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U.S. Department of Energy

Committee on Space, Science, and Technology

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Thank you Chairman Lummis, Ranking Member Swalwell, and members of the Subcommittee. I am pleased to represent the Department of Energy (DOE) Office of Science at this hearing to discuss the role of the Office of Science in providing tools for scientific discovery and basic energy research.

The DOE Office of Science has long been a leader of U.S. scientific discovery and innovation. Over the decades, the Office of Science has pushed the frontiers of understanding of the origins of matter and the universe; the Office Science has led the world in high performance computing and simulation; we have helped drive the transition from observing natural phenomena to the science of control and directed design at the nanoscale; the Office of Science has played an important role in initiating the modern biotechnology revolution through the initiation of the Human Genome Project; and the Office of Science has built and operated the large-scale scientific facilities that collectively form a major pillar of the current U.S. scientific enterprise. As the federal agency funding the largest fraction of basic research in the physical sciences, the Office of Science will continue to pursue scientific discoveries that provide the technological foundation to extend our understanding of nature and to enable new technologies that support DOE's energy, environment, and security missions.

Today, the Office of Science looks to the future by building on both our historic strengths and unique assets. The Office of Science conducts mission-focused research that employs the capabilities of the national laboratories, universities, and industry to deliver scientific breakthroughs and extend the Nation's knowledge of the natural world.

The Office of Science supports more than 30 national scientific user facilities, which provide researchers with the most advanced tools of modern science, including accelerators, detectors, colliders, supercomputers, light sources and neutron sources, and facilities for studying the nanoworld, the environment, and the atmosphere. Today, about 29,000 researchers from academia, industry, and government laboratories, spanning all fifty states and the District of Columbia, use these facilities to perform scientific research. The Office of Science continues to build on its legacy of excellence in creating and operating world-class, large-scale scientific tools. From the earliest accelerators to the new Linac Coherent Light Source, these facilities continue to redefine what is possible.

The Office of Science is also responsible for the oversight of 10 of DOE's 17 national laboratories: Ames Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Princeton Plasma Physics Laboratory, SLAC National Accelerator Laboratory, and Thomas Jefferson National Accelerator Facility.

Together, these laboratories comprise a preeminent federal research system, providing the Nation with strategic scientific and technological capabilities. The laboratories execute long-term scientific and technological missions, often with complex security, safety, project management, or other operational challenges; develop unique, often multidisciplinary, scientific capabilities beyond the scope of academic and industrial institutions; and develop and sustain critical scientific and technical capabilities to which the government requires assured access. These laboratories also play the major role in the design, construction, and operation of the world-leading facilities and research tools described above.

The DOE laboratories complement the roles and capabilities of the Nation's academic and industrial research efforts—they collaborate with universities in fundamental and applied research, and they partner with industry in technology development and deployment to aid the transfer of R&D to the marketplace.

Secretary Moniz recently created the National Laboratory Policy Council (NLPC) and the National Laboratory Operations Board (NLOB) to strengthen the partnership between the department and the laboratories. The NLPC provides a forum for Laboratory and Departmental leadership to improve laboratory strategic direction and program planning. Early topics addressed by the NLPC are expected to include accessibility of research facilities, support of technology transfer, and an enhanced role for the laboratories in addressing national priorities. The NLOB will focus on complex-wide management issues and is expected to provide input on developing, improving, and implementing effective and streamlined management and operations.

Secretary Moniz also approved a top-level reorganization of the Department that reallocates the responsibilities of the Department's three Offices of Under Secretary. This reorganization will improve integration of the science and applied energy R&D programs of the Department by establishing an Under Secretary for Science and Energy; will improve project management and increase the effectiveness and efficiency of our mission support functions across the Department by establishing an Under Secretary for Management and Performance; and will establish an enterprise-wide vision and coordination of major cross-cutting programs. The Under Secretary for Nuclear Security will oversee the National Nuclear Security Administration.

One aspect of this reorganization combines the energy and science programs of the department under a single Under Secretary for Science and Energy to include the energy technology portfolio, resulting in establishment of the Office of the Under Secretary for Science and Energy. This enables closer integration of basic science, applied research, and technology demonstration. This new position will enable DOE to build on existing collaborations between basic and applied sciences. For example, more than half a dozen "tech teams" serve as an ongoing mechanism for Secretary Moniz and the new office of the Under Secretary for Science and Energy to drive integration and bring together program managers in areas such as advanced computing, the electric grid, and energy storage. For further details, the Office of Science FY 2014 budget request details R&D coordination for each of our six program areas. Additionally, we are currently exploring other areas that would benefit from cross cutting science and technologies collaboration.

Today, the Office of Science focuses on strategic areas inspired by the most compelling scientific opportunities. Our six program areas collaborate and leverage the knowledge and experience of one another. Expertise in accelerator physics that started in High Energy Physics program now enables the synchrotron radiation light sources in the Basic Energy Sciences program. Climate modeling activities in the Biological and Environmental Research program benefit from atmospheric measurements in that same program and, also, from the high performance computing facilities supported by the Advanced

Scientific Computing Research Program. The following sections summarize current Office of Science activities in the six program offices.

ADVANCED SCIENTIFIC COMPUTING RESEARCH (ASCR)

The ASCR program supports mathematical, computational, and computer sciences research as well as high performance computing and network facilities. This research develops and deploys computational and networking capabilities to analyze, model, simulate, and predict complex phenomena.

No other nation has been as successful in scientific computing and innovation as the United States (U.S.). The U.S. has more supercomputers on the list of the 500 world's most advanced machines than any other nation–and it has held this advantage since the first such list was compiled in 1993. In large part, the U.S. owes its advantage to a longstanding and strategic effort by its universities, high-tech industries, and federal science agencies, in particular the Department and its national laboratory complex. These groups have pushed the boundaries of computing to support economic growth, quality of life, and national security. High performance computing and large data systems are now a mainstay for U.S. strategic industries. But our lead is not guaranteed, and maintaining it will require innovation and effective stewardship.

The National Energy Research Scientific Computing Center (NERSC) is the primary high performance scientific computing resource for researchers supported by the DOE Office of Science. NERSC-7 is a Cray XE6 with a peak theoretical performance of 1.29 Petaflop/s(or over 100 trillion operations per second). NERSC supports the largest and most diverse research community of any computing facility within the DOE complex. In 2012, over 600 projects ran at NERSC.

The Oak Ridge Leadership Computing Facility (OLCF) operates a 27 petaflop system, which is one of the most powerful computers in the world for scientific research according to the June, 2013 Top 500 list. The Argonne Leadership Computing Facility (ALCF) operates a 10 petaflop machine with relatively low electrical power requirements. In order to maximize the potential of these machines, the Office of Science requires that a large portion of the computing resources be devoted to jobs that require more than 20 percent of the computational resources of a given facility. The lessons learned about large-scale computing systems and user support inform NERSC and others about how to broaden and extend the impact of advanced scientific computing to the wider research community.

The Energy Sciences Network (ESnet) is a high-speed network optimized for the support of large-scale scientific research. ESnet interconnects the entire national laboratory complex, including its supercomputer centers and all user facilities. ESnet provides direct connections to more than 40 DOE sites at speeds up to 100 gigabits per second. ESnet differs from traditional providers of network services because massive science data flows require different handling than small flows generated on the global Internet.

ASCR, in collaboration with the NNSA, is pursuing the research necessary to enable and build the next-generation of supercomputers. These exascale machines (i.e., computing on order of 10^{18} operations per second and order of 10^{18} bytes of storage) will extend capability significantly beyond today's petascale computers to address next-generation problems in science, engineering, and large data. It is anticipated the exascale effort also will set the U.S. on a design trajectory of a broad spectrum of capabilities that will expand the use of terascale and petascale computing to smaller organizations, businesses, and individuals. This will require new technology advances, the most important of which involve advances in parallelism, the speed of memory access, and energy efficiency that are needed for scalable computing systems capable of greatly improved performance with acceptable power requirements. These research investments will impact computing at all scales from the largest scientific computers and data farms to Department-scale computing to home computers and laptops.

BASIC ENERGY SCIENCES (BES)

The BES program supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security.

The disciplines that BES supports—condensed matter and materials physics, chemistry, geosciences, and aspects of physical biosciences—are those that discover new materials and design new chemical processes to address important aspects of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation. The energy systems of the future—whether they tap sunlight, store electricity, or make fuel by splitting water or reducing carbon dioxide—will revolve around materials and chemical changes that convert energy from one form to another. Key to these energy systems will be new materials created using advanced synthesis and processing techniques coupled with high performance computational modeling that precisely predicts the atomic arrangements in materials. These advanced materials must be designed and fabricated to exacting standards.

The BES program also designs, constructs, and operates major scientific user facilities that provide researchers access to unique tools to advance a wide range of sciences, including chemistry, physics, geology, materials science, environmental science, biology, and biomedical science. These facilities enable the study of matter at the level of atoms and molecules, and employ instruments that can probe structures that are one thousand times smaller than those detectable by the most advanced light microscopes.. These probes, which are x-rays, electrons, and neutrons, provide unique capabilities to help understand the fundamental aspects of the natural world. A wide range of industries have found these facilities critical to product and process development. The facilities are operated on an open access, competitive merit review basis and serve more than 13,000 users each year.
The BES program also supports 46 Energy Frontier Research Centers (EFRCs) and two Energy Innovation Hubs (Hubs). These funding activities have a common theme—they are new approaches to accelerate the pace of discovery and innovation. EFRCs are based on community-identified basic research needs to advance areas of energy technology. These centers have demonstrated the power of small-team science that helps drive discovery and innovation beyond what individual investigators might accomplish. After four years, the 46 EFRCs have produced 3,800 peer-reviewed journal papers, 200 patent applications, 60 patent/invention disclosures, and 30 licenses for EFRC technologies. EFRC graduate students and staff have gone on to positions in industry, academia, and national laboratories. In FY 2014, an open recompetition is scheduled for the EFRCs.

The BES program supports two of the DOE five Hubs. The Hubs are intended to address technical challenges that require large, multi-institutional, multi-disciplinary efforts to dramatically advance technology in their areas; this might mean moving from discovery to prototypical technology or from early stage technology to commercial viability. The Hubs require strong leadership to shift research directions when needed. The two Hubs supported by the BES program are: (1) the Joint Center for Artificial Photosynthesis, established in September 2010, which focuses on advances in the development of artificial photosynthetic systems for converting sunlight, water, and carbon dioxide into a range of commercially useful fuels, and (2) the Joint Center for Energy Storage Research, established in

December 2012, which focuses on the fundamental performance limitations for electrochemical energy storage—beyond lithium ion batteries—relevant to both the electricity grid and transportation.

BIOLOGICAL AND ENVIRONMENTAL RESEARCH (BER)

The BER program supports fundamental research and scientific user facilities to achieve a predictive understanding of complex biological, climatic, and environmental systems. A hallmark of activities in recent years has been the integration within and between the disciplines of biological sciences and environmental sciences to address major issues in sustainable energy.

The BER-supported research uncovers nature's secrets from the diversity of microbes and plants to how entire biological systems work, how they interact with each other, and how they can be manipulated to harness their processes and products. Understanding how genomic information is translated into functional capabilities enables redesign of microbes and plants for sustainable biofuels production, improved carbon storage, and understanding the biological transformation of materials such as nutrients and contaminants in the environment. The DOE Joint Genome Institute remains an essential component for BER's systems biology efforts, providing high-quality genome sequence data to the research community and developing future capabilities to manipulate and synthesize DNA in support of biofuels, biodesign, and environmental research.

Today, the tools of plant and microbial systems biology are being used at the three DOE Bioenergy Research Centers (BRCs) to address barriers to the design and production of next-generation biofuels from non-food plant biomass. As forerunners of the Hubs, the BRCs expand scientific knowledge, starting with research needed to overcome the barriers to cellulosic biofuels. Like Hubs, the BRCs are large, multi-institutional and multi-disciplinary centers. They have strong leadership that has demonstrated flexibility to shift research directions as needed. As the BRCs have matured—they are in their second five-year award term—they have further advanced basic research and are partnering with the DOE technology offices and industry to help develop technology based on scientific discovery.

The BER program also supports modeling and experimental research to understand the roles of the Earth's biogeochemical systems (the atmosphere, land, oceans, sea ice, and subsurface) in determining climate in order to predict climate decades or centuries into the future, information needed to plan for future energy and resource needs.

As a major supporter of the Community Earth System Model (CESM), a leading U.S. climate model, BER research seeks to improve today's climate models by gaining a more accurate understanding of climate processes, including addressing two of the most critical areas of uncertainty in climate science—the impacts of clouds and aerosols. BER's Atmospheric Radiation Measurement Climate Research Facility (ARM) provides long-term land-based atmospheric observation and measurement data that is used by over a thousand scientists worldwide to study the impact of evolving clouds, aerosols, and precipitation on the Earth's radiative balance. A major goal of this work is quantifying and reducing the uncertainties in Earth system models based on advanced model development, diagnostics, and climate system analysis. Priority model components include the ocean, sea-ice, land-ice, aerosols, atmospheric chemistry, terrestrial carbon cycling, multi-scale dynamical interdependencies, and dynamical cores.

BER also supports research to understand the impacts of climate change (e.g. warmer temperatures, changes in precipitation, increased levels of greenhouse gases, and changing distributions of weather extremes) on different ecosystems such as forests, grasslands, and farmland. BER's Integrated

Assessment Program seeks to understand and describe the role of human activity (e.g., existing energy infrastructures, proposed renewable infrastructures, related water infrastructures, etc.) as an interdependent component of the regional climate and earth system, with a view to define system dynamical thresholds and tipping points, larger scale impacts, and possible mitigation strategies. Finally, BER research seeks understanding of the critical role that biogeochemical processes play in controlling the cycling and mobility of materials (e.g., carbon and other nutrients) in the Earth's subsurface and across key surface-subsurface interfaces in the environment.

HIGH ENERGY PHYSICS (HEP)

The HEP program supports research to understand how the universe works at its most fundamental level by investigating the elementary constituents of matter and energy, probing the interactions among them, and exploring the basic nature of space and time.

Today, particle physics is described by the Standard Model, a successful model of the elementary particles that make up ordinary matter—the matter that we can see—and the forces that govern them. However, astronomical observations indicate that ordinary matter makes up only about 5% of the universe, the remainder being dark energy and dark matter, both "dark" because they are either nonluminous or unknown. Neither is described by the Standard Model. The observation of very small but non-zero masses of the elementary particles known as neutrinos provides further hints of yet-to-be-understood physics beyond the Standard Model. A world-wide research program is underway to discover what lies beyond the Standard Model.

The HEP program explores these questions using a variety of tools and theories, which are described in three topical areas: the Energy Frontier, the Intensity Frontier, and the Cosmic Frontier. These are described below, each with an example of a key experiment. HEP continues to gather community input on possible future facilities via the Particle Physics Project Prioritization Panel—a subcommittee of the federal High Energy Physics Advisory Committee—that was charged in September, 2013 to assess current and future scientific opportunities over the next 20 years and recommend facilities that are best suited to address these opportunities.

The Energy Frontier uses the highest energy accelerators available to create particles never before seen in the laboratory, revealing their interactions and investigating fundamental forces. In 2012, HEP researchers at the Large Hadron Collider at CERN in Switzerland participated in the observation of the long-sought-after Higgs boson.

The Intensity Frontier uses intense particle beams, massive detectors, and/or high precision detectors to investigate fundamental forces and particle interactions by studying events that occur only rarely in nature. The NOvA neutrino experiment and detector contains the world's most intense neutrino beam; the goals of this experiment include improved measurements of neutrino properties. Other experiments at Fermilab will probe energy scales beyond those achievable at the LHC through the study of rare processes and precision measurements.

The Cosmic Frontier uses advanced telescopes and underground detectors to measure astrophysical phenomena that provide information about the nature of dark matter and dark energy. The *Large Synoptic Survey Telescope Camera (LSSTcam*) is a digital camera for the ground-based optical and near-infrared LSST observatory, located in Chile. LSST will provide deep images of half the sky every few nights. It will address a broad range of astronomical topics with an emphasis on precision studies of the nature of dark energy. The project is in collaboration with the National Science Foundation and private and foreign contributions. DOE will provide the camera for the facility.

HEP is also the steward of accelerator R&D technology for DOE. This extends accelerator science research to other fields of science and to R&D in specific technological areas, such as high-power lasers. Many of the advanced technologies and research tools originally developed for HEP have proven widely applicable to other sciences as well as industry, medicine, and national security.

NUCLEAR PHYSICS (NP)

The NP program supports research to discover, explore, and understand all forms of nuclear matter. The fundamental particles that compose nuclear matter—quarks and gluons—are themselves relatively well understood; however, the manner in which they interact and combine to form the different types of matter observed in the universe today and during its evolution remains largely unknown. In the quest to understand the properties of different forms of nuclear matter, NP supports both theoretical and experimental research. Theoretical approaches are based on a description of the interactions of quarks and gluons using a theory known as Quantum Chromodynamics.

The NP program also operates the Isotope Development and Production for Research and Applications activity (Isotope Program), which supports the production, distribution, and development of production techniques for radioactive and stable isotopes in short supply and critical to the Nation. The goals of the program are to make key isotopes more readily available to meet U.S. needs and to support R&D for developing new and more cost-effective and efficient production and processing techniques.

User facilities and their associated equipment account for about half of the NP program. Three national scientific user facilities are supported: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory; the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility; and the Argonne Tandem Linac Accelerator System at Argonne National Laboratory. These facilities serve more than 3,000 users each year. In addition, the planned Facility for Rare Isotope Beams (FRIB) is scheduled to begin construction at Michigan State University in FY 2014.

The RHIC facility, which began operations in 2000, remains the only collider in the world with dedicated running for heavy ion research (the CERN Large Hadron Collider runs heavy ions about one month per year), and it is the only polarized proton collider ever built. RHIC collides all ion beam species from protons to uranium. Two concentric accelerator rings 2.4 miles in circumference containing a total of 1700 superconducting magnets afford RHIC the capability to independently accelerate and collide different beam species and, for protons, different spin polarizations. RHIC is used by about 1,200 DOE, NSF, and international researchers each year.

CEBAF provides beams of polarized electrons for the study of quark and gluon structure of protons and neutrons. In 2012, CEBAF began an 18 month shut down to implement a major upgrade that will double the maximum energy to 12 GeV, upgrade instruments, and add a new experimental hall for research on exotic mesons. CEBAF is an unique scientific user facility with unparalleled capabilities world-wide using polarized electron beams to study the contributions of quarks and gluons to the properties of hadrons.

FRIB will provide intense beams of rare isotopes for research in nuclear structure, nuclear astrophysics, and fundamental symmetry studies to advance knowledge of the origin of the elements and the evolution of the cosmos. FRIB will allow research on many thousands of exotic nuclear species, most of which have never existed before or are only fleetingly created in the hot interiors of stars. As a result, FRIB will provide opportunities to test the predictive power of models by extending experiments to new regions of mass and proton-to-neutron ratio and to identify new phenomena that will challenge the existing many-body theory. FRIB offers the possibility that a broadly applicable theory of the structure of nuclei will emerge. It will offer new glimpses into the origin of the elements by providing better insight into the structure of exotic nuclei that, until now, have been created only in nature's most spectacular supernova explosions.

FUSION ENERGY SCIENCES (FES)

The FES program supports research to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. This is accomplished through the study of plasma, the fourth state of matter, and how it interacts with its surroundings. Activities include experimental facilities of various scales; international partnerships that leverage U.S. expertise; large-scale numerical simulations based on experimentally validated theoretical models; the development of advanced fusion-relevant materials; and the development of new measurement techniques. The knowledge gained through these activities helps to support the international fusion facility, ITER, which will be the world's first magnetic-confinement burning plasma experiment.

FES supports two scientific user facilities: The National Spherical Torus Experiment (NSTX) at Princeton Plasma Physics Laboratory and DIII-D National Fusion Facility (DIII-D) at General Atomics in San Diego, California.

Currently undergoing an upgrade, NSTX is one of two major facilities in the world exploring the physics of plasmas confined in a spherical torus (ST) configuration. The ST configuration, with its very strong magnetic curvature, can confine plasmas with a pressure that is higher than a conventional tokamak. Research on the ST configuration could lead to the development of smaller, more economical future fusion research facilities. In addition, with its high heating power and compact geometry, NSTX, when upgraded, will have unique capabilities among existing tokamaks to explore new solutions to the plasma-material interface.

DIII-D is the largest magnetic fusion research experiment in the U.S., with a program mission to establish the scientific basis for the optimization of the tokamak approach to fusion energy production. Research focuses on the development of the advanced tokamak concept using active control techniques to manipulate and optimize the plasma to obtain conditions scalable to robust operating points and high fusion gain for ITER and future fusion reactors. A key feature of the DIII-D physics program is the development and use of a large suite of diagnostic measurement capabilities.

ITER, currently under construction as an international project in France, is designed to generate the first sustained burning plasma (300 seconds, self-heated). The ITER Project is an international consortium consisting of the U.S., China, India, Japan, South Korea, the Russian Federation, and the European Union (the host). The U.S. Contributions to the ITER Project is 9.09% of the ITER Project construction costs. The U.S. contributions consist of in-kind hardware components, personnel, and cash to the ITER Organization (IO) for the ITER construction phase. Over 80% of the funding for U.S. contributions to the ITER Project will be spent on in-kind hardware sourced from U.S. industries, national laboratories, and universities. Though progress has been made in the design and early construction at the ITER site, particularly in site preparation; the delivery of support and office buildings; and the foundation of the tokamak building, the overall progress has been slower than anticipated. We have two reviews to help us assess the path forward the DOE/SC Office of Project Assessment review which will be submitted in October, and the biennial 2013 Management Assessment of ITER that will be released in November.

SCIENCE LABORATORIES INFRASTRUCTURE (SLI)

The Science Laboratories Infrastructure (SLI) program makes important investments in improving the safety, efficiency, and mission readiness of laboratory infrastructure in order to support the scientific mission of the laboratories. Through SLI, SC is ensuring that its laboratories have state-of-the-art facilities and utilities that are flexible, reliable, and sustainable. SLI projects include new and renovated buildings with modern research and support space, as well as important infrastructure improvements that are needed to maintain the lab's ability to support world-leading science.

The SLI program has invested in projects that have the potential for the greatest impact to the scientific mission of the laboratories. For example, construction of the Research Support Building at SLAC National Accelerator Laboratory, completed in May of 2013, allowed for the removal of more than a dozen 35-year old, expensive-to-maintain, trailers. In their place, the new Research Support Building achieved LEED® Gold Certification, the second highest rating for high-performance green buildings offered by the United States Green Buildings Council.

In another example, the renovations and building replacement conducted as part of the Seismic Life-Safety, Modernization, and Replacement of General Purpose Buildings Phase II project at Lawrence Berkeley National Laboratory (2012) addressed significant safety concerns related to potential earthquakes, while providing a modernized home for the laboratory's Earth Science Division.

Other projects, including construction of the Physical Sciences Facility at Pacific Northwest National Laboratory (2011), the Chemical and Materials Sciences Building at Oak Ridge National Laboratory (2011), the Technology and Engineering Development Facility at Thomas Jefferson National Accelerator Facility (2012), and the Interdisciplinary Science Building at Brookhaven National Laboratory (2013), have added state-of-the-art, multidisciplinary research space at each of these institutions.

CONCLUSION

Chairman Lummis, Ranking Member Swalwell, thank you again for the opportunity to testify before the Energy Subcommittee to discuss Office of Science activities and programs as well as challenges and opportunities facing the Department's basic research mission. I would be happy to take any questions you have.