSA	122,985	-	136,800	136,800	136,800
LLNS Defined Benefit Pension Plan	NNSA	50,000	-	85,000	85,000	85,000
National Renewable Energy Laboratory Retirement Plan	EERE	30,000	11,654	22,054	33,708	33,708
Consolidated Nuclear Security, LLC Retirement Plan for Bargaining Unit Members of the Pantex Guards Union	NNSA	2,100	-	2,600	2,600	2,600
Retirement Plan for Bargaining Unit Employees of the Metal Trades Council of Consolidated Nuclear Security, LLC	NNSA	7,600	4,200	4,400	8,600	8,600
NTESS Retirement Income Plan	NNSA	111,148	-	105,443	105,443	105,444
Savannah River Nuclear Solutions, LLC Multiple Employer Pension Plan	EM	296,000	195,420	100,580	296,000	296,000
Pension Plan for Employees at ORNL	Science	102,000	-	150,000	150,000	150,000
NNSS Staff Pension Plan	NNSA	1,776	72	1,105	1,177	1,177
NNSS IGAN Pension Trust Fund	NNSA	2,482	678	1,833	2,511	2,511
West Valley Pension Plan	EM	4,490	3,670	10,481	14,151	14,151
Total		970,840	267,189	819,576	1,086,765	1,086,765

Projections of future DB pension plan contributions are highly sensitive to underlying data, methods, and especially assumptions. Changes in the population data that are different from the expected data impact the future costs of these plans; participants retiring earlier and/or living longer than expected may increase costs; compensation increases that are higher than expected will increase the costs. The most significant assumptions affecting the contribution amounts are those assumptions with respect to future market conditions. In particular, the difference between actual experience of the markets and the assumption of the expected return on investments earned by the plans each future year, as well as future corporate bond yields, have the largest impact on the ultimate contributions that will be reimbursed by the DOE. For example, the actual contributions for fiscal year 2023 will not be known until January 2023 at the earliest because these contributions will be determined based on the asset value as of December 31, 2022, and the discount rate in effect at that time. Estimated contributions above the MRC submitted during this budget process do not receive final approval until the year of execution.

Therefore, it is important to emphasize that the actual amounts reimbursed for the applicable fiscal years shown will almost certainly vary from the projections provided in this section. The information provided for the funded plans (excluding the non-qualified plans) is based on plan contributions projected by the DOE's contractors in January 2022. The non-qualified plan amounts equal the expected benefit payments which were provided by the contractors for the prior year's financial statements. This information has been reviewed by NNSA, relevant DOE Program Offices, and by the Office of the Chief Financial Officer.

- Table 2 provides aggregate FY 2021 actual and FY 2022 and FY 2023 estimated pension plan contributions eligible for reimbursement for all plans.
- Table 3 provides plan-by-plan FY 2021 actual contributions and FY 2022 and FY 2023 estimated pension contributions eligible for reimbursement by NNSA, the DOE, and reimbursable work customers

Table 2: NNSA and DOE Program Office Actual Contributions for FY 2021 and Projected Contributions for FY 2022 and FY 2023 ($K)
Based on January 2022 data and allocated by Program Office [f]

Program Office	FY 2021	FY 2022	FY 2023
NNSA	637,147	536,522	344,452
EM	362,393	344,340	311,431
SC	142,114	141,966	76,687
EERE	59,108	49,261	30,970
NE	24,518	17,824	2,178
Reimbursable Work	149,930	144,468	57,718
Other	32,189	41,248	18,231
Total	**1,407,399**	**1,275,629**	**841,668**

There may be small variances in totals due to rounding. Numbers may not add.

Table 3 provides the following information for each plan:

Plan name and Plan type: Single employer, multiemployer, multiple employer, state, or non-qualified.

Status: *Open* means that the plans are open to new employees who earn benefits under a traditional defined benefit formula. *Closed* means that the qualified plans are closed to new employees, but active employees who were employed prior to the plan being closed continue to earn benefits; this includes plans where new entrants only or new entrants and legacy employees receive benefits under reduced hybrid formulas which are much less volatile (indicated by the word hybrid after closed). For non-qualified plans, "closed" means that the universe of possible participants is limited to individuals who are currently accruing benefits in the closed qualified plan at the respective site and who may at some point qualify for the non-qualified plan under the terms of the non-qualified plan). *Partially Closed* means that the plan is closed to some subset of the employee population, but that certain represented employees covered by collective bargaining agreements are still becoming members of the plan at the time of hire. *Frozen* means that plan liabilities are frozen (*i.e.,* that there are no longer any employees accruing credit for current service under the plan).

Reimbursements & Allocations: Expected contributions are allocated by program office for fiscal years 2021-2023 with 2021 representing actual contributions and contributions for later years based on submissions as outlined in footnote f.

[f] Final information for FY 2021 contributions was reported in October 2021 while projected contributions for FY 2022 and on were reported in January 2022 for all departmental elements.

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)
Based on January 2022 data and allocated by Program Office [g]

Plan Name	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
East Tennessee Technology Park Pension Plan for Grandfathered Employees	EM-Partially Closed	2021	29,375	-	29,375	-	-	-	-	-
	Multiemployer	2022	19,800	-	19,800	-	-	-	-	-
		2023	20,700	-	20,700	-	-	-	-	-
University of California Retirement Plan - Lawrence Berkeley National Laboratory	SC-Open	2021	52,244	423	157	35,171	6,797	256	8,270	1,170
	State	2022	49,879	424	105	33,773	6,350	205	7,956	1,067
		2023	46,840	398	98	31,715	5,963	192	7,471	1,002
Pension Plan for Eligible Bettis Employees and Retirees	NA-Closed	2021	30,500	16,775	-	-	-	-	13,725	-
	Single	2022	25,900	14,245	-	-	-	-	11,655	-
		2023	23,100	12,705	-	-	-	-	10,395	-
Pension Plan of the Pacific Northwest Laboratories, Battelle Memorial Institute	SC-Open	2021	45,000	9,540	810	7,875	5,760	900	14,085	6,030
	Single	2022	45,000	9,270	810	8,010	5,850	990	14,535	5,535
		2023	-	-	-	-	-	-	-	-
Retirement Program for Employees of Consolidated Nuclear Security, LLC at the U. S. Department of Energy Facilities at Oak Ridge, Tennessee	NA-Closed	2021	52,000	49,920	-	-	-	-	2,080	-
	Single	2022	58,400	56,064	-	-	-	-	2,336	-
		2023	48,700	46,752	-	-	-	-	1,948	-
HPMC Occupational Health Services Retirement Plan	EM-Closed	2021	522	-	522	-	-	-	-	-
	Single	2022	-	-	-	-	-	-	-	-
		2023	-	-	-	-	-	-	-	-
Hanford Multi-Employer Pension Plan	EM-Closed	2021	92,679	-	92,679	-	-	-	-	-
	Multiemployer	2022	99,859	-	99,859	-	-	-	-	-
		2023	95,951	-	95,951	-	-	-	-	-

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)
Based on January 2022 data and allocated by Program Office [g]

Plan Name	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
Idaho National Laboratory Employee Retirement Plan	NE-Closed	2021	60,000	3,420	26,500	214	1,088	16,520	11,192	1,066
	Multiple	2022	50,000	2,405	26,500	175	765	10,925	8,675	555
		2023	-	-	-	-	-	-	-	-
Salaried Employee Pension Plan for KAPL Employees and Retirees	NA-Closed	2021	30,500	16,775	-	-	-	-	13,725	-
	Single	2022	26,900	14,795	-	-	-	-	12,105	-
		2023	25,000	13,750	-	-	-	-	11,250	-
Pension Plan for KAPL Employees in Participating Bargaining Units	NA-Closed	2021	3,400	1,870	-	-	-	-	1,530	-
	Single	2022	2,700	1,485	-	-	-	-	1,215	-
		2023	2,400	1,320	-	-	-	-	1,080	-
Kansas City Division Hourly Employees' Pension Plan	NA-Closed	2021	-	-	-	-	-	-	-	-
	Single	2022	-	-	-	-	-	-	-	-
		2023	-	-	-	-	-	-	-	-
Honeywell Retirement Earnings Plan for Aerospace Employees at the Kansas City Division	NA-Closed	2021	-	-	-	-	-	-	-	-
	Single	2022	-	-	-	-	-	-	-	-
		2023	-	-	-	-	-	-	-	-
Triad Defined Benefit Pension Plan (TCP1)	NA-Closed	2021	136,800	116,922	1,724	3,721	602	602	11,300	1,929
	Multiple	2022	132,600	113,771	1,591	3,580	530	530	10,608	1,989
		2023	1,430	1,227	17	39	6	6	114	21
University of California Retirement Plan - Lawrence Livermore National Laboratory Retained Segment	NA-Frozen	2021	61,990	61,990	-	-	-	-	-	-
	State	2022	1,109	1,109	-	-	-	-	-	-
		2023	24,192	24,192	-	-	-	-	-	-

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)
Based on January 2022 data and allocated by Program Office [g]

Plan Name	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
LLNS Defined Benefit Pension Plan	NA-Closed	2021	85,000	63,750	-	2,550	850	-	13,600	4,250
	Single	2022	95,700	70,818	-	2,871	957	-	17,226	3,828
		2023	60,000	46,200	-	1,800	600	-	9,600	1,800
Fluor-BWXT Portsmouth, LLC USW Career Pension Plan for Appendix A USW-Represented Employees	EM-Closed	2021	1,844	-	1,844	-	-	-	-	-
	Single	2022	2,666	-	2,666	-	-	-	-	-
		2023	495	-	495	-	-	-	-	-
University of California Retirement Plan - Los Alamos National Laboratory Retained Segment	NA-Frozen	2021	53,970	53,970	-	-	-	-	-	-
	State	2022	18,472	18,472	-	-	-	-	-	-
		2023	32,036	32,036	-	-	-	-	-	-
National Renewable Energy Laboratory Retirement Plan	EE-Closed - Hybrid	2021	33,707	-	-	1,011	26,292	-	4,719	1,685
	Single	2022	23,000	-	-	1,380	17,480	-	2,990	1,150
		2023	23,000	-	-	1,380	17,480	-	2,990	1,150
Golden SVCS, LLC Pension Plan	SC-Closed	2021	1,308	-	1,046	262	-	-	-	-
	Multiple	2022	1,040	-	832	208	-	-	-	-
		2023	370	-	274	96	-	-	-	-
Mission Support and Test Services, LLC (MSTS) Employee Retirement Plan	NA-Closed-Hybrid	2021	17,505	14,950	945	-	-	-	1,190	420
	Single	2022	17,300	15,016	865	-	-	-	986	433
		2023	18,485	16,045	924	-	-	-	1,054	462
Consolidated Nuclear Security, LLC Retirement Plan for Bargaining Unit	NA-Closed	2021	2,600	2,600	-	-	-	-	-	-
	Single	2022	2,800	2,800	-	-	-	-	-	-

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)

Based on January 2022 data and allocated by Program Office [g]

Members of the Pantex Guards Union		2023	2,800	2,800	-	-	-	-	-	-

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

Plan Name	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
Retirement Plan for Bargaining Unit Employees of the Metal Trades Council of Consolidated Nuclear Security, LLC	NA-Closed	2021	8,600	8,600	-	-	-	-	-	-
	Single	2022	8,200	8,200	-	-	-	-	-	-
		2023	7,900	7,900	-	-	-	-	-	-
Consolidated Nuclear Security Retirement Plan for Non-Bargaining Pantex Location Employees	NA-Closed	2021	15,300	14,994	-	-	-	-	306	-
	Single	2022	15,200	14,896	-	-	-	-	304	-
		2023	13,900	13,622	-	-	-	-	278	-
NTESS Retirement Income Plan	NA-Closed	2021	105,443	65,691	527	2,109	2,003	949	32,371	1,793
	Single	2022	103,121	63,626	619	2,269	2,475	928	31,349	1,856
		2023	-	-	-	-	-	-	-	-
Savannah River Nuclear Solutions, LLC Multiple Employer Pension Plan	EM-Closed	2021	296,000	112,628	175,824	-	-	-	-	7,548
	Multiple	2022	296,000	109,076	169,312	-	-	-	-	17,612
		2023	296,000	112,658	172,953	-	-	-	-	10,390
DUF6 Pension Plan for Grandfathered Employees	EM-Partially Closed	2021	599	-	599	-	-	-	-	-
	Single	2022	-	-	-	-	-	-	-	-
		2023	-	-	-	-	-	-	-	-
USW Career Pension Plan for Appendix A USW-Represented Employees (Paducah)	EM-Closed	2021	1,572	-	1,572	-	-	-	-	-
	Single	2022	1,616	-	1,616	-	-	-	-	-

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)

Based on January 2022 data and allocated by Program Office [g]

		2023	350	-	350	-	-	-	-	-

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

Plan Name	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
Pension Plan for Employees at ORNL	SC-Open	2021	150,000	14,250	150	88,800	15,600	5,250	19,800	6,150
	Single	2022	150,000	14,400	150	89,100	14,700	4,200	20,400	7,050
		2023	69,000	6,624	69	40,986	6,762	1,932	9,384	3,243
Waste Isolation Pilot Plant Pension Plan	EM-Open	2021	13,423	-	13,423	-	-	-	-	-
	Single	2022	19,100	-	19,100	-	-	-	-	-
		2023	19,100	-	19,100	-	-	-	-	-
West Valley Pension Plan	EM-Closed	2021	14,151	-	14,151	-	-	-	-	-
	Single	2022	-	-	-	-	-	-	-	-
		2023	-	-	-	-	-	-	-	-
NNSS Staff Pension Plan	NA-Closed	2021	1,177	1,177	-	-	-	-	-	-
	Single	2022	140	140	-	-	-	-	-	-
		2023	47	47	-	-	-	-	-	-
NNSS IGAN Pension Trust Fund	NA-Closed	2021	2,511	2,511	-	-	-	-	-	-
	Single	2022	989	989	-	-	-	-	-	-
		2023	1,314	1,314	-	-	-	-	-	-
Battelle Memorial Institute Excess Benefit and Supplemental Executive Pension Plans	NA-Closed	2021	31	7	1	5	4	1	9	4
	Non-Qualified	2022	8	2	0	1	1	0	3	1
		2023	8	2	0	1	1	0	2	1
	NA-Closed	2021	1,835	1,009	-	-	-	-	826	-

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)

Based on January 2022 data and allocated by Program Office [g]

Executive and Supplemental Pension Plans for Designated Bettis Employees	Non-Qualified	2022	1,886	1,037	-	-	-	-	849	-
		2023	1,962	1,079	-	-	-	-	883	-

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

Plan Name	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
Excess and Supplemental Pension Plan for Designated KAPL Employees	NA-Closed	2021	353	194	-	-	-	-	159	-
	Non-Qualified	2022	346	190	-	-	-	-	155	-
		2023	340	187	-	-	-	-	153	-
Triad 401(a)(17) Restoration Plan	NA-Closed	2021	274	235	3	7	1	1	23	4
	Non-Qualified	2022	263	226	3	7	1	1	21	4
		2023	267	229	3	7	1	1	21	4
Triad Restoration Plan	NA-Closed	2021	93	80	1	3	-	-	8	1
	Non-Qualified	2022	169	145	2	5	1	1	14	3
		2023	187	160	2	5	1	1	15	3
LLNS 401(a)(17) Restoration Plan	NA-Closed	2021	1,096	822	-	33	11	-	175	55
	Non-Qualified	2022	1,142	845	-	34	11	-	206	46
		2023	1,340	1,032	-	40	13	-	214	40
LLNS Restoration Plan	NA-Closed	2021	226	170	-	7	2	-	36	11
	Non-Qualified	2022	343	254	-	10	3	-	62	14
		2023	441	339	-	13	4	-	70	13
NTESS Nonqualified Pension Plan	NA-Closed	2021	2,367	1,475	12	47	45	21	727	40
	Non-Qualified	2022	2,304	1,422	14	51	55	21	701	41
		2023	2,274	1,435	14	52	48	20	662	43

Table 3: Actual FY 2021 and Projected FY 2022 and FY 2023 Contributions by Plan, NNSA, and Program Office ($K)

Based on January 2022 data and allocated by Program Office [g]

Savannah River Nuclear Solutions, LLC Nonqualified Pension Plan	EM-Frozen	2021	460	175	273	-	-	-	-	12
	Non-Qualified	2022	435	160	249	-	-	-	-	26
		2023	411	156	240	-	-	-	-	14

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

	Plan status	Fiscal Year	Total	NNSA	EM	SC	EERE	NE	Reimbursable Work	Other
Washington Government Services Executive Pension Plan (TRU Solutions Participants Only)	EM-Frozen	2021	71	-	71	-	-	-	-	-
	Non-Qualified	2022	70	-	70	-	-	-	-	-
		2023	68	-	68	-	-	-	-	-
Washington Government Services Executive Pension Plan (West Valley Participants Only)	EM-Frozen	2021	184	-	184	-	-	-	-	-
	Non-Qualified	2022	177	-	177	-	-	-	-	-
		2023	172	-	172	-	-	-	-	-
Consolidated Nuclear Security, LLC Equalization Retirement Income Plan and Supplemental Retirement Income Plan	NA-Closed	2021	183	176	-	-	-	-	7	-
	Non-Qualified	2022	167	160	-	-	-	-	7	-
		2023	161	154	-	-	-	-	6	-
UT-Battelle Equalization Retirement Income Plan and Supplemental Retirement Income Plan	SC-Open	2021	506	48	-	299	53	18	67	21
	Non-Qualified	2022	827	79	1	491	81	23	112	39
		2023	929	89	1	552	91	26	126	44
Total		**2021**	**1,407,399**	**637,147**	**362,393**	**142,114**	**59,108**	**24,518**	**149,930**	**32,189**
		2022	**1,275,629**	**536,522**	**344,340**	**141,966**	**49,261**	**17,824**	**144,468**	**41,248**
		2023	**841,668**	**344,452**	**311,431**	**76,687**	**30,970**	**2,178**	**57,718**	**18,231**

[g] May be small variances in totals due to rounding. For the Naval Reactors contractor's plans, Reimbursable Work includes the portion of contributions covered by the contract with the Department of the Navy.

Section II - Other Postretirement Benefit Plans

For the most part, contractors do not fund other postretirement benefit plans in advance, but instead pay the claims incurred by the retired members or the premiums required to cover the plan benefits. The other postretirement benefits covered by the contractors are primarily medical, including prescription drugs, but may also include dental, vision, and life insurance benefits that are provided upon retirement from the contractor. The costs associated with these plans are expected to grow as the retired population grows and as healthcare cost trends continue to increase.

Due to the fact that the claims are not paid until incurred and processed, the actual amounts of contractors' payment of claims that DOE will reimburse for FY 2022 and FY 2023 will not be known until after budget development. The contractor costs are included in indirect costs. The budget assumes an indirect rate sufficient to meet reimbursement requirements. [h] As mentioned in the pension section, the allocation of contributions among NNSA, the Program Offices, and Reimbursable Work, is done based on each site's best estimate of the allocation of work based on current and anticipated work for the various parties that the site serves.

The contractors are making concerted efforts to reduce the costs associated with these plans as the costs have steadily increased. In recent years, contractors have made changes to their other postretirement benefit plans in an effort to reduce the costs associated with them, simplify administration, or increase the efficiency of the delivery of benefits. These changes, effective January 1, 2021 or later, including adjusting plan options to include high deductible health plan options, putting in place Employer Group Waiver Plans (EGWP) and other programs to manage prescription drug costs, adjusting the premiums for health and dental plans, and adjusting eligibility rules for retiree health plans.

Projections of future postretirement benefits to be paid are highly sensitive to underlying data, methods, and assumptions, particularly assumptions related to future increases in the expected claims paid each year as well as the underlying assumptions regarding usage and coverage. Thus, the actual amounts reimbursed in a future fiscal year may be different. All of the information for FY 2022 and FY 2023 is based on expected reimbursements as reported by the DOE's respective contractors in January 2022; this information has been reviewed by the appropriate NNSA and DOE program office and the Office of the Chief Financial Officer. The information reported for FY 2021 is primarily based on information of final employer contributions as reported by the contractors for the FY 2021 agency financial statements. Table 5 provides these aggregate FY 2021-2023 projected other postretirement benefit reimbursements.

Table 5: FY 2021-2023 NNSA and DOE Program Office Projected Other Postretirement Benefits Payments ($K)
Based on January 2022 data and allocated by Program Office [h]

Program Office	FY 2021	FY 2022	FY 2023
NNSA	161,459	178,452	186,133
EM	64,765	69,303	70,819
SC	49,616	58,144	60,376
EERE	6,193	7,023	7,279
NE	5,551	7,137	7,300
Reimbursable Work	39,812	47,603	47,576
LM	36,634	39,875	38,662
Other	7,367	9,681	8,187
Total	**371,396**	**417,217**	**426,332**

There may be small variances in totals due to rounding. Numbers may not add in total.

[h] The LM plans rely on direct costs.

Infrastructure

Infrastructure funding is managed within several programs and includes direct and indirect funding for capital equipment, maintenance and repair, minor construction, line-item construction, and excess facilities. The DOE program offices and 17 National Laboratories are working to research, develop, and deploy the clean energy technologies of the future, including battery storage, renewable power, electric vehicles, carbon capture, and resilient grid infrastructure. Infrastructure funding is to improve the reliability, efficiency, and capability of core infrastructure to meet mission requirements. The Department's Infrastructure activities are tied to its programmatic missions, goals, and objectives. DOE will also use its expansive loan authority to invest in American, and its regulatory authority to innovate in advanced building technologies, and energy efficient appliances. DOE prioritizes infrastructure investments to reduce safety risk by addressing numerous obsolete support and safety systems, to reduce mission risk by revitalizing facilities that are beyond the end of their design life, and to maximize return on investment while considering climate risk, improving sustainability, and working toward meeting the Department's climate action goals by addressing climate adaptability and resilience. This crosscut summarizes the infrastructure funding that is distributed through the budget volumes.

Descriptions of each program's Infrastructure components can be found in the budget justifications for:
- Defense and Non-defense Environmental Cleanup
- Defense Nuclear Nonproliferation
- Electricity
- Energy Efficiency and Renewable Energy
- Enterprise Assessments
- Fossil Energy Research and Development
- Legacy Management
- Naval Reactors
- Nuclear Energy
- Science
- Strategic Petroleum Reserve
- Weapons Activities

Table 1 provides a department-wide summary of infrastructure funding by Program, while Table 2 provides the breakout by category of expenditures.

Table 1. Overall DOE Infrastructure Funding by Program (FY 2021 – FY 2023)

Infrastructure by Program[2] $ in thousands	FY 2021 Enacted	FY 2022 Annualized	FY 2023 Request	FY 2023 vs FY 2021	% Change
Defense Environmental Cleanup	1,874,176	1,848,203	1,602,526	-271,650	-14.49%
Defense Nuclear Nonproliferation	271,220	260,167	223,296	-47,924	-17.67%
Electricity	23,000	23,000	0	-23,000	-100.00%
Energy Efficiency and Renewable Energy	110,443	50,050	201,600	91,157	82.54%
Enterprise Assessments	1,278	1,770	1,824	546	42.72%
Legacy Management	4,935	4,935	5,947	1,012	20.51%
Naval Reactors	445,271	446,466	657,584	212,313	47.68%
Nuclear Energy	76,977	64,683	40,803	-36,174	-46.99%
Science	1,858,793	1,745,533	1,844,921	-13,872	-0.75%
Strategic Petroleum Reserve	467,041	38,908	29,822	-437,219	-93.61%
Weapons Activities	4,546,865	4,720,965	5,461,294	914,429	20.11%
Fossil Energy & Carbon Management	31,336	39,092	44,820	13,484	43.03%
UED&D Fund	63,136	63,139	48,040	-15,096	-23.91%
Total, Infrastructure	**9,774,471**	**9,306,911**	**10,162,477**	**388,006**	**3.97%**

Table 2. Overall DOE Infrastructure Funding by Category (FY 2021 – FY 2023)

Infrastructure Category $ in thousands	FY 2021 Enacted	FY 2022 Annualized	FY 2023 Request	FY 2023 vs FY 2021	% Change
Capital Equipment					
Defense Nuclear Nonproliferation	92,168	92,886	110,927	18,759	20.35%
Energy Efficiency and Renewable Energy	20,262	14,400	38,775	18,513	91.37%
Naval Reactors	1,000	7,000	41,600	40,600	4060.00%
Nuclear Energy	2,845	1,000	0	-2,845	-100.00%
Science	239,552	239,739	248,988	9,436	3.94%
Strategic Petroleum Reserve	6,795	6,795	0	-6,795	-100.00%
Weapons Activities	895,425	1,113,192	1,215,664	320,239	35.76%
Subtotal, Capital Equipment	**1,258,047**	**1,475,012**	**1,655,954**	**397,907**	**31.63%**
Excess Facilities					
Defense Environmental Cleanup	35,000	35,000	52,523	17,523	50.07%
Naval Reactors	21,930	21,930	61,007	39,077	178.19%
Science	1,349	1,291	2,858	1,509	111.86%
Weapons Activities	44,123	41,276	39,000	-5,123	-11.61%
Fossil Energy & Carbon Management	54	40	40	-14	-25.93%
Subtotal, Excess Facilities	**102,456**	**99,537**	**155,428**	**52,972**	**51.70%**
Line Item Construction[3]					
Defense Environmental Cleanup	1,082,564	1,082,564	675,264	-407,300	-37.62%
Defense Nuclear Nonproliferation	148,589	148,589	71,764	-76,825	-51.70%
Electricity	23,000	23,000	0	-23,000	-100.00%
Energy Efficiency and Renewable Energy	4,000	4,000	91,500	87,500	2187.50%
Naval Reactors	334,000	334,000	455,265	121,265	36.31%
Nuclear Energy	26,500	28,500	7,300	-19,200	-72.45%
Science	1,094,000	1,017,750	1,072,550	-21,450	-1.96%
Strategic Petroleum Reserve	425,774	0	0	-425,774	-100.00%
Weapons Activities	2,002,215	2,002,215	2,550,551	548,336	27.39%
UED&D Fund	63,136	63,139	48,040	-15,096	-23.91%
Subtotal, Line-Item Construction	**5,203,778**	**4,703,757**	**4,972,234**	**-231,544**	**-4.45%**
Maintenance and Repair[4]					
Defense Environmental Cleanup	669,327	643,354	787,910	118,583	17.72%
Energy Efficiency and Renewable Energy	16,760	18,550	19,400	2,640	15.75%
Enterprise Assessments	1,278	1,770	1,824	546	42.72%
Legacy Management	4,935	4,935	5,947	1,012	20.51%
Naval Reactors	46,936	46,936	50,192	3,256	6.94%
Nuclear Energy	39,817	32,583	33,503	-6,314	-15.86%
Science	322,714	303,867	308,685	-14,029	-4.35%
Strategic Petroleum Reserve	34,472	32,113	29,822	-4,650	-13.49%
Weapons Activities	1,055,719	1,058,354	1,106,599	50,880	4.82%
Fossil Energy & Carbon Management	19,282	19,780	19,780	498	2.58%
Subtotal, Maintenance and Repair	**2,211,240**	**2,162,242**	**2,363,662**	**152,422**	**6.89%**

Minor Construction					
Defense Environmental Cleanup	87,285	87,285	86,829	-456	-0.52%
Defense Nuclear Nonproliferation	30,463	18,692	40,605	10,142	33.29%
Energy Efficiency and Renewable Energy	69,421	13,100	51,925	-17,496	-25.20%
Naval Reactors	41,405	36,600	49,520	8,115	19.60%
Nuclear Energy	7,815	2,600	0	-7,815	-100.00%
Science	201,178	182,886	211,840	10,662	5.30%
Weapons Activities	549,383	505,928	549,480	97	0.02%
Fossil Energy & Carbon Management	12,000	19,272	25,000	13,000	108.33%
Subtotal, Minor Construction	**998,950**	**866,363**	**1,015,199**	**16,249**	**1.63%**
Total, Infrastructure	**9,774,471**	**9,306,911**	**10,162,477**	**388,006**	**3.97%**

Capital Equipment

Capital equipment funding includes the cost of equipment either acquired by purchase or fabricated by a site/facility management contractor that exceeds the capitalization threshold of $500,000. Included in the capital equipment funding are major items of equipment (MIEs). MIEs are listed individually in each program's budget justification.

Minor Construction

Minor Construction funding includes all minor construction projects. A Minor Construction Project is any construction project not specifically authorized by law for which the approved total estimated cost does not exceed the minor construction threshold[1]. Minor Construction Projects, including Accelerator Improvement Projects (AIPs), that exceed $5M are listed individually in each program's budget justification.

Line-Item Construction

Line-Item Construction funding includes all construction projects specifically authorized by law for which the approved total estimated cost exceeds the minor construction threshold [50 US Code 2741]. The funding captured in this crosscut includes the annual total project costs – both total estimated costs and other project costs. The individual line-item construction projects can be found in both the programs' construction projects summary and the individual project data sheets.

Maintenance and Repair

The Facilities Maintenance and Repair activities funded by this budget are intended to improve asset condition and maintain operability. This excludes maintenance of excess facilities (including high-risk excess facilities) necessary to minimize the risk posed by those facilities prior to disposition.

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 funding to deactivate and dispose (D&D) of excess infrastructure, including stabilization and risk reduction activities at high-risk excess facilities, resulting in surveillance and maintenance cost avoidance and reduced risk to workers, the public, the environment, and programs is included. Also included is the maintenance of excess facilities (including high-risk excess facilities) necessary to minimize the risk posed by those facilities prior to disposition.

[1] 50 USC 2743 only allows authorized programs to conduct minor construction projects under annual National Defense Authorization Acts; 50 USC 2741 sets the minor construction threshold

[2] Does not include annual lease costs

[3] Reflects Total Project Costs (TPC) for each Line-Item Construction Project

[4] Includes both direct- and indirect-funded dollars.

Exascale Computing Initiative Crosscut

Funding by Appropriation and Program
($K)

	FY 2021 Enacted	FY 2022 Annualized	FY 2023 Request	FY 2023 vs FY 2021 ($ Change)	FY 2023 vs FY 2021 (% Change)
SC-ECP (17-SC-20)	$168,945	$129,000	$77,000	-$91,945	-54.4%
Argonne Leadership Computing Facility (ALCF)	$150,000	$150,000	$150,000	—	0%
Oak Ridge Leadership Computing Facility (OLCF)	$120,000	$120,000	—	-$120,000	-100%
Basic Energy Sciences	$26,000	$26,000	$26,000	—	0%
Biological and Environmental Research	$15,000	$15,000	$15,000	—	0%
Total, SC Exascale[1]	**$479,945**	**$440,000**	**$268,000**	**-$211,945**	**-44.2%**
Advanced Simulation and Computing (ASC)					
-Advanced Technology Development & Mitigation (ATDM)	$40,000	$40,000	$12,000	-$28,000	-70.0%
ECP Focus Area 1: Applications	*$15,000*	*$15,000*	*—*	*-$15,000*	*-100%*
ECP Focus Area 2: Software	*$15,000*	*$15,000*	*$12,000*	*-$3,000*	*-20%*
ECP Focus Area 3: Hardware	*—*	*—*	*—*	*—*	*—*
ECI Stockpile Simulation	*$10,000*	*$10,000*	*—*	*-$10,000*	*-100%*
ECI Stockpile Computing	*—*	*—*	*—*	*—*	*—*
- Defense Applications and Modeling (DAM)	$28,000	$18,000	$18,000	-$10,000	-35.7%
- Computational Systems and Software Environment (CSSE)	$124,000	$145,000	$130,000	$6,000	4.8%
Exascale System	*$100,000*	*$125,000*	*$110,000*	*$10,000*	*10%*
Next-Generation Computing Technologies	*$24,000*	*$20,000*	*$20,000*	*-$4,000*	*-16.7%*
- Facility Operation and User Support (FOUS)	$19,000	$1,000	—	-$19,000	-100%
- Exascale Class Facility Modernization (18-D-620)[2]	$29,200	—	—	-$29,200	-100%
Total, NNSA Exascale	**$240,200**	**$204,000**	**$160,000**	**-$80,200**	**-33.4%**
Total, ECI	**$720,145**	**$644,000**	**$428,000**	**-$292,145**	**-40.6%**

[1] The SC-ECP project was initiated in FY 2017 and in FY 2018 funds to prepare the LCFs for deployment of at least one exascale system were included in ECI. The OLCF accepted their exascale system in 2022 and into operations in 2023 so is no longer included in the crosscut; funding for the ALCF is primarily focused on the acceptance of their exascale system.

[2] In FY 2021 and FY 2022, NNSA funded ASC as a subprogram to the higher-level Stockpile Research, Technology, and Engineering Program. At that time, NNSA funded ECFM through Programmatic Construction within Infrastructure and Operations. ECFM will reach CD-4 by end of FY 2022.

Summary:

The Exascale Computing Initiative (ECI) is a partnership between the Office of Science (SC) and the National Nuclear Security Administration (NNSA) to develop and deploy three exascale-capable computing systems with an emphasis on sustained performance for relevant applications and analytic computing to support DOE missions. In 2015, the National Strategic Computing Initiative (NSCI) was established to maximize the benefits of HPC for U.S. economic competitiveness, scientific discovery, and national security and within NSCI DOE 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 computing industry has reached a point where the continued improvement in processing performance requires technological breakthroughs to mitigate memory bottlenecks, reduce power consumption, and solve unique problems of computing at unprecedented scales. As a result, DOE's approach in ECI is aimed not simply at realizing a single, albeit exceptional, computing performance objective, but rather at setting the U.S. on a new design trajectory to support a broad spectrum of capabilities over the succeeding years. It is imperative for the United States to retain its primacy in HPC to ensure its national security, economic prosperity, technological strength, and scientific and energy research leadership to prevent other nations with demonstrated commitment to HPC investment to take the lead not only in high-end computing but also eventually in science, national defense, and energy innovation, as well as in the commercial computing market.

Crosscut Objectives:

ECI is currently comprised of three components: the Exascale Computing Project (ECP) which is focused on the research, development, and deployment of the exascale applications and software ecosystem; additional investments by NNSA and other SC Program offices for their mission-specific work; and the actual exascale system procurements and deployment at Argonne (Aurora), Lawrence Livermore (El Capitan), and Oak Ridge National Laboratories (Frontier). The DOE ECP is organized around three technical focus areas: 1) Application Development, targeting specific R&D activities and outcomes that address critical DOE applications and grand challenge problems; 2) Software Technology, with efforts that span low-level operational software to high-level applications development environments, including the software infrastructure to support large data management and workflows; and 3) Hardware and Integration, which supports vendor-based R&D efforts and the integration of ECP with the facilities projects that are delivering the exascale systems.

- ***Crosscut Objective 1:*** Successfully completed objective with the installation of Frontier at the Oak Ridge Leadership Computing Facility (OLCF) by September 20, 2021. By September 30, 2021, begin deployment (receiving and installing hardware) of at least one Exascale Computing system (DOE Agency Priority Goal).
- ***Crosscut Objective 2:*** *ECP* Application Development – Develop and enhance the predictive capability of applications critical to DOE in national security, clean energy, earth systems chemistry and materials.
- ***Crosscut Objective 3:*** *ECP* Software Technologies- Deliver expanded and vertically integrated software stack to achieve full potential of exascale computing.
- ***Crosscut Objective 4:*** *ECP* Hardware and Integration- Integrate delivery of ECP products on targeted systems at leading DOE HPC facilities.
- ***Crosscut Objective 5:*** In the 2022-2023 timeframe begin deployment of DOE's two additional exascale systems to support DOE's mission in scientific discovery and national security.

Program 'Action Areas':

1. ***Action Area 1:*** NNSA and DOE/SC will continue their close partnership to meet the ECI goals and objectives.
2. ***Action Area 2:*** In this focus area, ASCR will complete execution of applications critical to the scientific and energy missions of the Department and other Federal agencies on the OLCF's Frontier, the Nation's first exascale system.

In addition, the application teams will have access to Aurora, the nation's second exascale system located at the Argonne Leadership Computing Facility (ALCF), to initiate scale-up and execution activities.

3. ***Action Area 3:*** In partnership with NNSA, investments in the Software Technology focus area will provide the required software that effectively bridges between the other focus areas of the ECP. The ECP software technology effort will continue to harden the software stack on the OLCF's Frontier system while deploying the updated versions to Aurora and El Capitan, which will be sited at Lawrence Livermore National Laboratory (LLNL) in the 2022-2023 timeframe, respectively.
4. ***Action Area 4:*** Continue the support of the close integration between ECP and DOE HPC facilities, while deploying application and the software stack on the exascale platforms.
5. ***Action Area 5:*** SC: Basic Energy Sciences (BES) and Biological and Environmental Research (BER) exascale application development. Within this focus area BES is responsible for determining the scope and management of the Functional Material and Computational Chemistry programs and BER is responsible for determining the scope and management of the Earth Systems Modeling programs.
6. ***Action Area 6:*** ASCR will transition Frontier at ORNL to operations and initiate the acceptance testing process of Aurora at Argonne National Laboratory (ANL).
7. ***Action Area 7:*** NNSA will productionize the transferred Advanced Technology Development and Mitigation (ATDM) next-generation codes (to the ASC code base in FY 2022) to directly support the stockpile management and annual assessment activities.
8. ***Action Area 8:*** NNSA will accept delivery of El Capitan system at LLNL.

Program Organization:

1. SC ($268M): See action areas, 1, 2, 3, 4, 5, and 6 above.

2. NNSA ($160M): See action areas 1, 3, 4, 7, and 8 above.

ECP is being executed within a tailored project framework that follows the principles of DOE Order 413.3B, which defines critical decision points, overall project management, and requirements for control of a baselined schedule and cost. A single federal project director (FPD) from the ORNL Site Office has overall responsibility for execution of the project and the FPD reports to the cognizant SC and NNSA Headquarters program offices and are accountable to an Acquisition Executive, as defined in DOE Order 413.3B. Project execution is governed by a baselined schedule and cost envelope, using Office of Science processes, and follow defined processes for change control and management of contingency per the established ECP performance baseline.

Because of the breadth and complexity of the research and development of the applications, software environment and hardware technologies, along with the deployment of usable exascale computers for DOE, an Integrated Project Team (IPT) has been established through an IPT charter with defined roles and responsibilities. The IPT supports the FPD who leads the IPT through the lifetime of the project.

Energy Sector Cybersecurity
($K)

Appropriation and Program Control	FY 2021 Enacted	FY 2022 Annualized	FY 2023 Request	FY 23 vs. FY 21 ($ Change)
Cybersecurity, Energy Security, and Emergency Response	**139,100**	**139,100**	**125,020**	**-14,080**
Risk Management Technology & Tools	139,100	139,100	125,020	-14,080
Electricity	**0**	**0**	**20,000**	**+20,000**
Cyber Resilient and Secure Utility Communication Networks (SecureNet)	0	0	20,000	+20,000
Energy Efficiency and Renewable Energy	**31,064**	**12,350**	**26,200**	**-4,864**
Advanced Manufacturing Office (AMO)	14,000	0	0	-14,000
Bioenergy Technologies (BETO)	200	0	200	0
Building Technologies (BTO)	7,250	6,000	5,000	-2,250
Federal Energy Management Program (FEMP)	2,071	0	0	-2,071
Hydrogen and Fuel Cell Technologies (HFTO)	1,000	0	1,000	0
Solar Energy Technologies (SETO)	4,000	4,000	5,000	+1,000
Vehicle Technologies (VTO)	2,000	2,000	2,000	0
Water Power Technologies Office (WPTO)	13	350	5,000	+4,987
Wind Energy Technologies Office (WETO)	530	0	8,000	+7,470
Nuclear Energy	**5,000**	**5,000**	**7,500**	**+2,500**
Fossil Energy and Carbon Management	**1,170**	**1,170**	**1,800**	**+630**
Chief Information Officer	**1,303**	**1,303**	**1,553**	**+250**
Total, Energy Sector Cybersecurity	**177,637**	**158,923**	**182,073**	**+4,436**

Overview

The Department of Energy's (DOE's) FY 2023 budget request is aligned with the National Cyber Strategy and demonstrates the Administration's commitment to strengthening the Nation's cybersecurity capabilities and addressing the most pressing cyber threats. The FY 2023 budget supports DOE's responsibilities as Sector Risk Management Agency (SRMA) for cybersecurity for the energy sector, as established under the Fixing America's Surface Transportation (FAST) Act of 2015. As SRMA, DOE works closely with the critical infrastructure lead, the Department of Homeland Security (DHS), and our other federal partners including law enforcement and the intelligence community, as well as stakeholders across industry, and state and local governments, to secure the Nation's critical energy infrastructure from cyber threats and attacks.

Departmental Collaboration

As adversaries increase the frequency and sophistication of their malicious cyber activities, the Department has increased investment in cybersecurity to identify solutions to reduce risk for the energy sector, as well as the enterprise systems supporting the Department's internal operations. The FY 2023 request builds upon the strategy outlined in the Multiyear

Plan (MYP) for Energy Sector Cybersecurity and the establishment of the Office of Cybersecurity, Energy Security and Emergency Response (CESER).

Highlights and Major Changes

Office of Cybersecurity, Energy Security, and Emergency Response

The FY 2023 CESER budget request supports:

- CESER is lead for energy sector cybersecurity initiatives across the Department. In FY 2023, CESER will make investments in the following programmatic areas of Risk Management Tools & Technologies:

- ADVANCE CYBERSECURITY TOOLS & TECHNOLOGIES FOR THE SECTOR
  Develop, demonstrate, deploy, and transition to practice next generation technology and tools for broad adoption in energy industry. These tools will focus on protection, monitoring, detection, response, containment, forensics, and recovery. The request supports competitive Funding Opportunity Announcements (FOA) and Lab Research Calls for the development of such tools for Information Technology (IT) and Operational Technology (OT) spaces. The request also supports the Grid Modernization Laboratory Consortium (GMLC) initiatives.

- ADVANCED THREAT MITIGATION
  Enhance the speed and effectiveness of government and private sector bi-directional machine-to-machine threat information sharing and analysis. This initiative will use the latest available technology and architecture together with innovative partnerships in the energy sector to promote enhanced cyber protection for the sector. The vision is to dramatically increase the visible footprint across the energy sector infrastructure and to gain a higher level of threat detection capability. The request will allow for near-real-time capability for energy owners and operators, analyze their data, identify adversary activities, and execute mitigative measures.

- CYBER RISK ASSESSMENT TOOLS
  Develop and transition to practice tools, guidance, and practices that help energy organizations' understanding and management of cybersecurity risk to systems, people, assets, data, and capabilities. The CESER Cybersecurity Capability Maturity Model (C2M2) and energy sector Cybersecurity Framework profiles initiatives improve understanding of cybersecurity capabilities, gaps and challenges facing electricity, oil, and natural gas sectors. These tools connect business context, critical resources and functions, and the related cybersecurity risks to enable an organization to focus and prioritize its cybersecurity efforts, consistent with its risk management strategy and business needs.

- RESEARCH & DEVELOPMENT COORDINATION
  Coordinate with DOE applied program offices to streamline Research and Development (R&D) of cybersecure energy delivery systems preventing redundancies and gaps across electricity, fossil fuels, nuclear, and renewable technologies.

- SITUATIONAL AWARENESS TOOLS
  The funding will enable CESER to continue providing visibility in sector threat environment and supplementing that with analytical capability to support the sector. This funding will enable expansion of CRISP and associated information sharing and situational awareness tools

- CYBER TESTING FOR RESILIENT INDUSTRIAL CONTROL SYSTEMS (CyTRICS) ($35 Million)
  CyTRICS is the Department of Energy's program for cybersecurity supply chain vulnerability testing, digital subcomponent enumeration, and mitigation. CyTRICS partners across energy sector stakeholders to identify threat-informed, high priority operational technology (OT) components, perform expert testing, share information about vulnerabilities in the digital supply chain, and inform improvements in component design and manufacturing. FY2022 funding will enable inclusion of two additional testing Labs (NREL and ORNL) and scaling up cyber supply chain testing of digital components in renewables and distributed energy systems. CyTRICS includes integrated cyber supply chain programs for the energy sector that leverage outputs of cyber vulnerability testing. These include integration with intelligence community programs, DOE CIO cyber supply chain programs, energy sector demonstration projects for automated generation and exchange of hardware and software bills of materials, and digital subcomponent supply

chain illumination tools.

Major Changes from FY 2021 Request
Cybersecurity R&D efforts have been reassigned from CESER CEDS to DOE applied program offices. CESER CEDS will coordinate with the other offices to streamline Research and Development (R&D) of cybersecure energy delivery systems preventing redundancies and gaps across electricity, fossil fuels, nuclear, and renewable technologies.

Electricity (OE)

OE's Cyber R&D program requested in FY 2022 is renamed to Cyber Resilient and Secure Utility Communications Networks, or SecureNet, in the FY 2023 Request.
The FY 2023 SecureNet request provides support to research and develop advanced solutions that focus on a security-by-design approach based on data and physics to address vulnerabilities of the grid and critical operational data acquisition, processing, communications, and control systems that are specific to the electricity delivery system, both transmission and distribution. It also addresses OE's responsibility for catalyzing energy sector cybersecurity associated with electricity delivery systems, providing an opportunity to strengthen the relationship with other OE research for accelerated results. CESER retains lead responsibility for crosscutting cybersecurity issues that span beyond electricity delivery systems, as well as for coordinating energy sector cybersecurity activities across the Department.

Office of Energy Efficiency and Renewable Energy

In FY 2023, EERE requests $26.2 million for high priority RD&D with a clear path to deployment, technical assistance, and Development best practices to identify and mitigate cyber risks. Work supported by EERE complements the DOE Multiyear Plan for Energy Sector Cybersecurity and includes the following:

- Analysis of cybersecurity risks in integrated biorefineries, and other investments in the Bioenergy Technologies portfolio, to ensure projects are identifying risks and taking necessary precautionary measures. The Request supports efforts to develop and implement findings and recommendations throughout laboratory project portfolio and competitive solicitations.
- Cybersecurity work though the Building Technologies the Grid-interactive Efficient Buildings (GEB) Initiative. In addition to improving the energy efficiency of the overall building, this research focuses on making equipment more intelligent through next-generation sensors, controls, connectivity, and communication.
- Technical Assistance for facility related control systems and the integration of Distributed Energy Technologies and Integration to assist with climate adaptation and electrification strategies in Federal buildings and other installations through the Federal Energy Management Program.
- Continued support for Hydrogen at Scale (H2@Scale) investments which include a cybersecurity component. H2@Scale is a concept that explores the potential for wide-scale hydrogen production and utilization in the United States to enable resiliency of the power generation and transmission sectors, while also aligning diverse multibillion dollar domestic industries, domestic competitiveness, and job creation.
- Integration of cybersecurity into relevant distributed energy resource controls, bulk power system protections, and other Grid Modernization Lab Consortium activities supported by Solar Energy Technologies.
- Sustained support for cyber physical security of the charging of Plug-in Electric Vehicles (PEV) and the interface between PEV charging and the electric grid through Vehicles Technologies.
- Continued development of digital tools and a pilot program to simulate hydropower cyber-attack and subsequent recovery by Water Power Technologies.
- Support for efforts focused on setting up wind plant communication, control, and power system co-simulation environment and conducting wind plant cybersecurity assessment and risk mitigation through Wind Energy Technologies.

Office of Nuclear Energy

In FY 2023, NE requests $7.5 million for the Nuclear Energy Enabling Technologies (NEET) Crosscutting Technology Development (CTD) subprogram to conduct research and development on methods to incorporate cybersecurity by design into advanced reactor concepts, advanced control architectures including autonomous and remote operations, standards

for reducing supply chain risks, and the cost-effective integration of nuclear safety risk management with cybersecurity risk management.

Office of Fossil Energy and Carbon Management (FECM)

In FY 2023, the Office of Fossil Energy and Carbon Management (FECM) (Headquarters) requests $1.8 million to support central coordination of the strategic and operational aspects of cybersecurity and facilitates cooperative efforts for incident response and the implementation of Department-wide Identity, Credentials, and Access Management (ICAM).

Office of the Chief Information Officer

In FY 2023, CIO requests $1.553M for the DOE Spectrum Management Program to manage DOE radio frequency spectrum-dependent resources for NNSA, Power Marketing Administrations (PMAs), Office of Secure Transportation, and National Laboratory spectrum-dependent assets. As the 9th largest holder of radio frequencies with more than 7,300 individual radio assignments, the Program provides technical, logistical, and administrative support, as well as ongoing oversight and advocacy at an inter-agency level in the National Capital Region. Critical DOE missions and essential functions utilizing Spectrum services include the National Power Grid, Interstate Electricity Transmission, Satellite Missions, Nuclear Emergency Search, Radiological Assistance, Secure Transportation and Safeguards, and Protective Force Communications.