INVESTIGATING THE NATURE OF MATTER, ENERGY, SPACE, AND TIME

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

HOUSE OF REPRESENTATIVES

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C O N T E N T S

June 22, 2022

INVESTIGATING THE NATURE OF MATTER, ENERGY, SPACE, AND TIME

WEDNESDAY, JUNE 22, 2022

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10 a.m., in room 2318 of the Rayburn House Office Building, Hon. Jamaal Bowman [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Investigating the Nature of Matter, Energy, Space, and Time

Jun 22, 2022
10:00 AM ET

PURPOSE

The Subcommittee's hearing will examine two major components of the Department of Energy's Office of Science: the High Energy Physics (HEP) program and the Nuclear Physics (NP) program. The Isotope Program and potential impacts and supply shortages due to the Russia-Ukraine conflict and the development of accelerator technology through the Accelerator R&D and Production program will also be discussed. The hearing will focus on initiatives to advance foundational research on the nature of matter, energy, and the cosmos; the construction and operation of large-scale experiments and unique user facilities; and the relevance of these research areas to the development of accelerator technologies, isotope production, and other applications. The centrality of these activities to U.S. preeminence in particle and nuclear physics, and to isotope research and supply, will also be highlighted. Finally, the hearing will examine ways that Congress and the Administration should consider directing the activities of these programs going forward.

WITNESSES

- **Dr. Asmeret Berhe**, Director, Office of Science, Department of Energy
- **Professor Brian Greene**, Director, Center for Theoretical Physics, Columbia University
- **Dr. Lia Merminga**, Director, Fermi National Accelerator Laboratory
- **Mr. Jim Yeck**, Associate Laboratory Director and Project Director, Electron-Ion Collider, Brookhaven National Laboratory
- **Mr. Michael Guastella**, Executive Director, Council on Radionuclides and Radiopharmaceuticals, Inc.

BACKGROUND

<u>High Energy Physics Program</u>

The mission of the High Energy Physics (HEP) program is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time. HEP pursues this mission through particle physics research, and through stewardship of unique scientific user facilities and large-scale experiments.

The Administration requested $1.12 billion for HEP in Fiscal Year (FY) 2023, which would constitute an increase of $44 million or 4.1 percent above the FY 2022 enacted level. Of the additional funding, $30 million would be provided to ongoing construction projects while the remaining $14 million would be allocated for research. Despite the disproportionate growth to the construction line, HEP's flagship project, the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) would be underfunded relative to what the National Laboratories and the Department itself have estimated will be required to maintain its schedule while minimizing total costs. This issue is not unique to HEP and would stymie efforts to control the cost and schedule of several projects across multiple Office of Science programs, including NP and Isotope R&D and Production (IP).[1]

HEP Research

The research agenda of HEP and its counterpart programs at the National Science Foundation (NSF) are largely guided by the May 2014 report of the Particle Physics Project Prioritization Panel (P5), "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context".[2] The P5 report outlines a ten-year strategic plan in the context of a 20-year vision for particle physics. While the process for updating the P5 recommendations is currently underway, the science drivers that the 2014 report originally identified are still applicable. These specific lines of inquiry could inform what lies beyond the Standard Model[3], which currently governs our understanding of matter and energy. These lines of inquiry are as follows:

- Use the Higgs boson as a new tool for discovery.
- Pursue the physics associated with neutrino mass.
- Identify the new physics of dark matter.
- Understand cosmic inflation, acceleration, and dark energy.
- Explore the unknown: including new particles, interactions, and physical principles.

HEP addresses the priorities outlined the P5 report through a strategy organized along three interrelated frontiers of particle physics. Frontier research is supported by a theory program and enabled by the development of advanced technology. The Accelerator Stewardship program, which makes investments in accelerator technology available to U.S. science and industry, was

[1] The Office of Science's management of large construction projects was the focus of the Committee's April 27th hearing entitled, *Science and Energy Research Infrastructure Needs of the U.S. Department of Energy*. The hearing charter, which provides expansive detail on how the Administration's FY 2022 and FY 2023 requests would underfund LBNF/DUNE and other projects, can be found at https://science.house.gov/imo/media/doc/Hearing%20Charter%20-%20DOE%20Science%20and%20Energy%20Infrastructure%20Needs%20-%20FY23%20Request%20-%204.27.22.pdf.

[2] *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context*, Available at https://www.usparticlephysics.org/wp-content/uploads/2018/03/FINAL_P5_Report_053014.pdf.

[3] "The Standard Model describes the elementary particles, which come in three distinct types: (i) the matter particles, quarks and leptons, (ii) the photon, gluons and massive W and Z, which mediate the electromagnetic, strong, and weak forces, respectively, and (iii) the Higgs boson, which gives mass to the elementary particles. The Standard Model provides a quantitative, quantum mechanical description of the interactions of these particles that has been remarkably successful." See page 3 of the P5 report linked in reference 3.

previously funded through HEP but has since been relocated to the newly formed Accelerator R&D and Production (ARDAP) program.[4] Descriptions of each HEP subprogram follow below:

- **Energy Frontier** researchers use sophisticated accelerators and detectors to accelerate particles to the highest-energies ever made by humanity, and collide them to produce and study the fundamental constituents of matter and the architecture of the universe.

- **Intensity Frontier** researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, study some of the rarest particle interactions predicted by the Standard Model of particle physics, and search for new physics.

- **Cosmic Frontier** researchers seek to reveal the nature of dark matter and dark energy by using ultra-sensitive underground detectors to study particles from space and explore new phenomena.

- **Theoretical, Computational, and Interdisciplinary Physics** provide the framework to explain experimental observations and gain a deeper understanding of nature. A thriving theory program is essential to support current experiments and identify new directions for the field. Advanced computing tools are necessary for designing, operating, and interpreting experiments while performing the computational science and simulations that enable discovery research in the three frontiers.

- **Advanced Technology R&D** fosters fundamental research into particle acceleration and detection techniques and instrumentation. These in turn provide the enabling technologies and new research methods that can advance scientific knowledge in high energy physics and a broad range of related fields.

In addition to pursuing research in the P5 priority areas, HEP also supports research that contributes to areas of strategic national importance, including quantum information science (QIS) and artificial intelligence and machine learning (AI/ML). Conversely, these emerging capabilities will also help advance scientific knowledge in particle physics. Many of the advanced technologies, research tools, and analysis techniques originally developed for high energy physics have proved widely applicable to other scientific disciplines as well as for health services, national security, and the private sector. For example, the superconducting magnet technology originally developed for particle physics research comprises the core of MRI machines, greatly enhancing our medical diagnostic capabilities.[5]

HEP Facilities

HEP supports two scientific user facilities and is currently supporting construction of three large-scale experiments and the development of five major items of equipment (MIEs), which are smaller in scale. Descriptions of each of these facilities and projects can be found below.

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[4] https://science.osti.gov/hep/Research.
[5] https://science.osti.gov/hep/Benefits-of-HEP

Construction Projects:

- **Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE)** – DUNE is an international flagship experiment to unlock the mysteries of neutrinos, and will be installed in the LBNF. DUNE will pursue three major science goals: 1) determine whether neutrinos could be the reason the universe is made of matter; 2) look for subatomic phenomena that could help realize Einstein's dream of the unification of forces; and 3) watch for neutrinos emerging from an exploding star, perhaps witnessing the birth of a neutron star or a black hole.[6] The project is overseen by HEP and hosted at the Fermi National Accelerator Laboratory (Fermilab), with the major underground component of the experiment located in the Sanford Underground Research Facility in South Dakota. The preliminary total project cost (TPC) range is $1,260,000,000 to $1,860,000,000, as approved on September 1, 2016, but additional planning and analysis has resulted in an increased scope and thus an updated TPC estimate of $3,000,000,000.[7]

- **Proton Improvement Plan II (PIP-II)** – The PIP-II project will enhance the Fermilab Accelerator Complex to enable it to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics. PIP-II will be a critical component of LBNF/DUNE. The project will design and construct an 800 megaelectronvolt superconducting radio-frequency proton accelerator and beam transfer line, with associated modifications of other components to withstand the increased beam intensity. Some of the new components and the cryoplant will be provided through international, in-kind contributions. The approved project baseline included a TPC of $978,000,000.[8]

- **Muon to Electron Conversion Experiment (Mu2e)** – Mu2e, under construction at Fermilab, will search for evidence that a muon can undergo direct (neutrinoless) conversion into an electron, enabling investigations into new physics at energy scales beyond the collision energy of the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN). If observed, this major discovery would signal the existence of new particles or new forces beyond the Standard Model. The funding profile through FY 2019 supported the current TPC of $273,677,000. However, the COVID-19 pandemic caused delays and disruptions that necessitate a rebaselining of the project. Until that process is complete, none of the funds appropriated in FY 2021 or FY 2022 will be available to spend and construction of Mu2e will remain unfinished.[9]

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[6] https://lbnf-dune.fnal.gov/

[7] DOE FY 2023 Congressional Budget Request, Science, pages 321-322: https://www.energy.gov/sites/default/files/2022-05/doe-fy2023-budget-volume-5-science-v2.pdf.

[8] Ibid.

[9] Ibid.

MIEs:

- **Accelerator Controls Operations Research Network (ACORN)** – ACORN will replace Fermilab's dated accelerator control system with a modern system which is maintainable, sustainable, and capable of utilizing advances in AI/ML to create a high-performance accelerator for the future. ACORN will also be compatible with PIP-II, and the lab plans to collaborate with other national labs that have experience with accelerator control systems. The project has an estimated cost range of $100,000,000 to $142,000,000.[10]

- **Cosmic Microwave Background Stage 4 (CMB-S4)** – CMB-S4 is expected to be carried out as a partnership with NSF, with DOE as the lead agency and a distribution of scope planned to be determined by FY 2023. The project supports the fabrication of an array of small and large telescopes at two locations: the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. Lawrence Berkeley National Laboratory was selected in August 2020 to lead the efforts in providing the DOE scope for the project. The project has an estimated cost range of $320,000,000 to $395,000,000.[11]

- **High-Luminosity Large Hadron Collider (HL-LHC) Upgrades** – HEP is supporting upgrades to the LHC Accelerator, ATLAS Detector, and CMS Detector. Collectively, these projects ultimately will increase the particle collision rate by a factor of at least five and integrate a higher amount of data per run by a factor of at least ten. This will make the physical conditions in which the detectors operate very challenging, necessitating significant upgrades to various detector components. The President's FY 2023 budget request notes that the COVID-19 pandemic caused delays and increased costs for each of these three projects, which may necessitate the Office of Science to consider additional funding during the baselining process. The current estimated TPC for each of these MIE projects is below:

    - **HL-LHC Accelerator** – $242,720,000.

    - **HL-LHC ATLAS Detector** – estimated range of $149,000,000 to $181,000,000.

    - **HL-LHC CMS Detector** – estimated range of $144,100,000 to $183,000,000.[12]

User Facilities:

- **Fermilab Accelerator Complex** – Fermilab's particle accelerators help drive discovery in fundamental physics, innovations in accelerator science and advances in accelerator-based applications. Its main accelerator complex comprises four particle accelerators and storage rings — the Linac, Booster, Recycler and Main Injector — the last of which produces the world's most powerful high-energy neutrino beam and provides proton

[10] DOE FY 2023 Congressional Budget Request, Science, pages 328-329.
[11] Ibid.
[12] Ibid.

beams for various experiments and R&D programs. PIP-II will significantly enhance this facility's capabilities.[13]

- **Facility for Advanced Accelerator Experimental Tests (FACET-II)** – FACET-II provides DOE with the unique capability to develop advanced acceleration and coherent radiation techniques with high-energy electron and positron beams. It is hosted at SLAC National Accelerator Laboratory.[14]

Nuclear Physics Program

The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter observed in nature and how that knowledge can benefit society in the areas of commerce, medicine, and national security. The NP program stewards theoretical and experimental research, user facilities, and training in support of this mission. DOE and NSF together fund almost all basic research in nuclear physics.

The Administration requested $739.2 million for NP in FY 2023, which would be an increase of $11.2 million or 1.6 percent above the FY 2022 enacted level.

NP Research

The NP program supports research in the following areas:

- **Medium Energy Physics** focuses primarily on the experimental tests of the theory of the strong nuclear force, which is the most powerful force involved in holding matter together.[15] This research contributes to the search for possible explanations of the excess of matter over antimatter in the universe.[16]

- **Heavy Ion Physics** focuses on studies of nuclear matter at extremely high densities and temperatures by trying to recreate and characterize new and predicted forms of matter and other new phenomena which may not have existed since the Big Bang.[17]

- **Low Energy Physics** focuses on using nuclear interactions and decays to answer overarching questions related to nuclear structure, nuclear astrophysics, and fundamental symmetries.[18] This research aims to understand the basic properties and nature of matter and nuclear interactions, and uses this information to try to understand more about the composition of the cosmos and what drives stellar phenomena.

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[13] https://www.fnal.gov/pub/science/particle-accelerators/accelerator-complex.html
[14] https://facet-ii.slac.stanford.edu/overview
[15] https://www.energy.gov/science/doe-explainsquarks-and-gluons
[16] DOE FY 2023 Congressional Budget Request, Science, page 388.
[17] https://science.osti.gov/np/Research
[18] DOE FY 2023 Congressional Budget Request, Science, page 399.

- **Nuclear Theory** provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science programs and to advance new ideas and hypotheses that identify potential areas for future experimental investigations.[19]

Like HEP, NP also contributes to crosscutting initiatives across DOE such as AI/ML and QIS. Improvements in these research areas can lead to improvements in nuclear physics research.

NP Facilities

NP supports four scientific user facilities and is currently supporting construction of one large-scale facility and the development of five MIEs. Descriptions of each of these facilities and projects can be found below.

Construction Projects:

- **Electron Ion Collider (EIC) –** The EIC, to be located at Brookhaven National Laboratory with significant support from Thomas Jefferson National Accelerator Facility, will be used to help understand how the fundamental properties of the proton are generated by the nuclear strong force. The project is expected to attract international collaboration and contributions. The project has an estimated TPC range of $1.7 billion to $2.8 billion.[20]

MIEs:

- **Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)** – sPHENIX will use advanced measurement techniques to further characterize nuclear phenomena discovered at the Relativistic Heavy Ion Collider (RHIC) user facility. The project has a TPC of $27,000,000 and is funded within the existing funds for RHIC operations.[21]

- **Gamma-Ray Energy Tracking Array (GRETA) –** GRETA is an advanced detector that will improve detection techniques in homeland security and medicine. It will be used to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. Without GRETA, the Facility for Rare Isotope Beams (FRIB) user facility will be subject to accommodating less experiments, and some experiments would not be feasible at all. The project has a TPC of $58,300,000.[22]

- **High Rigidity Spectrometer (HR) –** The HRS at FRIB will increase the scientific potential of state-of-the-art devices, such as GRETA, and other ancillary detectors. The HRS will provide access to critical isotopes not available otherwise. The project has an estimated cost range of $85,000,000 to $111,400,000.[23]

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[19] DOE FY 2023 Congressional Budget Request, Science, page 405.
[20] DOE FY 2023 Congressional Budget Request, Science, page 405.
[21] DOE FY 2023 Congressional Budget Request, Science, page 418.
[22] DOE FY 2023 Congressional Budget Request, Science, page 418-419.
[23] Ibid.

- **Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) –** The MOLLER experiment would use new, advanced techniques to provide an ultra-precise measurement which would inform the nature of nuclear matter. The project has an estimated cost range of $42,000,000 to $60,100,000.[24]

- **Ton-Scale Neutrinoless Double Beta Decay (NLDBD) –** The NLDBD experiment explores a unique nuclear interaction. The observation of this experiment could answer questions surrounding nuclear matter and interactions that have perplexed modern physics for decades. The project has an estimated cost range of $215,000,000 to $250,000,000.[25]

User Facilities:

- **Relativistic Heavy Ion Collider (RHIC) –** RHIC, located at Brookhaven National Laboratory, is the first machine in the world capable of colliding heavy ions. The observation of the collision of these particles helps inform the nature of matter.[26]

- **Continuous Electron Beam Accelerator Facility (CEBAF) –** CEBAF, located at Thomas Jefferson National Accelerator Facility, produces a stream of charged electrons used to probe the nucleus of the atom. The observation of experiments at CEBAF helps inform the structure of the nucleus of an atom.[27]

- **Facility for Rare Isotope Beams (FRIB) –** FRIB, located at Michigan State University, is a heavy-ion accelerator which enables scientists to make discoveries about the properties of rare isotopes, nuclear astrophysics, and nuclear interactions. Research carried out at this facility has applications for society including medicine, homeland security, and industry.[28]

- **Argonne Tandem Linac Accelerator System (ATLAS) –** ATLAS is the world's first superconducting accelerator for projectiles heavier than the electron. ATLAS is able to produce high precision heavy-ion beams of all kinds and energies, which allows for a wide range of experimental capabilities to help inform our understanding of nuclear matter.[29]

<u>Isotope R&D and Production</u>

The Isotope R&D and Production (IP) Program develops isotope production methods and supplies isotopes and related services to the U.S. IP produces critical radioactive and stable isotopes in short supply for the nation or that no domestic entity has the infrastructure or core

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[24] DOE FY 2023 Congressional Budget Request, Science, page 418-419.
[25] Ibid.
[26] https://www.bnl.gov/rhic/physics.php
[27] https://www.jlab.org/accelerator
[28] https://frib.msu.edu/about/index.html
[29] https://www.anl.gov/atlas/about-atlas

competency to produce. It is typically the only, or one of few, global producers for these novel isotopes. Isotopes are high-priority commodities of strategic importance and are essential in medical diagnosis and treatment, discovery science, national security, industrial processes and manufacturing, space exploration and communications, biology, archaeology, quantum science, and other fields.[30]

The administration requested $97.5 million for IP in FY 2023, which would be an increase of $15.5 million or 18.8 percent above the FY 2022 enacted level.

IP Research

IP supports research and development associated with creating novel and more efficient isotope production and processing techniques to assure availability of critical isotopes that are in short supply to address the needs of the nation. IP research is focused on technologies for production and processing of radioisotopes using reactor and accelerator facilities and new technologies for enriching stable isotopes. The program lies at the intersection of many scientific disciplines including nuclear and radiochemistry, nuclear physics, accelerator and reactor science, materials science and engineering, separations science, isotope enrichment, and nuclear data. Workforce development is viewed as an essential component of IP's research program.[31] IP produces and distributes isotopes critical for advances in quantum information science.[32]

IP Facilities

IP supports dozens of facilities across the nation at national laboratories and universities to advance research and development of isotope production methods and to produce and distribute critical radioactive and stable isotopes.[33] The sale and distribution of isotopes is coordinated through the National Isotope Development Center.[34]

IP supports the construction of the U.S. Stable Isotope Production and Research Center (SIPRC) at Oak Ridge National Laboratory. The SIPRC is intended to expand gas centrifuge production capability and significantly increase electromagnetic isotope separation production capability to meet the nation's growing demand for stable isotopes and mitigate dependence on foreign countries for stable isotope supply. The project has an estimated cost range of $187,000,000 to $338,000,000.[35]

Accelerator R&D and Production

The mission of the Accelerator R&D and Production (ARDAP) program is to help coordinate Office of Science accelerator R&D; advance accelerator science and technology relevant to the Department, other Federal Agencies, and U.S. industry; foster public-private partnerships to

[30] https://www.energy.gov/science/ip/isotope-rd-and-production-doe-ip
[31] https://science.osti.gov/Isotope-Research-Development-and-Production/Research
[32] https://science.osti.gov/Isotope-Research-Development-and-Production/Research/Quantum-Information-Science
[33] https://science.osti.gov/Isotope-Research-Development-and-Production/Facilities
[34] https://www.isotopes.gov/
[35] DOE FY 2023 Congressional Budget Request, Science, page 439.

develop, demonstrate, and enable the commercial deployment of accelerator technology; support the development of a skilled, diverse, and inclusive workforce; and provide access to accelerator design and engineering resources. The overarching goal is to ensure a robust pipeline of innovative accelerator technology, train an expert and diverse workforce, and reduce significant supply chain risks by reshoring critical accelerator technology. By ensuring the supply of leading accelerator technology and facilities, ARDAP supports physical science research that provides the foundations for innovative technologies for clean energy, medicine, security, and new tools to help clean up the environment and safeguard the water supply.[36]

The President's budget request for FY 2023 would provide ARDAP with $27.4 million, an increase of $9.4 million or 52.4 percent over the FY 2022 enacted level of $18 million.

ARDAP was established in 2020 following the removal of its component activities from HEP. DOE implemented this reorganization in an effort to ensure that the development of innovative accelerator technologies and associated workforce activities were carried out in a way that would benefit multiple Office of Science programs rather than being oriented primarily towards the needs of HEP.

ARDAP Research

ARDAP carries out its mission through two subprograms:

- **Accelerator Stewardship** – The Accelerator Stewardship subprogram supports cross-cutting R&D; facilitates access to unique state-of-the-art accelerator R&D infrastructure for the private sector and other users, including operating a dedicated user facility for accelerator R&D; and drives a limited number of specific accelerator applications towards practical, testable prototypes in a five-to-seven-year timeframe. The Accelerator Stewardship subprogram also supports the curation of software and material properties databases commonly used for accelerator design.[37]

- **Accelerator Production** – The Accelerator Production subprogram supports public-private partnerships to develop new accelerator technologies to sufficient technical maturity for use in scientific facilities, commercial products, or both. Development activities will support partnerships in advanced superconducting wire and cable, superconducting radiofrequency (RF) cavities, and high efficiency RF power sources for accelerators, among other areas.[38]

ARDAP Facilities

ARDAP maintains the Accelerator Test Facility (ATF), which is the DOE Office of Science User Facility providing users with high brightness electron beams, near-infrared and long-wave

[36] DOE FY 2023 Congressional Budget Request, Science, pager 463.
[37] Ibid.
[38] Ibid.

infrared laser beams, and an ultrafast electron diffraction facility. It is hosted at Brookhaven National Laboratory.[39]

COMMITTEE ACTIVITY

Legislation

The Committee has sought to provide comprehensive policy direction to HEP, NP, IP, and ARDAP as well as empower each program to complete the projects in its construction portfolio on time and on budget, as exemplified by the Department of Energy Science for the Future Act (H.R. 3593)[40], which is also included in the America COMPETES Act of 2022 (H.R. 4521)[41]. In addition, the funding profiles authorized for construction projects in each of these programs were incorporated into the Committee-passed portion of the *Build Back Better Act* (H.R. 5376)[42]. More information about each of these sections in H.R. 3593 and H.R. 4521 follows below:

- **HEP** – The bill authorizes theoretical and experimental research in elementary particle physics and fundamental accelerator science and technology development. Specific activities are detailed for high energy and cosmic frontier research, and the bill provides explicit direction regarding international collaborations such as those in support of LBNF/DUNE and the LHC. The bill authorizes five-year funding profiles that would enable optimal operation start dates for LBNF/DUNE, PIP-II, and CMB-S4, and includes support for other projects articulated in the P5 report. Finally, the bill authorizes targeted initiatives in underground science and in accelerator and detector research and development.

- **NP** – The bill authorizes research to discover and understand various forms of nuclear matter. It also authorizes appropriations for the construction of the Electron Ion Collider.

- **IP** – The bill authorizes a research, development, and production program for isotopes that are needed for research, medical, and industrial purposes.

- **ARDAP** – The bill authorizes research to advance accelerator science and technology. It also supports activities to improve stakeholder partnerships to develop accelerator technology and support the accelerator research workforce.

Oversight Activities

During the 116th and 117th Congresses, the Committee has held several hearings examining various Office of Science programs and initiatives. Most recently, the Subcommittee on Energy held a hearing on April 27 centered on the goals and impacts of DOE's FY 2023 budget request, with a primary focus on budget planning and management of construction of Office of Science

[39] https://www.bnl.gov/atf/
[40] https://science.house.gov/bills/the-doe-science-for-the-future-act
[41] https://science.house.gov/americacompetes
[42] https://science.house.gov/markups/full-committee-markup-of-committee-print-to-comply-with-the-reconciliation-directive-included-in-section-2002-of-the-concurrent-resolution-on-the-budget-for-fiscal-year-2022-s-con-res-14

user facilities, experiments, and upgrades, including those highlighted in this charter.[43] Dr. Geraldine Richmond, DOE's Under Secretary for Science and Innovation, served as the lone witness. Committee Members used this occasion to voice their interest in seeing the Administration provide budget requests that adequately meet the Office of Science's research and construction needs. Separately, Committee staff have been consistently engaging with officials from the Office of Science and DOE leadership, as well as the White House through the Office of Management and Budget and the Office of Science and Technology Policy, to convey the same points.

The Committee has also engaged with the IP program and other stakeholders in the past few months about the instability of the isotope supply chain due to the Russia-Ukraine conflict. Many of the critical isotopes that IP supplies to the nation, and many of the isotopes more readily available in the commercial market, have single sources in the world. And many of those sources rely directly on Russia at some point in the supply chain. Various isotopes that the nation depends upon for cancer treatments or food irradiation or other industrial purposes are facing potential shortages pending any future policy decisions related to sanctions. Several of these isotopes are only useful for a short period of time and impacts from the conflict such as constrained shipping relationships have threatened their supply. The Committee is actively conducting oversight and pursuing potential solutions to address this issue.

[43] https://science.house.gov/hearings/science-and-energy-research-infrastructure-needs-of-the-us-department-of-energy

Chairman BOWMAN. This hearing will come to order. Without objection, the Chairman is authorized to declare recess at any time.

Before I deliver my opening remarks, I wanted to note that, today, the Committee is meeting both in person and virtually. I want to announce a couple of reminders to the Members about the conduct of this hearing. First, Members and staff who are attending in person may choose to be masked, but it is not a requirement. However, any individuals with symptoms, a positive test, or exposure to someone with COVID–19 should wear a mask while present.

Members who are attending virtually should keep their video feed on as long as they are present in the hearing. Members are responsible for their own microphones. Please also keep your microphones muted unless you are speaking.

Finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the hearing.

Good morning, and thank you to our panel of esteemed witnesses for joining us today to discuss the research and infrastructure needs of the Department of Energy (DOE) in the exciting fields of high-energy physics and nuclear science. As part of the discussion today, we will examine the critical research and facilities supported by DOE's Office of Science Energy Physics and Nuclear Physics (NP) programs, as well as related work in its Accelerator and Isotope programs. I especially want to welcome the newly Senate-confirmed Director of the Office of Science, Dr. Berhe, to her first appearance before Congress since being confirmed. I look forward to working with you, and congratulations.

As Chairman of the Subcommittee on Energy, I often reflect on how the work we do here will prepare us for a better and brighter future for everyone. Experts such as yourselves help us to understand and fight for better policies here in Congress that will enable a healthier and safer world through innovations in science and technology. We need to keep these big-picture goals top of mind with everything we do. We need to continue to take urgent action to make these goals a reality. This starts with supporting robust funding across our scientific enterprise.

In April, I chaired a hearing in which DOE's Under Secretary for Science and Innovation, Dr. Geraldine Richmond, testified on the importance of strong Federal science programs to maintain our scientific leadership and tackle the problems of the 21st century, including the climate crisis. We discussed the lackluster Fiscal Year 2023 budget request from the Administration for DOE's Office of Science at length and the impact that will have on our goals by insufficiently supporting large-scale scientific experiments, research, and associated facilities. We need to do much, much better.

But the budget request is not the sole focus of today's hearing, though I'm certain it will be part of the discussion. We are here to discuss the fields of high-energy physics and nuclear physics, which probe some of the biggest unanswered questions on the most basic nature of our world. What is the universe made of? Why is the universe made of something rather than nothing? And how do the materials that make up the universe stay together? We are able to push the frontiers of human knowledge on these topics through

cutting-edge research and large experiments that attract international participation, including by supporting a diverse scientific work force that is necessary to the success of these programs.

A related area of nuclear science that we'll be discussing today is on nuclear isotope research, development, and production. Isotopes are materials that we use every day to enhance our lives. Dozens of isotopes are produced worldwide for unique applications, ranging from cancer research, to powering batteries in space exploration, to making the food we consume safer. And the list goes on. Unfortunately, many isotopes have a single source in the entire world, and many of those rely on Russia in some part of the supply chain. Like many commodities, the Nation's isotope supply is at risk due to the Ukraine-Russia conflict. Even without policy action banning the isotope trade between the U.S. and Russia specifically, our supply is threatened by the impacts we are already seeing in the banking and shipping industries. We need to have these conversations to better enable a secure and resilient U.S. isotope supply.

Before I close, I want to acknowledge the important role that these fundamental scientific fields play in enhancing our well-being. Humanity has always been driven to understand the nature of the universe and our place within it. Thanks to Federal support for this kind of research, unprecedented discoveries are within our grasp.

Another huge benefit of fundamental research is the applications it can have on the Nation's health, prosperity, and security. For example, the research supported by the Office of Science in these high-energy and nuclear science fields contribute to advanced technology development, such as artificial intelligence (AI) and quantum information science. The materials, properties, and interactions we discover in these programs are directly applicable to the development of microelectronics, which in turn are used to strengthen the experiments these programs steward. These are crosscutting areas of scientific importance to our country's future.

I just want to emphasize this point to my colleagues here in Congress as we work to support robust and historic authorizations for these Federal science programs in bipartisan, bicameral conference negotiations on national competitive policies.

With that said, thank you all again for being here today, and I look forward to this discussion.

[The prepared statement of Chairman Bowman follows:]

Good morning, and thank you to our panel of esteemed witnesses for joining us today to discuss the research and infrastructure needs of the Department of Energy in the exciting fields of high energy physics and nuclear science. As part of the discussion today we will examine the critical research and facilities supported by DOE's Office of Science High Energy Physics and Nuclear Physics programs, as well as related work in its Accelerator and Isotope programs. I especially want to welcome the newly Senate-confirmed Director of the Office of Science, Dr. Berhe, to her first appearance before Congress since being confirmed. I look forward to working with you.

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This starts with supporting robust funding across our scientific enterprise. In April, I chaired a hearing in which DOE's Under Secretary for Science and Innovation Dr. Geraldine Richmond testified on the importance of strong federal science programs to maintain our scientific leadership and tackle the problems of the 21st century, including the climate crisis. We discussed the lackluster FY 2023 budget request from the administration for DOE's Office of Science at length, and the impact that will have on our goals by insufficiently supporting large-scale scientific experiments, research, and associated facilities. We need to do better.

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With that said, thank you all again for being here today, and I look forward to this discussion.

Chairman BOWMAN. The Chair now recognizes Mr. Weber for an opening statement.

Mr. WEBER. Thank you, Mr. Chairman.

The title of today's hearing is "Investigating the Nature of Matter, Energy, Space, and Time." That certainly sounds like a daunting task. However, there are three programs within the Department of Energy's Office of Science that are doing exactly that. The High Energy Physics (HEP) Program probes the fundamental characteristics of matter and energy, including interactions through the study of particle physics. This program supports research and development (R&D) activities that involve investigating the nature of dark matter, accelerating particles to the highest energies ever produced by man and colliding them to study the results, and then using particle beams and detectors to discover new physics.

As you can imagine, studying the smallest building blocks of matter requires cutting-edge facilities. Fermi National Acceleratory Laboratory, the particle physics and accelerator laboratory within

the Department's national laboratory complex, hosts thousands of scientists from all over the world. Their accelerator, detector, and computing facilities are some of the best in the entire world, and more exciting new projects are under construction.

One such project, the Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE), or LBNF/DUNE, will be the first large-scale international science facility in the United States. It will help us answer some of the most fundamental questions we have about our universe, including why matter exists. This is valuable science that will continue to support our position at the cutting edge of discovery.

However, building these facilities will take a steady funding stream commitment. And recent budget requests from the Administration are low and would actually extend the completion dates, which will risk our international advantage.

We will also discuss the progress of the Office of Science's Nuclear Physics Program, which provides approximately 95 percent of the United States' investment in fundamental nuclear physics research. To support this work, the Department has initiated construction of the Electron-Ion Collider (EIC), located at Brookhaven National Laboratory. The Electron-Ion Collider will collide high-energy electrons with high-energy protons and nuclei to produce a view of these particles' inner structure.

Last but not least, we will access—assess the Office of Science's Isotope Research and Development Program and its role in preventing shortages of the stable and radioactive isotopes needed for essential activities such as medical treatments, industrial processes, and explosive detection, just to name a few. In addition to conducting research and development on isotope production and processing techniques, this program produces and distributes critical isotopes that are in short supply or that no domestic entity can produce.

Russia's invasion of Ukraine has underscored the importance of this program and the risks of reliance on foreign supply chains for critical isotopes. And let me opine kind of parenthetically that that's true in so many instances. We need to be producing things here. We need to have that—our supply chain right here in the good old United States of America. For example, we currently rely on Russia's State nuclear energy corporation and its subsidiaries to supply us with a number of critical medical and industrial isotopes. We must pursue domestic production solutions to counter this disturbing vulnerability and a whole lot of others I just mentioned.

We will not effectively address our most urgent energy-related challenges such as lowering household energy costs or reducing dependence on foreign supply chains if we neglect the fundamental research and development required to unlock the next generation of technologies. Additionally, if we do not demonstrate a commitment to maintaining and modernizing our research infrastructure, we actually risk losing our seat at the head of the table when it comes to international scientific standing.

For those reasons, I am proud to be part of the Science Committee's ongoing bipartisan effort to get H.R. 3593, the *DOE Science for the Future Act,* enacted into law. This legislation authorizes robust funding for all three Office of Science programs I highlighted,

as well as LBNF/DUNE, the Electric-Ion Collider, and other critical infrastructure projects. This legislation is absolutely critical to supporting the future of U.S. research and development, and I'm hopeful we can move it forward as we negotiate our competitiveness legislation with the Senate.

I thank all of the witnesses for their testimony today. Dr. Berhe, I offer my word of congratulations also on your recent confirmation as Director of the Office of Science, and we are delighted to have you appear for the first time before the Committee today. Please don't make it your last. So I look forward to working with you to ensure the success of the Office. And I want to say thank you, Mr. Chairman, and I yield back.

[The prepared statement of Mr. Weber follows:]

Thank you, Chairman Bowman.

The title of today's hearing is, "Investigating the Nature of Matter, Energy, Space, and Time." That certainly sounds like a daunting task. However, there are three programs within the Department of Energy's Office of Science that are doing just that.

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Their accelerator, detector, and computing facilities are some of the best in the world and more exciting new projects are under construction. One such project, the Long- Baseline Neutrino Facility and Deep Underground Neutrino Experiment, or "L-B-N-F / DUNE" will be the first large-scale international science facility in the United States.

It will help us answer some of the most fundamental questions we have about our universe, including why matter exists. This is valuable science that will continue to support our position at the cutting edge of discovery.

However, building these facilities takes a steady funding commitment. And recent budget requests from the Administration are low and would extend completion dates, risking our international advantage.

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I thank all of the witnesses for their testimony today. Dr. Berhe ("bear-hay"), congratulations on your recent confirmation as Director of the Office of Science, and we are delighted to have you appear before the Committee for the first time today. I look forward to working with you to ensure the success of the Office.

Thank you again, Mr. Chairman, and I yield back the balance of my time.

Chairman BOWMAN. Thank you, Mr. Weber. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Chairman Bowman, thank you for holding this important hearing today, and thank you to our esteemed panel of witnesses for being here.

We are here to examine the Department of Energy's role in advancing our understanding of the foundational underpinnings of matter, energy, space, and time. DOE supports research in these areas through the Office of Science's High Energy and Nuclear Physics programs. We will also use this occasion to highlight how progress in these fields can be translated into technologies, such as particle accelerators and isotope production systems, that improve the health and welfare of American citizens across the nation. The latter has become a particularly salient issue due to Russia's war on Ukraine and its impact on the supply chains for several important isotopes.

The High Energy Physics program studies fundamental particles and their interactions with each other to gain insight into the very nature of our universe. This program pursues this mission through research at universities and national labs, and through its stewardship of unique scientific facilities and large-scale experiments.

Many other scientific disciplines and economic sectors have benefited from the advanced technologies, research tools, and analysis techniques pioneered by this program. For example, the superconducting magnet technology first developed for this research now comprises the core of MRI machines, which as we all know have significantly enhanced our medical diagnostic capabilities.

Of equal importance is the Department's Nuclear Physics program. This program aims to discover, explore, and understand all forms of nuclear matter observed in nature, and translate that knowledge into technologies that can benefit society in the areas of commerce, medicine, and national security.

This program has led to practical outcomes that benefit Americans every day, including advances in nuclear power, medicine, and environmental and geological sciences.

Also of note, until recently, DOE's Isotope R&D and Production program was a part of its Nuclear Physics program, and it still benefits immensely from that research. The Isotope program develops production methods and supplies critical radioactive and stable isotopes for a variety of uses. These isotopes are high-priority commodities of strategic importance because of the essential role they play in medical diagnosis and treatment, discovery science, national security, and a host of other areas. As we will hear today, this program is a vital source of isotopes that are in short supply or that we are not yet capable of producing domestically.

As illustrated by a slate of recent hearings, other oversight activities, and current legislation including the *America COMPETES Act,* a top priority of this Committee is the overall health of the DOE Office of Science, especially in light of its lackluster budget requests over multiple Administrations. This is particularly true of its portfolio of construction projects and user facilities, each of which is a unique resource that drives scientific progress and serves as a magnet for international research talent. I look forward to discussing these issues and more with our witnesses here today.

Thank you. I yield back.

Chairman BOWMAN. At this time, I would like to introduce our witnesses. Dr. Asmeret Berhe is the Director of the Office of Science at the Department of Energy. She is on leave from the University of California Merced where she is a Professor of Soil Biochemistry and holds the Ted and Jan Falasco Chair in Earth Sciences and Geology. Dr. Berhe's scientific leadership has been recognized by multiple national awards, including the Joanne Simpson Medal from the American Geophysical Union, the Bromery Award in the Geological Society of America, and she was selected as a new voice in science from the U.S. National Academies of Science, Engineering, and Medicine in 2018. Dr. Berhe also is a founding investigator of the ADVANCEGeo Partnership, a National Science Foundation (NSF)-funded effort to empower geoscientists to transform their workplace climate through interventions to reduce harassment, discrimination, and bullying.

Dr. Brian Greene is a Professor of Physics at Columbia University and Director of Columbia's Center for Theoretical Physics. He is recognized for a number of groundbreaking discoveries in his field of superstring theory, including the discoveries of mirror symmetry and topology change. Dr. Greene has written four *New York Times* bestsellers that explore physics for general audiences. He also co-founded the World Science Festival, which aims to cultivate a general public informed by science and take science out of the laboratory and into the streets of New York City and beyond.

Dr. Lia Merminga is the Director of Fermi National Accelerator Laboratory and a renowned accelerator physicist. She previously led the Proton Improvement Plan II (PIP–II) project at Fermilab that will enable the world's most intense neutrino beam for the lab's flagship Long Baseline Neutrino Facility and a Deep Underground Neutrino Experiment, LBNF/DUNE, and drive a broad physics research program. Dr. Merminga has held leadership roles at SLAC National Accelerator Laboratory in California; TRIUMF in Vancouver, Canada; and the Thomas Jefferson National Accelerator Facility in Virginia. She is a Fermilab distinguished scientist and a Fellow of the American Physical Society and a graduate of the Department of Energy's Oppenheimer Energy Science Leadership Program.

Mr. Jim Yeck is the Associate Laboratory Director and the Project Director for the Electron-Ion Collider at Brookhaven National Laboratory. He has over 30 years of project managing experience, including serving as the Director General of the European Spallation Source. He has also previously served as the Department of Energy's Project Manager for the Relativistic Heavy Ion Collider (RHIC) and a U.S. contribution to the Large Hadron Collider (LHC). As Project Director for the construction of the IceCube Neutrino Observatory, and as the Deputy Project Manager for the National Synchrotron Light Source II facility at Brookhaven. Mr. Yeck serves as Chair for numerous advisory committees for large projects supported by DOE, NSF, and international funding agencies.

And last but certainly not least, Mr. Michael Guastella is the Executive Director of the Council on Radionuclides and Radiopharmaceuticals Inc., or CORAR. CORAR is a trade association that represents developers, manufacturers, and distributors of radio-

pharmaceuticals and radioisotopes. Prior to CORAR, he worked in the nuclear pharmacy industry with both SENCOR International Corporation and Cardinal Health, holding a number of leadership positions over 18 years. Mr. Guastella has served on the CORAR Board of Directors for 10 years. Thank you all for joining us today.

As our witnesses should know, you will have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you all have completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel.

We will start with Dr. Berhe. Dr. Berhe, please begin.

TESTIMONY OF DR. ASMERET BERHE,
DIRECTOR OF THE OFFICE OF SCIENCE,
DEPARTMENT OF ENERGY

Dr. BERHE. Thank you, Chairman Bowman, Ranking Member Weber, and the distinguished Members of the Committee. It's with great pleasure that I join you today to represent the Department of Energy at this hearing on the Office of Science.

As Members of this Committee know, it was only a little over a month ago that I was sworn in as the Director of the Office of Science. But I have a long history with the Department of Energy, dating to my time as a graduate student when I was a Ph.D. student at Berkeley when I conducted research at the Lawrence Berkeley National Lab and the Pacific Northwest National Lab, both Office of Science stewarded laboratories, and I'm deeply familiar with the research goals of the Office of Science.

Perhaps the deepest and most awe-inspiring questions humanity asks are about the nature of matter, energy, space, and time. Today, world-leading research into these questions is being conducted by scientists supported by the Office of Science's programs on high-energy physics, nuclear physics, and isotope research and development and production.

The Office of Science is crucial to progress in these fields. We provide approximately 85 percent of the funding in particle physics research and 90 percent of the funding in nuclear physics research in the United States. As Director, it is my priority to ensure that these and all other Office of Science programs are robustly supported and maintain their world-leading status.

High energy and nuclear physics, as much as any scientific endeavors, demonstrate that scientific research is evolving more rapidly perhaps than most time since the scientific revolution. Science in these fields is also becoming more reliant on large-scale, cutting-edge facilities and technologies is becoming more data-centric and more democratic. The Office of Science is uniquely positioned to support these transformations and to unlock the future of science and technology.

Large-scale, multi-institutional, multidisciplinary science is a core competence of the Office of Science. Research we support, including in high-energy and nuclear physics programs, require some of the largest and most complex experimental facilities ever designed and built. The Office of Science makes these projects a reality.

We are—we not only support the construction and management and operation of the facilities but also the research and development of new technologies needed to realize their scientific potential. Science in the fields of high-energy physics and nuclear physics also prioritizes the production, dissemination, and analysis of massive amounts of data in both fields experiments. Experiments that are done in both fields have tens of millions of events that are generated in the largest and most complex scientific instruments ever designed. The resulting big data must be captured, curated, stored, shared among scientists and analyzed using the fastest supercomputers and most sophisticated algorithms in the world.

The Office of Science uniquely has the expertise and infrastructure needed to achieve these Herculean tasks. Enormous data repositories, the fastest data transfer networks, the world's fastest performance computers, including Frontier, the Nation's first exascale computer at Oak Ridge National Lab, and the expert staff needed to leverage these tools for discovery.

Further, many of these technologies end up benefiting society outside the lab in fields as diverse as national security and medicine. The Department of Energy's Isotope R&D and Production Program stewarded by the Office of Science supports world-leading research and development to create novel and more efficient isotope production and processing techniques. Isotopes are vital for ensuring the Nation's security and prosperity and enabling components and technologies used for numerous mission-critical applications.

Russia's invasion of Ukraine has significantly impacted the availability of many critical isotopes, given Russia's outsize role in isotope production and distribution in the world. Removing U.S. dependence on Russian isotopes is a long-term project for the Department, one we began 5 years ago and continue today. We are committed to building the needed infrastructure to produce critical isotopes domestically, and we'll continue to work tirelessly with our Federal industrial and academic partners to help alleviate the challenge with isotope supply in the near term.

Across all scientific areas we support, the Office of Science is committed to training, recruitment, retention of highly skilled work force that draws from the best minds across the full spectrum of backgrounds and cultures within the Nation.

In closing, the DOE's Office of Science is supporting science that continues to push the frontiers of knowledge today and will enable discoveries of tomorrow. DOE Office of Science is uniquely capable of providing the physical, human, and intellectual infrastructure needed to do big, multi-institutional, multidisciplinary science and do it well. And we deliver the science and technology needed for building the cutting-edge science and experimental facilities and for training the diverse and talented STEM (science, technology, engineering, and mathematics) work force that the future will demand. With support for infrastructure and continuing programs for developing the diverse and highly skilled work force, the Office of Science will continue to provide insights into the fundamental nature of matter, energy, space, and time.

Thank you again for the opportunity to speak with the Subcommittee, and I look forward to answering your questions.

[The prepared statement of Dr. Berhe follows:]

Testimony of Dr. Asmeret Asefaw Berhe

Director, Office of Science

U.S. Department of Energy

Before the

Committee on Science, Space, and Technology

Subcommittee on Energy

U.S. House of Representatives

June 22, 2022

INTRODUCTION

Thank you, Chairman Bowman, Ranking Member Weber, and distinguished members of the Committee. It is with great pleasure that I join you today to represent the Department of Energy (DOE or the Department) at this hearing on the Office of Science. As members of this committee know, the Office of Science's (SC) core mission is to deliver both the scientific discoveries and major scientific tools that will transform our understanding of nature and advance the energy, economic, and national security goals of the U.S. It is the largest Federal sponsor of basic research in the physical sciences and the lead in supporting fundamental scientific research for our energy future. Over decades, the investments and accomplishments in basic research and enabling research capabilities we've made have provided the foundation for countless new technologies that have benefited large and small businesses and launched new industries. These investments have contributed immensely to our Nation's economy, national security, and quality of life. SC continues this work today.

The core science programs in SC—Advanced Scientific Computing Research (ASCR), Biological and Environmental Research (BER), Basic Energy Sciences (BES), Fusion Energy Sciences (FES), High Energy Physics (HEP), and Nuclear Physics (NP)—along with the Offices of Isotope R&D and Production (DOE IP) and Accelerator R&D and Production (ARDAP) support research conducted at hundreds of universities and all 17 of DOE's National Laboratories, including the 10 for which SC has direct stewardship responsibility. SC supports different types of research programs—from single investigators and small teams to large, multi-disciplinary, multi-institutional collaborations. These programs probe fundamental questions to address nature's most compelling mysteries—from fundamental subatomic particles, atoms, and

molecules that form the building blocks of our universe, to highly complex and dynamic systems, such as energy storage processes, microbial cells, and carbon cycling in the environment. The knowledge gleaned from this research provides the foundation for new discoveries and innovations that are essential to fulfilling the Department's missions.

Many of the transformative scientific discoveries made by our research community are enabled by our stewardship of 28 scientific user facilities, which are available to all researchers based on the scientific merit of their proposed research. These tools include the world's most powerful computers, brightest X-ray light sources, most intense neutron sources, fastest information network, and specialized capabilities, such as nanofabrication and multiple modes of imaging, within centers for nanoscience and bio-characterization. The Department continues to invest in the development of the next generation of scientific tools to maintain U.S. leadership in scientific discovery and technology development to support our Nation's economic competitiveness and national security.

Expanding Our Understanding of Matter, Energy, Space, and Time
SC-supported research in High Energy Physics (HEP) and Nuclear Physics (NP) expands our understanding of the universe, from the subatomic scale to the cosmic scale. Our investments ensure that the United States maintains its leading roles in these highly international efforts. Many of the groundbreaking discoveries enabled by the support provided by these programs and their predecessors at DOE—from the discovery of the top quark and the Higgs Boson to the discovery and characterization of the quark-gluon plasma to the recent measurements at the Muon g-2 experiment that call into question the standard model of physics—have been possible only due to the coordinated efforts of thousands of scientists in the U.S. and abroad working together at some of the most complex scientific instruments ever conceived and constructed. SC's support for research in fundamental physics requires the development of cutting-edge technologies, including those for accelerator science.

Half of the 28 current SC user facilities have a particle accelerator as a central component, providing particles and radiation of unmatched quality and facilitating research for thousands of researchers each year (almost 14,000 scientists in 2021). Keeping the accelerator-based SC facilities at the cutting edge requires continued, transformative advances in accelerator science and technology, as well as a workforce able to employ these tools to perform world-leading research. Developing new accelerator technologies for future generations of experimental facilities and supporting translation of these technologies into a broad range of applications that benefit society requires a coordinated effort across SC.

HIGH ENERGY PHYSICS

Program Intro
The HEP program's mission is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time. U.S. investments in this area have been guided since 2014 by the report of the Particle Physics Project Prioritization Panel (P5), a multiyear scientific community effort coordinated by the High Energy Physics Advisory Panel (HEPAP) that identified five intertwined science drivers of particle physics with great promise for discovery. We pursue breakthroughs in these areas through a global program that

includes national and international partnerships that have enabled the U.S. to host world-leading facilities like the future Long Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE), and for U.S. scientists to access the most advanced facilities located abroad.

SC, through HEP, has played an important role in the collaboration between the U.S. and the European Organization for Nuclear Research (CERN) at the Large Hadron Collider (LHC), the world's largest and highest-energy particle collider. This collaboration continues with the High Luminosity upgrade of the LHC accelerator and two large detectors, which will increase the particle collision rate and increase the reach for discovering new physics. SC is leading in the development of LBNF/DUNE, our next big international mega-science project. When complete, this multi-location facility will be the centerpiece of a U.S.-hosted world-leading neutrino research program. It will use the world's most intense neutrino beam and large, sensitive underground detectors to reveal answers to fundamental mysteries of the universe.

Going forward, the scientific community is set to undertake the next iteration of the P5 process. When completed in 2023, the next strategic plan is expected to help HEP chart a course to support this scientific community through the rest of this decade and develop a high-level vision that enables the following decade of fundamental discoveries. The next iteration of the P5 process will include input from across the HEP community via an inclusive, community-led process, as well as the P5 panel itself, where particular attention will be paid not only to representing the full range of the community's science interests and aspirations, but also its rich diversity in terms of type and geography of institutions, and individual backgrounds and career stages. HEP plays a central role in this community, providing approximately 85% of U.S. particle physics funding, as well as supporting international collaborations.

Research Goals

HEP continually explores the primary structure of the universe—always pushing to higher energy collisions, more intense particle beams, and extremely low background environments in search of new and unexpected phenomena. In recent years, a significant focus of the field has been probing the known but most mysterious fundamental particles and forces in the Universe, such as the Higgs boson, discovered at the LHC in 2012. It is a particle unlike any other because it endows most other particles with mass through its interactions. A greater understanding of these interactions may finally help us unlock what lies beyond our current knowledge of particle physics. Conversely, neutrinos fill up the universe but are elusive because they glide through almost everything without interacting. Neutrinos may hold the key to why matter exists at all in the universe, as opposed to nothing. The LBNF/DUNE experiment will find the answer to this and other compelling questions.

Beyond the known particles lie the known unknowns: phenomena whose existence has been inferred from observations, but whose fundamental nature is still unclear. Two of the most important are appropriately referred to as "dark matter" and "dark energy," indicating how little we know about them. In short, dark matter holds the universe together via gravity but cannot be seen; it is thought to be due to exotic new kinds of particles yet to be discovered. Dark energy acts as a kind of anti-gravity, slowly pulling the universe apart over time. Physicists have no idea

yet what causes that effect, but it is clearly seen in multiple types of observations. Exploration of the "dark sector" is one of the great challenges for particle physics in the 21st century and has inspired several new collaborative efforts between SC and other Federal agencies. For example, SC is working with the National Science Foundation on the Cryogenic Dark Matter Search experiment and the Vera C. Rubin Observatory, which will make precision measurements of the effects of dark energy. SC continues its long-standing collaboration with NASA on the Fermi Gamma Ray Space Telescope mission and the Alpha Magnetic Spectrometer experiment on the International Space Station, both of which provide important indirect constraints on dark matter, among other science goals.

While HEP provides insights about the universe that inspire awe and intellectual curiosity, it also leads to practical advances here on Earth. The best-known practical application to emerge from HEP is the World Wide Web, created by researchers at CERN who needed a simple, platform-independent way to share data between collaborators separated across time-zones. Less known but also broadly impactful is the significant role HEP played in developing the critical technology underlying modern Magnetic Resonance Imaging (MRI) systems. The superconducting material developed for high-field magnets in large particle accelerators—as well as the industrial-scale deployment of the magnets needed in those facilities—drove down the cost and drove up the performance of the technology, making modern high-resolution MRI an accessible and indispensable tool for medical diagnostics. Numerous other medical imaging technologies were derived from advanced sensors originally developed as particle physics detectors. More than 30,000 particle accelerators are in operation around the world, serving medicine, industry, energy, the environment, national security, and discovery science, with over 7,000 of them medical accelerators dedicated to the diagnosis and treatment of disease, including cancer. [1] As accelerator science and technology continue to advance, so too will their benefits to society.

NUCLEAR PHYSICS

Program Introduction

The NP program focuses on discovering, exploring, and understanding all forms of nuclear matter—including not only the familiar forms of matter we see around us, but also exotic forms that existed in the first moments of the universe and that may exist today inside neutron stars. The overarching goal of this program is to understand why matter takes on the specific forms observed in nature. The science supported by NP covers an extraordinary range in both time and scale: from probing quarks and gluons inside protons, to searching for the largest nuclei that can exist from microseconds after the Big Bang up to the present day. The community therefore requires access to a suite of accelerator facilities with unique, complementary capabilities. Currently, NP operates four national user facilities: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL), the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF), the Argonne Tandem Linear Accelerator System (ATLAS), and the recently commissioned Facility for Rare Isotope Beams (FRIB) at Michigan State University. In the future, the Electron-Ion Collider (EIC), to be located at BNL, will provide the ability to "look inside" the proton and discover how the mass of

[1] The Accelerators for America's Future website has information about the broad range of applications of accelerator technology and links to workshops over the last more-than-a-decade sponsored by DOE. The website can be accessed at http://www.acceleratorsamerica.org/.

everyday objects is dynamically generated by the interaction of quark and gluon fields inside protons and neutrons. As noted by the National Academy of Sciences,[2] the EIC will also maintain U.S. leadership in accelerator science and technology of colliders. NP provides over 90 percent of the nuclear science research funding in the United States and supports U.S. participation in select international collaborations.

Research Goals

As documented in the National Research Council report, *Nuclear Physics: Exploring the Heart of Matter*,[3] NP research explores a broad range of epochs in the universe. RHIC recreates new forms of matter and phenomena that occurred in the extremely hot, dense environment that existed in the infant universe, including quark-gluon plasmas. CEBAF extracts information on quarks and gluons bound inside protons and neutrons that formed shortly after the universe began to cool. ATLAS "gently" accelerates nuclei to energies typical of nuclear reactions in the cosmos to further our understanding of the ongoing synthesis of heavy elements such as gold and platinum. FRIB, SC's newest scientific user facility located at Michigan State University, will afford access to eighty percent of all isotopes predicted to exist in nature and help to answer the long-standing "grand challenge" question of the ultimate limits of nuclear existence—extending our understanding of the extent to which neutrons can be added to elements before they become unstable—and the astrophysical sites and isotopic paths to heavy element production in the cosmos. All these experimental efforts, as well as the theoretical research that underpins them, is focused on understanding why matter takes on the specific forms observed in nature and how that knowledge can benefit society in the areas of energy, climate, commerce, medicine, and national security.

The future EIC will be a discovery machine for unlocking the secrets of the "glue" that binds the building blocks of visible matter in the universe. It will look inside the nucleus, and even inside its protons and neutrons. The EIC will be a particle accelerator that collides electrons with protons and nuclei to produce snapshots of those particles' internal structure. The electron beam will reveal the arrangement of the quarks and gluons that make up the protons and neutrons of nuclei. The force that holds quarks together, carried by the gluons, is the strongest force in nature. The EIC will allow us to study this "strong nuclear force" and the role of gluons in the matter within and all around us. While protons and neutrons make up the bulk of everything we see in the universe, their constituent quarks account for only a small fraction of their mass. That means gluons—massless particles that generate the glue-like force field of the strong nuclear force that holds quarks together—could account for more than 90 percent of the mass of visible matter in the universe, but the mechanism is unknown. The EIC will be a novel tool for exploring this inner microcosm dominated by gluons.

In addition to advancing scientific knowledge, pushing the boundaries of nuclear physics research facilities enables development of technologies that have near- and long-term benefits for society, even well outside of nuclear physics. The EIC currently beginning construction will be

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[2] National Academies of Sciences, Engineering, and Medicine 2018. An Assessment of U.S.-Based Electron-Ion Collider Science. Washington, DC: The National Academies Press. https://doi.org/10.17226/2517, p. 1.

[3] National Research Council 2013. Nuclear Physics: Exploring the Heart of Matter. Washington, DC: The National Academies Press. https://doi.org/10.17226/13438.

the most advanced collider ever built, and even at this early stage promises multiple game changing technological advances. First among these is the ability to "cool" the forces that ordinarily diffuse the packets of closely packed charged particles in an accelerator beam and reduce the probability of the particles colliding as desired to provide new scientific insights. The development of so-called "strong cooling" technology for the EIC will allow it to have the highest collisions rate ("luminosity") possible and is also of central interest to any application requiring an extremely intense particle beam, such as materials testing and modification, production of X-rays for lithography, radiography, high-power microwave generation, or nuclear fusion.

The ability to develop, for the first time ever, a three-dimensional tomograph of the interior of the proton will require the development of innovative signal processing/noise reduction techniques as well as ultrafast on-the-fly data syncing and image reconstruction. These are technological advances with ready extension to imaging for other important applications in the physical sciences and medicine.

As the most challenging and complex particle collider ever built, the EIC will require full integration of innovative artificial intelligence, machine learning and advanced sensor technology, advancing the state-of-the-art for optimization of particle accelerator facility command and control as well as operational safety and efficiency—technological advances readily extensible to any complex electro-mechanical system.

ISOTOPE R&D AND PRODUCTION

Program Introduction:

The Department of Energy Isotope R&D and Production Program (DOE IP) supports world-leading research and development associated with creating novel and more efficient isotope production and processing techniques and has been at the forefront of the development and production of radioactive and stable isotopes that are used worldwide.[4] Isotopes are vital to ensuring the Nation's security and prosperity. They are enabling components in technologies used for numerous mission critical applications. Isotopes are used in, for example, the development and deployment of technologies for national security and defense, energy production, industrial manufacturing, medicine, quantum information, space exploration, and discovery science. DOE IP is uniquely responsible for producing critical radioactive and stable isotopes for the Nation that are either in short supply or not commercially available. For many isotopes, DOE IP is the only producer in the world.

DOE IP maintains robust partnerships with Federal and industrial stakeholders. This ensures its isotope production and R&D activities are focused on meeting the Nation's critical isotope needs. For example, DOE IP chairs an interagency group to ensure helium-3 availability for national security and cryogenics. DOE IP has recently established production capabilities for strontium-90, promethium-147, and other radioisotopes for nuclear batteries and long-lived radioisotope power sources for defense and space applications. Advanced stable isotope

[4] DOE IP was restructured to a stand-alone program within the Office of Science (SC) in 2020 after more than a decade as a subprogram within the SC Office of Nuclear Physics (NP). To assist DOE IP in planning for the future of the isotope research and production, SC is establishing a dedicated advisory committee for the program.

enrichment capabilities are being established to address demand in medicine, research, and quantum information science (QIS). DOE IP is working with advanced nuclear fission and fusion energy companies to establish the enriched stable isotope supply chains necessary for development, demonstration, and deployment projects. The DOE IP is collaborating with the National Cancer Institute (NCI) to accelerate the transition of promising medical isotopes, such as actinium-225, from the laboratory to clinical trials. DOE IP works closely with U.S. industry, providing isotopes that our foundational to a multitude of applications, such as californium-252 for oil/gas well logging, nickel-63 for explosives testing at airports, and barium-133 for industrial radiography. Overall, DOE IP has a profound impact on the Nation and contributes daily to its security and prosperity.

Research Goals:
The research portfolio of DOE IP is high impact, encompassing advanced targetry, radiochemistry, accelerator and reactor physics, engineering, robotics, and artificial intelligence. The two primary focus areas of the research program are 1) isotopes that can be transformative for cancer therapy, and 2) developing modern enrichment technology for stable isotopes.

A dramatic shift from chemotherapy, targeted alpha therapy (TAT) is an emerging cancer treatment that has shown stunning success in treating metastasized cancers.[5] For more than a decade, DOE IP has conducted research aimed at developing production and chemical separation techniques to increase availability of isotopes used in TAT in large enough quantities to support clinical trials and applications, in direct response to requests from the NIH and medical community. As a result, DOE IP leads globally in the provision of TAT isotopes and is currently supporting multiple clinical trials.

The U.S. and Russia are the only two countries with expansive stable isotope inventories. Russia still produces enriched stable isotopes with electromagnetic-type devices and gas centrifuges. DOE IP has been re-establishing stable isotope enrichment production in the U.S. that has not existed since the 1990's to replenish dwindling inventories and alleviate dependence on Russia. DOE IP successfully developed novel electromagnetic isotope separation (EMIS) and modern gas centrifuge capabilities in 2017 and currently operates a small EMIS capability at ORNL. The Stable Isotope Production and Research Center (SIPRC), currently under construction, will include modern electromagnetic and gas centrifuge devices and dramatically increase our ability to perform multiple isotope production campaigns at large scale.[6] China is also developing significant stable isotope enrichment capabilities, moving quickly on multiple projects, including construction of a facility that seems similar in magnitude to SIPRC. The U.S. is third in stable isotope production capabilities, behind Russia and China. DOE IP is developing new enrichment capabilities using Atomic Vapor Laser Isotope Separation (AVLIS), to restore U.S. leadership

5 For a brief description of TAT, see https://joint-research-centre.ec.europa.eu/scientific-activities-z/medical-applications-radionuclides-and-targeted-alpha-therapy_en#:~:text=Targeted%20Alpha%20Therapy%20is%20based,are%20spread%20throughout%20the%20body. For review articles summarizing research on TAT, see https://link.springer.com/article/10.1007/s12210-020-00900-2, https://pubmed.ncbi.nlm.nih.gov/30326033/, or https://pubmed.ncbi.nlm.nih.gov/22143940/. . A teaching video for an IB Chemistry course can be found at https://www.youtube.com/watch?v=bH3plIzYLS8.
6 SIPRC is expected to begin operations in 2032.

and core competencies in multiple stable isotope enrichment capabilities. When implemented, the technique could provide large quantities of enriched isotopes needed for advanced, high-burnup nuclear fuels, improving operational reliability and reducing spent fuel generation. Other AVLIS enriched isotopes can support medical, scientific, and research purposes.

Impacts of Russian Invasion of Ukraine on Isotope Availability

The U.S. is dependent upon Russia for many critical isotope supply chains. Russia is the sole or primary source globally of many isotopes needed for medical, commercial, national security, and scientific applications. Current major projects supported by DOE IP, including SIPRC, were identified and initiated prior to Russia's invasion of Ukraine in part due to the recognition of the increased risk posed by reliance on a single country for critical isotopes.[7] Currently, DOE IP is actively working with Federal agencies and industry to identify and mitigate shortages in essential isotopes, within available funds; examples include helium-3 for cryogenics, carbon-14 for radio labeling of bio-chemical compounds for new drug development, cobalt-57 for Mossbauer Spectroscopy (heavily used in the study of nuclear structure in the physical sciences), and ytterbium-171 for quantum computing memory.

To entirely remove U.S. dependence on Russia in the long-term and meet growing U.S. radioisotope demand requires additional radiochemistry infrastructure through the completion of the Radioisotope Processing Facility (RPF) at Oak Ridge National Laboratory (ORNL) for reactor target processing. DOE IP is re-establishing stable isotope enrichment in the U.S. that has not existed since the 1990s. While currently Russia is the major commercial producer of stable isotopes world-wide, the SIPRC will provide the U.S. with large scale production capabilities of stable isotopes to rival those of Russia as well as the new Chinese facility under construction.

INFRASTRUCTURE

National Laboratory Infrastructure

The DOE mission is supported by the 17 DOE National Laboratories. SC supports research across the entire laboratory complex, with the largest share of contributions going to the 10 SC-stewarded National Laboratories. The expertise of the laboratory staff, and the research capabilities they help develop and operate, are invaluable assets that serve to advance the frontiers of fundamental scientific discovery, train the scientific and technical workforce in the U.S., and develop the tools and advanced instrumentation that keep our Nation at the forefront of innovation. The DOE National Laboratories are essential resources that the Nation turns to in time of emergencies. The optimal operation of this complex is indispensable to the country's leadership in science and technology development to ensure our energy, economic, and national security.

The DOE National Laboratories were established from the 1940s to 1960s, with some approaching 80 years of service. The research facilities at these Laboratories—including general research laboratories, specialized research centers, accelerators, light sources, high-performance computers, and two nuclear reactors—are supported by general-purpose infrastructure and a vast network of utilities that form the backbone of each site. The 10 SC-stewarded laboratories alone

7 DOE IP is the only Mission Essential Function in the Office of Science and continues to operate during times of national crisis, mitigating disruptions in isotope supply chains.

comprise an infrastructure portfolio worth nearly $22 billion, consisting of more than 1,600 buildings accounting for 24 million gross square feet, roads, utilities, and other supporting infrastructure assets on more than 18,000 acres of land. Today, nearly two-thirds of this support infrastructure, including utility systems, is rated as substandard or inadequate, with current deferred maintenance costs totaling $1 billion. This results in unplanned outages, costly repairs, elevated safety risks, and inefficiencies that impact our ability to maximize contributions to science and society. The Office of Science is pursuing a robust portfolio of maintenance and modernization construction projects across the 10 laboratories in our stewardship, which enable our continued innovation in the conduct of scientific discovery itself to address modern problems, including the application of AI and automation to scientific discovery.

Large-Scale Experimental Facilities
DOE's Office of Science stewards the construction and operation of some of the largest scale experimental facilities ever conceived to probe fundamental questions about the nature of matter, energy, and the cosmos. These powerful discovery tools have helped us unlock exciting insights into the universe that inspire scientists to continue asking new and ever more ambitious questions. It is part of SC's mission is to "deliver…the scientific tools to transform our understanding of nature…", in part because the scale of these projects is too vast to be pursued by smaller groups of researchers or by individual institutions (e.g., universities, private companies). Though realization of these discovery tools is challenging given their scope and ambition, SC has a demonstrated track record of working across constituencies to define these projects and bring them to fruition to meet the Department's science, energy, and security goals, in addition to the wider range of scientific and technical efforts pursued by other Government agencies and the private sector.

NP supports operations at multiple national accelerator user facilities, including the Relativistic Heavy Ion Collider (RHIC), the Continuous Electron Beam Accelerator Facility (CEBAF), the Argonne Tandem Linear Accelerator System (ATLAS), and the Facility for Rare Isotope Beams (FRIB). Completed earlier this year, FRIB is now beginning to deliver on its promise to afford access to eighty percent of all isotopes predicted to possibly exist in nature, including over 1,000 never produced on Earth. The operations of these facilities will be further enhanced by deployment of data analytics tools for autonomous decision making, currently under development through support from NP as well as parallel efforts being advanced across the SC programs. FRIB came in ahead of schedule and on-budget, serving as an exemplar of SC's project management approach and the value of the unique Cooperative Agreement with Michigan State University that was developed for the project.

Currently under construction, the Long Baseline Neutrino Facility/Deep Underground Network Experiment (LBNF/DUNE) aims to enable detection and study of one of nature's most abundant, yet elusive, particles by generating an intense beam of neutrinos, sending it underground for hundreds of miles, and measuring it using very massive detectors. These studies could advance understanding of fundamental science questions—such as, why the universe is comprised of matter instead of antimatter. The project is uniquely complex given both the scale and novelty of the detectors as well as the environment within which they will operate. This complexity made it difficult to advance the design of all parts of LBNF/DUNE simultaneously, so it has been split

into subprojects to facilitate more nimble project management. DOE has continuously evaluated LBNF/DUNE and made adjustments to continue advancing it in a timely manner. The Department and its international partners have confidence that the current approach with sub-projects will provide stability going forward and will allow the project to meet its goals more quickly; this approach will be more thoroughly assessed this summer.

Isotope production and processing requires significant and varied infrastructure: nuclear reactors, particle accelerators, facilities to handle nuclear materials and waste, nuclear facilities for radiochemical processing and separations, and secure facilities for enrichment technology. DOE IP has maximized use of existing capabilities throughout the DOE/NNSA complex and university landscape, cost-effectively exploiting capabilities and recovering valuable isotopes from legacy wastes. However, new infrastructure investments are required to mitigate dependencies on foreign supplies of critical isotopes. In the coming years, DOE IP will be completing two projects—the Stable Isotope Production and Research Center (SIPRC) and Radioisotope Processing Facility (RPF), both at Oak Ridge National Laboratory—that will significantly expand on the program's existing laboratory and university-based capabilities in R&D and production of both stable and radioisotopes. SIPRC will provide the U.S. with the capability to enrich large-scale amounts of multiple stable isotopes simultaneously.[8] RPF will provide urgently needed radiochemical separation capabilities to meet the growing demand for radioisotopes.[9] In addition, DOE IP is reviewing the potential need and use of new facilities and will continue to support R&D at the Facility for Rare Isotope Beams (FRIB) to extract and process unreacted isotopes collected after experiments.

The upcoming Electron Ion Collider (EIC) will extend the conventional facilities and technical infrastructure initially constructed for the Relativistic Heavy Ion Collider. Beyond the partnership between Brookhaven National Laboratory and the Thomas Jefferson National Accelerator Facility, the EIC is being constructed with participation by multiple DOE labs including Argonne, Lawrence Berkeley, Los Alamos, Lawrence Livermore, and Oak Ridge National Laboratories.[10] The EIC is intended to be a scientific asset for the world, and international collaboration with Italy, France, the U.K., Canada, Japan, Poland, and the Czech Republic is actively being pursued. Other countries have expressed interest as well.

These major infrastructure investments and feats of scientific inquiry are aimed at harnessing efforts from broad swaths the HEP, NP, and IP communities. Input regarding the needs for these sorts of facilities is derived from our strategically assembled advisory committees and planning processes to ensure that investment dollars are enabling extensive and impactful research portfolios as we continue to build our understanding of the universe.

Science Laboratories Infrastructure (SLI)

[8] The Stable Isotope Production and Research Center (SIPRC) achieved CD-1 in 2021 and its completion has been delayed to at least 2032, due to constrained funding.
[9] RPF achieved CD-0 in 2021, but constrained funding has pushed completion to at least 2032.
[10] The project received CD-1 in June of 2021. Operation of the EIC is envisioned to begin early in the early 2030s, subject to annual appropriations.

The Science Laboratories Infrastructure (SLI) program enables scientific and technical innovation at the SC-stewarded laboratories by funding and sustaining general purpose infrastructure. Though these investments are not directed to specific program areas or projects, it is important to note that they enable an expansive portfolio of experiments, including the large-scale experiments. Since 2006 and with the support of Congress, the SLI program has invested over $1.2 billion to support general purpose buildings and utilities in line-item construction, general plant, and focused utility projects that have successfully provided modern, reliable, and mission-ready facilities and infrastructure to support the SC mission now and into the future. The Department's continued emphasis on addressing core infrastructure issues across the DOE laboratory complex will enhance the ability of these laboratories to continue delivering scientific and technical leadership for the next 80 years and beyond.

WORKFORCE DEVELOPMENT

SC and all its programs are committed to training a highly skilled research workforce drawing from the best minds across the full spectrum of backgrounds and cultures within the Nation, in alignment with the Biden administration's priorities emphasizing diversity, equity, and inclusion in STEM fields. SC workforce development initiatives support undergraduates, graduate students, and postdoctoral researchers through research and development awards at universities and at the DOE national laboratories as well as educational and training programs to promote science and energy literacy.

Many of the future STEM professionals trained by SC are in the crucial areas of high energy and nuclear physics and isotope production. For example, DOE NP operates a traineeship opportunity for undergraduate students to help ensure the future U.S. nuclear science workforce remains the most competent and capable resource of its kind in the world, while DOE IP trains students and postdoctoral researchers to address the high demand for all core competencies in isotope research and production. The DOE IP traineeship program, in which Texas A&M is the lead institution partnering with 13 other academic sites and 3 DOE/NNSA National Laboratories, was designed to link academic institutions, particularly minority serving institutions (MSIs), with active programs and researchers involved in isotope production and processing, enabling students to participate in activities at a minimum of two different isotope production sites.

The Reaching a New Scientific and Energy Workforce (RENEW) program aims to build foundations for SC research at institutions historically underrepresented in the SC research portfolio. RENEW leverages SC's unique national laboratories, user facilities, and other research infrastructures to provide training opportunities for undergraduate and graduate students, postdoctoral researchers, and faculty at academic institutions not currently well represented in the U.S. science and technology ecosystem. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities. HEP and IP have issued new funding opportunity announcements (FOAs) through the RENEW program, while NP is using RENEW funding to expand its current undergraduate program with an emphasis on engaging institutions and communities historically underrepresented in nuclear physics research.

Workforce development by these SC programs benefits society not just through advancing research into fundamental questions about the universe, but also by providing career pathways beyond the physics research community. It is estimated that more than two-thirds of people trained in particle physicists and over half of those trained in nuclear physics find their way to diverse sectors of the economy, including energy, information technology, medical physics and imaging, nuclear medicine, electronics, communications, space exploration, national security, and finance. For example, scientists trained in high energy and nuclear physics have pioneered methods in meteorology to measure raindrop sizes with optical sensors. Others are working to develop technologies essential for the realization of a long-distance quantum network. And many of the top financial analysts developed their modeling skills while being trained in particle physics. Wherever the workforce requires highly developed analytical and technical skills, the ability to work in large teams on complex, often globally distributed projects, and the ability to think creatively to solve unique problems, you will find people trained by HEP, NP, and DOE IP workforce development programs.

CONGRESSIONAL GUIDANCE

SC welcomes the opportunity to work with Congress and our communities to plan and direct the activities of programs in high energy and nuclear physics and isotope research moving forward. We continue to adhere to a structured planning process for developing our world-leading portfolios that treats researchers as valued partners. The Particle Physics Project Prioritization Panel (P5) Strategic Planning process, coordinated by the High Energy Physics Advisory Panel (HEPAP), plays a crucial role in setting priorities for particle physics. The joint DOE/NSF Nuclear Science Advisory Committee (NSAC) provides guidance for nuclear physics and periodically pursues a long-range planning activity to identify the most compelling science questions in the field and guide major programmatic decisions, including next-generation facilities. Going forward, we are pursuing establishing an advisory committee dedicated to isotope R&D and Production, replacing the isotope subcommittee of NSAC. The National Academy of Sciences contributes regular Decadal Surveys on Astronomy and Astrophysics. SC incorporates advising from the research communities through these mechanisms into broader strategic planning and communicates with OMB and OSTP to cooperatively develop budget requests. It is by following this process that SC can be confident that information we provide to Congress accurately reflects the consensus priorities of the relevant research communities and the executive branch of the Federal Government. SC welcomes Congressional guidance and oversight in developing program directions, ensuring necessary authorizations, and determining appropriate funding levels to achieve mission goals.

CONCLUSION

Chairman Bowman, Ranking Member Weber, and members of the Committee, thank you again for the opportunity to speak with you about our High Energy and Nuclear Physics programs, the importance of isotopes and the work of our Isotope R&D and Production program to meet national needs, and our efforts on ensuring reliable infrastructure and the skilled workforce to enable both missions. Within the Federal Government's research enterprise, SC's core competence is in large scale, multi-institutional, multi-disciplinary science, which takes many forms—large research centers and national laboratories, user facilities, and hosting international

mega-science projects such as LBNF/DUNE. To do "big science" well, SC researches and develops the science and technology needed for building the large experimental facilities where future research will be done—cutting-edge particle accelerators, isotope harvesting facilities, exascale supercomputers running artificial intelligence algorithms, and so on. In this way, SC is a force multiplier accelerating scientific advances in multiple fields. SC also serves as the Federal Government's science and technology research service and research laboratories. At the aptly named DOE National Laboratories, staff conduct research not just to meet DOE's mission, but also on behalf of other Federal agencies, as well as state and local governments, and even in partnership with industry to serve the public good. SC's 28 user facilities are where researchers in government, academia, and industry employ world-leading experimental tools to do research at scales that cannot be supported by individual institutions such as universities or corporate laboratories.

Perhaps in no other fields are these massive scales and futuristic technologies as necessary as in High Energy and Nuclear Physics and Isotope R&D and Production. To answer extreme questions about the smallest-scale structures of the universe and its earliest moments requires extreme technologies and engineering, such as the most powerful and highest luminosity particle accelerators and fastest supercomputers. With support for infrastructure and continuing programs for developing a diverse and highly skilled workforce, SC will continue to provide insights into the fundamental nature of the universe and deliver the isotopes and technologies to meet the Nation's needs.

Director, Office of Science

Asmeret Asefaw Berhe

Dr. Asmeret Asefaw Berhe is Director of the Office of Science at the U.S. Department of Energy. She is on leave from the University of California, Merced where she is a Professor of Soil Biogeochemistry, holds the Ted and Jan Falasco Chair in Earth Sciences and Geology, and serves as the Interim Associate Dean for Graduate Education. Berhe's internationally recognized research lies at the intersection of soil science, global change science, and political ecology, with an emphasis on how the soil system regulates the earth's climate and the dynamic two-way relationship between the natural environment and human societies. Berhe's expertise on feedbacks in the earth system brings a unique perspective for integrating across the physical and natural sciences.

Berhe's scientific leadership has been recognized by multiple national awards. She is a Fellow of both the American Geophysical Union (AGU) and the Geological Society of America (GSA) and has received numerous awards and honors including the Joanne Simpson Medal from AGU (2020), Bromery Award from GSA (2019), and was selected as a New Voice in Science from the U.S. National Academies of Science, Engineering, and Medicine (2018).

Berhe previously served as the Chair of the US National Committee on Soil Science at the National Academies and chaired the U.S. delegation to the International Union of Soil Sciences' General Assembly at the World Congress of Soil Sciences. Berhe equally has demonstrated leadership in broadening participation in science, as a former Leadership board member for the Earth Science Women's Network and as a founding investigator of the ADVANCEGeo Partnership – a National Science Foundation funded effort to empower (geo)scientists to transform workplace climate through interventions to reduce harassment, discrimination, bullying, and other exclusionary behaviors in research environments.

Berhe was born and raised in Asmara, Eritrea and currently lives in Merced with her husband and two children. She received a B.Sc. in Soil and Water Conservation from the University of Asmara, an M.Sc. in Political Ecology from Michigan State University, and a Ph.D. in Biogeochemistry from the University of California, Berkeley.

Chairman BOWMAN. Thank you so much.
Next, we will have Dr. Greene.

TESTIMONY OF DR. BRIAN GREENE, DIRECTOR OF THE CENTER FOR THEORETICAL PHYSICS, COLUMBIA UNIVERSITY

Dr. GREENE. Thank you so much for this privilege to speak about some of the vital issues of science as it relates to the future of United States. Now, in my professional life I actually wear two related hats. First, I direct the Center for Theoretical Physics at Columbia University where I undertake mathematical research to investigate nature's forces and to determine what the insights that reveal can tell us about the fundamental structure of space and time, the goal being to answer some of the questions we've already heard. What is matter made of? Does space go on forever? What happened before the Big Bang, questions that puzzle young children and even adults who have an interest in understanding their place in the cosmic order.

My second professional preoccupation is related but distinct, bringing cutting-edge scientific insights to broad swaths of the general public through books and articles, television documentaries, live public events, performances, activities that can reach and have reached hundreds of millions of people worldwide. And while I'm happy to share in the question period relevant insights from either of these pursuits, research or public engagement, as my distinguished colleagues on the panel will speak directly to various and vital research efforts, I'm going to focus my remarks on the impact of public engagement with science has on the health and vitality now and in the long run of our country and the world.

Now part of this impact is manifest. We've already heard some of it. I suspect at least a few of us are old enough to think back to our own experiences with rotary telephone, electric typewriters, bottles of Wite-Out, and for those of us who are technically savvy in that earlier era, large stacks of computer punch cards ready to be loaded into card readers, delivering instructions to massive computers that filled entire rooms. And while I can personally testify to having experienced all of that, and they are fond memories I admit, I can't imagine going back to those days. And historians, of course, can trace with great detail the roots of our modern electronic age.

But the coarse yet sufficiently accurate summary is that the modern era emerged from breakthroughs in the very subjects we're talking about here today, understanding the constituents of matter and the forces that govern these constituents. And briefly put, if you want to manipulate matter on small scales, the very capacity at the core of everything from cell phones to the relatively tiny computers sitting on our desks, you have to understand matter on small scales.

And here is the amazing thing. In the 1920's, as researchers were feverishly rewriting our understanding of matter on subatomic scales—it's a body of work known as quantum mechanics—they had no idea what impact the revelations would one day have, or the scientific titans of those early pursuits who have testified here. And were you to have asked them how their work would im-

pact the world, most would have focused on things like human curiosity, the human urge to understand, with barely a mention of the far-off and, at that time, difficult-to-envision applications.

And yet, fast-forward 100 years, and a non-trivial portion of the gross national product of the United States can be traced back to those seemingly esoteric investigations into the heart of matter, forces, and energy, which is a wonderful demonstration of how the fundamental science of one era can become the economic engine of the next.

And of course, the impact goes well beyond economics. As my colleagues today will no doubt mention, sophisticated and lifesaving medical diagnostics and medical treatments have also emerged from these foundational scientific works. So it is anything but hyperbolic to describe these scientific pursuits is having radically transformed both life and death.

Now, this is heavy stuff. These are profound impacts. Yet to leave the discussion there would be to miss what I consider an even more important aspect, which is this. The reason science really matters is because science is a way of life. Science is a perspective. Science is the process that takes us from confusion to understanding in a manner that's precise, predictive, and reliable, a transformation for those lucky enough to experience it that is empowering and emotional. To be able to think through and grasp explanations for everything from why the sky is blue, to how life formed on Earth, not because they are declared dogma but rather because they reveal patterns confirmed by experiment and observation, well, I must tell you, that is one of the most precious of human experiences.

Now to be sure, as a practicing scientist, I know this from my own work and study. But I also know that you don't have to be a scientist to experience the transformative power of science. I've seen kids' eyes light up as I've told them about black holes and the Big Bang, and I've spoken with high school dropouts, who stumbled on popular science books and then returned to school with newfound purpose. I've received letters from soldiers on the battlefield and incarcerated prisoners seeking in the beginning——

Chairman BOWMAN. I'm sorry, Dr. Greene, you're a few seconds over. We'll come back to you on questioning.

Dr. GREENE. Oh, OK, thank you.

[The prepared statement of Dr. Greene follows:]

Subcommittee on Energy of the House Committee on Science, Space, and Technology
Investigating the Nature of Matter, Energy, Space, and Time

Brian Greene
Professor of Mathematics and Physics, and Director of the Center for Theoretical Physics, Columbia University

I have spent much of my professional career on two parallel tracks: undertaking research in theoretical physics and bringing science to the general public through television, books, and articles. Through much of this work, a common misperception I have sought to correct is that science is a pursuit whose technological fruits we may enjoy but, nevertheless, is fundamentally an esoteric activity best left to scientists. In reality, science provides an unmatched capacity to contextualize our lives, allowing for vital and richly illuminating perspectives otherwise unattainable. This theme will inform my contributions to today's hearing and is one I explored in some detail in a New York Times Op-Ed, which I have reprinted below.

Why Science Matters

Some years ago I received a letter from an American soldier in Iraq. The letter began by saying that, as we've all become painfully aware, serving on the front lines is physically exhausting and emotionally debilitating. But the reason for his writing was to tell me that in that hostile and lonely environment, a book I'd written had become a kind of lifeline. As the book is about science - one that traces physicists' search for nature's deepest laws - the soldier's letter might strike you as, well, odd.

But it's not. Rather, it speaks to the powerful role science can play in giving life context and meaning. At the same time, the soldier's letter emphasized something I've increasingly come to believe: America's educational system fails to teach science in a way that allows students to integrate it into their lives.

When we consider the ubiquity of cell phones, iPods, personal computers and the Internet, it's easy to see how science is woven into the fabric of our day-to-day activities. When we benefit from MRI devices, pacemakers and arterial stents, we can immediately

appreciate how science affects the quality of our lives. When we assess the state of the world, and identify looming challenges like climate change, global pandemics, security threats and diminishing resources, we don't hesitate in turning to science to gauge the problems and find solutions.

And when we look at the wealth of opportunities hovering on the horizon - stem cells, genomic sequencing, longevity research, nanoscience, quantum computers, space technology - we realize how crucial it is to cultivate a general public that can engage with scientific issues; there's simply no other way that as a society we will be prepared to make informed decisions on a range of issues that will shape the future.

These are the standard reasons many would give in explaining why science matters.

But the reason science really matters runs deeper still. Science is a way of life. Science is a perspective. Science is the process that takes us from confusion to understanding in a manner that's precise, predictive and reliable - a transformation, for those lucky enough to experience it, that is empowering and emotional. To be able to think through and grasp explanations - for everything from why the sky is blue to how life formed on earth - not because they are declared dogma but rather because they reveal patterns confirmed by experiment and observation, is one of the most precious of human experiences. As a practicing scientist, I know this from my own work and study.

But I also know that you don't have to be a scientist for science to be transformative. I've seen children's eyes light up as I've told them about black holes and the big bang. I've spoken with high school dropouts who've stumbled on popular science books about the human genome project, and then returned to school with new-found purpose.

And in that letter from Iraq, the soldier told me how learning about relativity and quantum physics in the dusty and dangerous environs of greater Baghdad kept him going because it revealed a deeper reality of which we're all a part.

It's striking that science is still widely viewed as an isolated body of largely esoteric knowledge that sometimes shows up in the "real" world in the form of technological or medical advances. In reality, science is a language of hope and inspiration, providing discoveries that instill a sense of connection to our lives and our world.

I've spoken with so many people over the years whose encounters with science in school left them thinking of it as cold, distant and intimidating. What a shame. Like a life without music, art or literature, a life without science is bereft of something that gives experience a rich and otherwise inaccessible dimension.

It's one thing to go outside on a crisp, clear night and marvel at a sky full of stars. It's another to marvel not only at the spectacle but to recognize that those stars are the result of exceedingly ordered conditions 13.8 billion years ago at the moment of the big bang. It's another still to understand how those stars act as nuclear furnaces that supply the universe with carbon, oxygen and nitrogen, the raw material of life as we know it. And it's yet another level of experience to realize that those stars account for less than 5 percent of what's out there - the rest being of an unknown composition, so-called dark matter and energy, which researchers are now trying to divine.

As every parent knows, children begin life as uninhibited, unabashed explorers of the unknown. From the time we can walk and talk, we want to know what things are and how they work - we begin life as little scientists. But most of us quickly lose our intrinsic scientific passion. And it's a profound loss.

A great many studies have focused on this problem, identifying important opportunities for improving science education. Recommendations have ranged from increasing the level of training for science teachers to curriculum reforms.

But most of these studies avoid an overarching systemic issue: In teaching students, we continually fail to activate rich opportunities for revealing the breathtaking vistas opened up by science, and instead focus on the need to gain competency with science's underlying technical details.

In fact, many students I've spoken to have little sense of the big questions those technical details collectively try to answer: Where did the universe come from? How did life originate? How does the brain give rise to consciousness? Like a music curriculum that requires its students to practice scales while rarely if ever inspiring them by playing the great masterpieces, this way of teaching science squanders the chance to make students sit up in their chairs and say, "Wow, that's science?"

In physics, just to give a sense of the raw material that's available to be leveraged, the most revolutionary of advances have happened in the last 100 years - special relativity, general relativity, quantum mechanics - a symphony of discoveries that changed our conception of reality. More recently, we have witnessed an upheaval in our understanding of the universe's composition, yielding a wholly new prediction for what the cosmos will be like in the far future.

These are paradigm-shaking developments. But rare is the high school class in which these breakthroughs are introduced. It's much the same story in classes for biology, chemistry and mathematics.

At the root of this pedagogical approach is a firm belief in the vertical nature of science: You must master A before moving on to B. Certainly, when it comes to teaching the technicalities - solving this equation, balancing that reaction, grasping the discrete parts of any given cell - the verticality of science is unassailable.

But science is so much more than its technical details. And with careful attention to presentation, cutting-edge insights and discoveries can be clearly and faithfully communicated to students independent of those details; in fact, those insights and discoveries are precisely the ones that can drive a young student to want to learn the details. We rob science education of life when we focus solely on results and seek to train students to solve problems and recite facts without a commensurate emphasis on transporting them out beyond the stars.

Science is the greatest of all adventure stories, one that's been unfolding for thousands of years. Science needs to be taught to the young and communicated to the mature in a

manner that captures this drama. We must embark on a cultural shift that places science in its rightful place alongside music, art and literature as an indispensable part of what makes life worth living.

It is the birthright of every child, it is a necessity for every adult, to look out on the world, as the soldier in Iraq did, and see that the wonder of the cosmos transcends everything that divides us.

Brian Greene, professor of physics at Columbia University and director of Columbia's Center for Theoretical Physics, is recognized for a number of groundbreaking discoveries in his field of superstring theory including the discoveries of mirror symmetry and topology change. Greene has written four New York Times bestsellers, exploring physics for general audiences, which have sold more than 2 million copies worldwide.The orchestral adaptation of Greene's novella, Icarus at the Edge of Time, premiered at Lincoln Center and has been performed over 65 times worldwide and his work for the stage, Light Falls, which traces Einstein's discovery of General Relativity, was broadcast as a primetime national special on PBS.

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Columbia University: Professor of Physics and Mathematics, 1996 - present.
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Cornell University: Professor of Physics, 1996, Associate Professor of Physics, 1994 -1996, Assistant Professor of Physics, 1990 –1994.

Harvard University: Postdoctoral fellow in Departments of Mathematics and Physics, 1987-1990.

World Science Festival: Co-founder, Chairman of the Board, 2006 - present.

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Education:
Oxford University: Awarded D.Phil, 1987
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Selected Honors:
Michael Pupin Medal for Service to the Nation in Science, 2022.
Finalist, Premio Cosmos Book Prize, 2021.
Board of Overseers, Harvard University, 2015—present.
Merck-Serono Book Prize for Literature and Science, for *The Hidden Reality*, 2013.
Gamow Lecturer, University Colorado Boulder, 2013.
Best Documentary, Jackson Hole Film Festival, Fabric of the Cosmos, 2013
AAPT Richtmeyer Memorial Award for Research and Teaching, 2012.
Cooper Union Urban Visionary Award, 2010.

Phi Beta Kappa Book Award, 2004.
George Foster Peabody Award for NOVA, The Elegant Universe, 2003.
Gemant Award, American Institute of Physics, 2003.
Finalist, Pulitzer Prize in General Nonfiction, 2000.
Winner, Aventis Prize, 2000.
Alfred P. Sloan Foundation Fellowship, 1993 - 1997.
NSF National Young Investigator Award, 1992 - 1997.
National Science Foundation Postdoctoral Fellowship in Mathematical Sciences, 1987-1990.
Rhodes Scholarship: For study at Oxford University, 1984 to 1986.

Publications

1. "Relativity and Non-Trivial Topology," B. Greene, J. Levin, and D. Kabat, in preparation.
2. "Mirror Symmetry: Thirty Years Later," B. Greene, in preparation.
3. "Coherent Bubble Collisions in Boom and Bust Inflation," A. Brainerd and B. Greene, in preparation.
4. "Numerical Evaluation of Acceleration-Assisted Entanglement Harvesting," A. Brainerd and B. Greene, in preparation.
5. "Computational complexity of the landscape II - Cosmological considerations Frederik Denef , Michael R. Douglas, Brian Greene, Claire Zukowski . Annals Phys. 392 (2018) 93-127
6. "Random Field Theories in the Quintic Moduli Space," K. Eckerle and B. Greene, arXiv:1608.05189 [hep-th] 2016.
7. "Dark Energy in String Theory," B. Greene and G. Shiu Adv. Ser. Direct. High Energy Phys. 22 (2015) 385-410
8. "Kink Collisions in Curved Field Space," ," P. Ahlqvist, K. Eckerle, B. Greene, e-Print: arXiv:1411.4631 [hep-th] 2014
9. "Bubble Universe Dynamics After Free Passage," P. Ahlqvist, K. Eckerle, B. Greene, JHEP 1503 (2015) 031.
10. "Exploring Spiral Inflation in String Theory," P. Ahlqvist, B. Greene, D. Kagan, e-Print: arXiv:1308.0538 [hep-th] (2013).
11. "Tumbling Through a Landscape," B. Greene, D. Kagan, A. Masoumi, D. Mehta, E. Weinberg, X. Xiao, Phys. Rev. D 88 (2013) 026005
12. "On Three Dimensions as the Preferred Dimensionality of Space," B. Greene, D. Kabat, S. Marnerides, Phys. Rev. D 88 (2013) 043527.
13. "On three dimensions as the preferred dimensionality of space via the Brandenberger-Vafa mechanism," B. Greene, D. Kabat, S. Marnerides, Phys.Rev. D88 (2013) 043527
14. "Warped Vacuum Statistics," P. Ahlqvist, B. Greene, D. Kagan, JHEP 1207 (2012) 066
15. "Brane-World Motion in Compact Dimensions, B. Greene, J. Levin, M. Parikh, arXiv: 1103.2174, Class. Quant. Grav. 28 (2011) 155013.
16. "Conifolds and Tunneling in the String Landscape," P. Ahlqvist, B. Greene, D. Kagan, E. Lim, S. Sarangi, I. Yang, JHEP 1103: 119, 2011.

17. "A Bulk Inflation from Large Volume Extra Dimensions," B. Greene, D. Kabat, J. Levin, D. Thurston. arXiv: 1001.1423, Phys. Lett. B694:485-490, 2011.
18. "Smooth Initial Conditions form Weak Gravity." B. Greene, K. Hinterichler, S. Judes, M. Parikh, Phys. Letter B697 (2011) 178-183.
19. "Dynamical Decompactification and Three Large Dimensions," B. Greene, D. Kabat, S. Marnerides. arXiv:0908.0955, Phys. Rev. D82:043528, 2010.
20. "The Origin of the Universe as Revealed Through the Polarization of the Cosmic Microwave Background," S. Dodelson, R. Easther, S. Hanany, L. McAllister, S. Meyer, L. Page, P. Ade, A. Amblard, A. Ashoorioon, C. Baccigalupi, et al., e-Print arXiv:0902.3796 [astro-ph.CO] (2009).
21. "Bouncing and cyclic string gas cosmologies," B. Greene, D. Kaba, S. Marnerides, Phys.Rev D80 (2009) 063526.
22. "Dark Energy and Stabilization of Extra Dimensions," B. R. Greene and J. Levin, ' JHEP 0711, 096 (2007).
23. "Cosmological moduli dynamics" B. Greene, S. Judes, J. Levin, S. Watson, A. Weltman, JHEP 0707 (2007) 060.
24. "Families of quantic Calabi-Yau 3-folds with discrete symmetries," C. Doran, B. Greene, S. Judes, Commun.Math,Phys. 280 (2008) 675-725.
25. "Universal correction to the inflationary vacuum," B. Greene, M. Parikh, J. Pieter van der Scharr, JHEP 0604 (2006) 057.
26. "An Effect of alpha' corrections on racetrack inflation," B. Greene, A. Weltman, JHEP 0603 (2006) 057.
27. "Extracting new physics from the CMB," B. Greene, K. Schalm, J. Pieter van de Schaar, G. Shiu, eConf C041213 (2004) 0001.
28. "Decoupling in an expanding universe: Backreaction barely constrains short distance effects in the CMB," B. Greene, K. Schalm, G. Shiu, J. Pieter van der Schaar, JCAP 0502 (2005) 001.
29. "String windings in the early universe", R. Easther, B. Greene, M. Jackson, D. Kabat, JCAP 04 (2004) 006.
30. "Brane gas cosmology in M theory: Late time behavior", R. Easther, B. Greene, M. Jackson, D. Kabat, Phys.Rev. d67 (2003) 123501.
31. "On the Hagedorn behavior of PP wave strings and N=4 SYM theory at finite R charge density", B. Greene, K, Schalm, C. Shiu, Nucl.Phys. B652 (2003) 105-126.
32. "A Generic estimate of transPlanckian modifications to the primordial power spectrum in inflation", R. Easther, B. Greene, W. Kinney, G. Shiu, Phys.Rev. D66 (2002) 023518.
33. "Cosmological string gas on orbifolds", R. Easter, B. Greene, M. Jackson, Phys.Rev. D66 (2002) 023502.
34. "Imprints of Short Distance Physics On Inflationary Cosmology", R. Easther, B. R. Greene, W. H. Kinney, G. Shiu, *Phys.Rev.D67:063508,2003.*
35. "Split attractor flows and the spectrum of BPS D-branes on the quintic", F. Denef, B.R. Greene, M. Raugas, JHEP 0105 (2001) 012.
36. "Remarks on inflation and noncommutative geometry", C. Chu, B.R. Greene, S. Shiu, Mod.Phys.Lett. A16 (2001) 2231-2240.
37. "Aspects of collapsing cycles", B. R. Greene, Int.J.Mod.Phys. A16 (2001) 767-779.
38. "Dynamical topology change in M theory", B.R. Greene, K. Schalm, G. Shiu, J. Math.Phys. 42 (2001), 3171-3187.

39. “Superstrings and related matters. Proceedings, Spring Workshop, Trieste, Italy, March 22-30, 1999”, B. Greene, J. Louis, K.S. Narain, S. Randjbar-Daemi, Singapore, Singapore: World Scientific (2000) 312p.
40. “Warped compactifications in M and F theory”, B. R. Greene, K. Schalam, G. Shiu, Nucl.Phys. B584 (2000) 480-508.
41. “Collapsing D-branes in Calabi-Yau moduli space” B.R. Greene, C.I. Lazariou, Nucl.Phys. B604 (2001) 181-255.
42. “Nonperturbative Aspects of String Theory and Supersymmetric Gauge Theories; Proceedings of the Trieste Conference on Super-Five-Branes and Physics in 5 + 1 Dimensions”, Trieste, Italy, March 23-April 3, 1998”, M.J. Duff, E. Sezgin, C.N. Pope, B. Greene, J. Louis, K.S. Narain, S. Randjbar, G. Thompson, Singapore, Singapore: World Scientific (1999). 454 pp.
43. “D-3-branes on partial resolutions of Abelian quotient singularities of Calabi-Yau threefolds”, C. Beasley, B.R. Greene, C.I, Lazariou, M.R. Plesser, Nucl. Phys. B566 (2000) 599-640.
44. “String theory, gauge theory and quantum gravity. Proceedings, Conference on Duality Symmetries in String Theory, Trieste, Italy, April 1-4, 1997, Spring School of String Theory, Gauge Theory and Quantum Gravity, Trieste, Italy, April 7-12, 1997”, E. Gava, B. Greene, J. Louis, K.S. Narain, S. Randjbar-Daemi, Nucl.Phys.B, Proc. Suppl. 67 (1998) 251 p.
45. New constructions of mirror manifolds: Probing moduli space far from Fermat points”, B.R. Greene, M.R. Plesser, S.S. Roan, In Yau, S.T. (ed.): Mirror symmetry I 347-389.
46. “An introduction to mirror manifolds”, B.R. Greene, M.R. Plesser, In Yau, S.T. (ed.):Mirror symmetry I 1-30.
47. “D-branes on nonAbelian threefold quotient singularities”, B.R. Greene, C.I.Lazaroiu, M. Raugas, Nucl. Phys. B553 (1999) 711-749.
48. “String theory”, B.R. Greene, D.R. Morrison, J. Polchinski, Proc.Nat.Acad.Sci. 95 (1998) 11039-11040.
49. “D particles on T**4/Z(n) orbifolds and their resolutions”, B.R. Greene, C.I. Lazaroiu, P. Yi, Nucl.Phys. B539 (1999) 135-165.
50. Fields, strings and duality. Proceedings, Summer School, Theoretical Advanced Study Institute in Elementary Particle Physics, TASI’96, Boulder, USA, June 2-28, 1996”, C. Efthimiou, B. Greene, Singapore, Singapore: World Scientific (1997) 1069 p.
51. “Mirror symmetry II”, B. Greene, S. Yau, Providence, USA: AMS (1997) 844 p.
52. “Geometry and quantum field theory: A brief introduction”, B.R. Greene, H. Ooguri, In*Greene, B (ed.): Yau, S.T. (ed.): Mirror symmetry II* 3-27.
53. “Brane Gases in the Early Universe: Thermodynamics and Cosmology”, R. Easther, B. R. Greene, M. Jackson, D. Kabat, *JCAP 0401 (2004) 006.*
54. “Brane Gas Cosmology in M-Theory: Late Time Behavior”, R. Easther, B. R. Greene, M. Jackson, D. Kabat, *Phys. Rev. D67 (2003) 123501.*
55. “ Inflation as a Probe of Short Distance Physics”, R. Easther, B. R. Greene, W. H. Kinney, G. Shiu, *Phys.Rev. D64 (2001) 103502.*
56. “Warped Compactifications in M and F Theory”, B. Greene, K. Schalm, G. Shiu, *Nucl.Phys. B584 (2000) 480.*

57. “Constructing mirror manifolds”, B.R. Greene, *Greene, B (ed.): Yau, S.T. (ed.): Mirror symmetry II* 29-69.
58. “F theory and linear sigma models”, M. Bershadsky, T.M. Chiang, B.R. Greene, A. Johansen, C.I. Lazaroiu, Nucl.Phys. B527 (1998) 531-570.
59. “D-Brane Topology Changing Transitions”, B.R. Greene, *Nucl.Phys. B525 (1998) 284.*
60. “Metrics on d-brane orbifolds”, M.R. Douglas, B.R. Greene, Adv.Theor.Math.Phys. 1 (1998) 184-196.
61. “Inflation decay and heavy particle production with negative coupling”, B.R. Greene, T. Prokopec, T.G. Roos, Phys.Rev. D56 (1997) 6484-6507.
62. “Orbifold Resolution by D-branes”, M. Douglas, B. Greene, D. Morrison, *Nucl.Phys. B506 (1997) 84.*
63. “Some features of (0,2) moduli space”, T. Chiang, J.Distler, B.R. Greene, Nucl.Phys. B496 (1997) 590-616.
64. “String theory on Calabi-Yau manifolds”, B.R. Greene, ePrint: hep-th/9702155 (1996).
65. “Small volumes in compacted string theory”, B.R. Greene, Y. Kanter, Nucl.Phys. B497 (1997) 127-145.
66. “A Geometric realization of confinement”, B.R. Greene, D>R. Morrison, C. Vafa, Nucl.Phys. B481 (1996) 513-58.
67. “Resolving singularities in (0,2) models”, J. Distler, B.R. Greene, D.R. Morrison, Nucl.Phys. B481 (1996) 289-312.
68. “Black hole condensation and topology change”, B.R. Greene, In Montreal 1995, Mirror symmetry 3 1-67.
69. Lectures on the quantum geometry of string theory”, B.R. Greene, In Les Houches 1995, Quantum symmetries 387-471.
70. “Black hole condensation and the web of Calabi-Yau manifolds”, T. Chiang, B.R. Greene, M. Gross, Y. Kanter, Nucl.Phys.Proc.Suppl.46 (1996) 82-95.
71. “Phases of mirror symmetry”, T. Chiang, B.R. Greene, In Los Angeles 1995, Future perspectives in string theory (1995) 97- 199.
72. “Black Hole Condensation and the Unification of String Vacua”, B.R. Greene, D.R. Morrison and A. Strominger Nucl. Phys. B451 (1995) 109.
73. “Lectures on quantum geometry”, B.R. Greene, Nucl.Phys.Proc.Suppl. 41 (1995) 92-150.
74. “Space-time topology change and stringy geometry”, P.S. Aspinwall, B.R. Greene, Nucl.Phys. B437 (1995) 205-230.
75. What can we do with string theory?”, B.R. Greene, AIP Conf. Proc. 302 (1993) 489-529.
76. “Mirror manifolds in higher dimension”, B.R. Greene, D.R. Morrison, M. Ronen Plesser, Commun.Math.Phys. 173 (1995) 559-598.
77. “The Monomial divisor mirror map”, P.S. Aspinwall, B.R. Greene, D.R. Morrison, Adv. Stud. Princeton - IASSNS-HEP-93-43 (93/09,rec.Oct.) 22 p. Cornell Univ. Ithaca - CLNS-93-1237 (93/09,rec.Oct.) 22 p. e: LANL alg-geom/9309007
78. “Space-time topology change: The Physics of Calabi-Yau moduli space”, P.S. Aspinwall, B.R. Greene, D.R. Morrison, In Berkeley 1993, Proceeding, Strings ’93 and Inst. Adv.Stud.Princeton – IASSNS-HEP-93-081 (1993).

79. "Measuring small distances in N=2 sigma models", P.S. Aspinwall, B.R. Greene, D.R. Morrison, Nucl.Phys. B420 (1994) 184-242.
80. "Calabi-Yau Moduli Space, Mirror Manifolds and Spacetime Topology Change in String Theory", P. Aspinwall, B.R. Greene and D. Morrison, Nucl. Phys. B416 (1994) 414.
81. "Multiple mirror manifolds and topology change in string theory", P.S. Aspinwall, B.R. Greene, D.R. Morrison, Phys.Lett B303 (1993) 249-259.
82. "A Brief survey of mirror symmetry", B.R. Greene and M.R. Plesser, In Goeteborg 1992, Proceedings, Pathways to fundamental theories 267-288.
83. "Eluding the no hair conjecture: Black holes in spontaneously broken gauge theories", B.R. Greene, S.D. Mathur, C.M. O'Neill, Phys.Rev. D47 (1993) 2242-2259.
84. "Inverse phase transitions: Does baryogenesis lead to dark matter?" S. Dodelson, B.R. Greene, L.M. Widrow, (1992).
85. "Classical versus Landau-Ginzburg geometry of compactifications" P. Berglund, B.R. Greene, T. Hubsch, Mod.Phys.Lett. A7 (1992) 1855- 1870.
86. "Mirror manifolds: A Brief review and progress report", B.R. Greene, M.R. Plesser, In Boston 1991, Proceedings, Particles, strings and cosmology 648-666 (1991).
87. "Superconformal compactifications in weighted projective space", B.R. Greene, Commun.Math.Phys. 130 (1990) 335-355.
88. "Lectures on string theory in four-dimensions", B.R. Greene, Lectures fivenat Trieste HEP Cosmology 1990: 0334-420.
89. "Mirror manifold in N=2 string compactification" B.R. Greene, In Boston 1990, Proceedings, Particles, strings and cosmology 402-425 and Cornell Univ. Ithaca-CLNS-90-1015.
90. "Gauge symmetry breaking in superconformal orbifolds", B.R. Greene, M.R. Plesser, E. Rusjan, X. Wang, Mod.Phys.Lett. A6 (1991) 591-604.
91. "Lectures on compactified string theory", B.R. Greene, Prepared for XIII International School OConferece: C89-09-19.1. 363-406.
92. "Calabi-Yau superconformal field theory", B.R. Greene, In Islamabad 1989, Proceedings, Mathematical physics 171-199.
93. "Special Points in Three Generation Moduli Space" B.R. Greene, PhysRev. D40 (1989) 16-45-1652.
94. "(2,2) And (2,0) Superconformal Orbifolds", B.R. Greene, M.R. Plesser, (1989).
95. "Duality in Calabi-Yau Moduli Space", B.R. Greene and M.R.Plesser, Nucl. Phys. B338 (1990) 15-20.
96. "Stringy Cosmic Strings and Noncompact Calabi-Yau Manifolds", B.R.Greene, A. Shapere, C. Vafa and S-T.Yau, Nucl. Phys. B337 (1990) 1.
97. "Calculating Endomorphism Valued Cohomology: Singlet Spectrum in Superstring Models", J. Distler, B.R. Greene, K.H. Kirklin, P.J. Miron, Commu.Math.Phys. 122 (1989) 117-124.
98. "Recent Results IN Calabi-Yau Compactification, B.R. Greene, Presented at Conference: C88-05-24.1in College Park, MD (1988)
99. "Calabi-Yau Manifolds and Renormalization Group Flows", B.R.Greene, C.Vafa and N.P.Warner, Nucl.Phys. B324 (1989) 371.
100. "Some Exact Results on the Superpotential from Calabi-Yau Compactifications", J. Distler, B.R. Greene, Nucl.Phys. B309 (1988) 295.

101. "Evaluation of 27-bar**3 Yukawa Couplings in a Three Generation Superstring Model", J. Distler, B.R. Greene, K. Kirklin, P. Miron, Phys.Lett. B195 (1987) 41.
102. "Aspects of (2,0) String Compactification", J. Distler, B.R. Greene, Nucl.Phys. B304 (1988) 1.
103. "On the Equivalence of the Two Most Favored Calabi-Yau Compactifications", B.R. Greene, K.H. Kirklin, Commun.Math.Phys. 113 (1987) 105-114.
104. "Searching for Three Generation Calabi-yau Manifolds", P.S. Aspinwall, B.R. Greene, K.H. Kirklin, P.J. Miron, Nucl.Phys. B294 (1987) 193.
105. "27^3 Yukawa Couplings for a Three Generation Superstring Model", B.R. Greene, K.H. Kirklin, P.J. Miron, G.G. Ross, Nucl.Phys. B292 (1987) 606.
106. "A Superstring Inspired Standard Model", B.R. Greene, K.Kirklin, P.Miron and G.Ross, Phys. Lett.180B, (1986) 192.
107. "A Three Generation Superstring Model II: Symmetry Breaking and the Low Energy Theory", B. Greene, K.Kirklin, P.Miron and G.Ross, Nucl. Phys. B292, (1987) 606.
108. "Superstring Models With SU(5) and SO(10) Unifying Groups, B.R. Greene, K.K. Kirklin, P.J. Miron, NuclPhys. B274 (1986) 574.
109. "Geometric singularities and spectra of Landau-Ginzburg models", B.R. Greene, S.S. Roan, S.T. Yau, Commun.Math.Phys. 142 (1991) 245-260.
110. Baryogenesis, dark matter and the width of the Z", S. Dodelson, B.R. Greene, L.M. Widrow, Nucl.Phys. B372 (1992) 467-493.
111. "Duality in Calabi-Yau Moduli Space", B.R. Greene, M.R. Plesser, Nucl.Phys. B338 (1990) 15-37.
112. "Coupling in the Heterotic Superconformal Three Generation Model", B.R. Greene, C.A. Lutken, G.G. Ross, Nucl.Phys. B325 (1989) 101.
113. "Topology And Geometry In Superstring Inspired Phenomenology", B.R. Greene, K.H. Kirklin, P.J. Miron, Conf.Proc. C8607214 (1986) 441-487.
114. "A Three Generation Superstring Model I: Compactification and Discrete Symmetries", B.R.Greene, K.Kirklin, P.Miron and G.Ross, Nucl. Phys. B278, (1986) 66.
115. "Supersymmetric Cosmology With a Gauge Singlet", B.R. Greene, P.J. Miron, Phys.Lett. B168 (1986) 226.

Books:

1. *Until the End of Time; Mind, Matter, and Our Search for Meaning in an Evolving Universe*. A. A. Knopf, 2020.
2. *The Hidden Reality: Parallel Universes and the Deep Laws of the Cosmos*. A.A. Knopf, 2011.
3. *The Fabric of the Cosmos: Space, Time, and the Texture of Reality*. A.A. Knopf, 2004.
4. *The Elegant Universe: Superstrings, Hidden Dimensions, and the Deep Laws of the Cosmos.* W. W. Norton, 1999.
5. *Icarus at the Edge of Time.* A. A. Knopf, 2008.

Documentaries:

1. *Light Falls: Space, Time, and an Obsession of Einstein*, PBS (with Great Performances), 2019.
2. *The Fabric of the Cosmos*, Host and Executive editor, 4-part NOVA mini-series, 2011.
3. *The Elegant Universe*, Host, 3-part NOVA mini-series, 2003.

Stage & Musical Works:

1. *Icarus at the Edge of Time*. Orchestral, filmic adaptation of book. Music by Philip Glass, film by Al and Al, adaptation by Brian Greene and David Henry Hwang. World Premiere, June, 2010 at Alice Tully Hall, Lincoln Center. UK Premier July 2010, Southbank Centre, London. Subsequently performed in 50 cities worldwide.
2. *Light Falls*: Space, Time and an Obsession of Einstein. Written by B. Greene, music by Jeff Beal, visuals by 59 Productions. National PBS broadcast, May, 2019. Live performances in New York, Princeton, Brisbane.
3. *Time, Creativity and the Cosmos*. Written by B. Greene, Choreography by Pilobolus. Premiered at Lincoln Center, 2017, performed in Australia, March 2019.

Virtual Reality:

1. *String Theory and Hyperspace*. Co-created live communal virtual reality experience for 58 students in 13 countries, to explore ideas of string theory and to build and explore higher dimensional shapes.
2. *Visceral Physics*: Leading team from Columbia University and World Science Festival to create VR experience leveraging Verizon 5G network for middle school students to gain deeper experience and appreciation of essential scientific concepts. Experiences created to date:
   a. Stars and Planets
   b. The Gravity Simulator
   c. Near the Speed of Light
3. *Richness of Reality*: With Unity and Evil Eyes production, a VR experience of scales in the cosmos.

Chairman BOWMAN. Thank you.
Next, we will have Dr. Merminga.

TESTIMONY OF DR. LIA MERMINGA, DIRECTOR, FERMI NATIONAL ACCELERATOR LABORATORY

Dr. MERMINGA. Thank you. Energy Subcommittee Chairman Bowman and Ranking Member Weber and other distinguished Members of this Subcommittee, I'm Lia Merminga, Director of Fermilab since 2 months ago, an honor to speak with you today about high-energy physics.

As we meet here today, the U.S. high-energy physics community is getting ready to assemble in Seattle for what is called Snowmass, the decadal planning exercise that outlines the future vision of particle physics. From Snowmass, the Particle Physics Project Prioritization Panel, or P5, will produce a 10-year plan that prioritizes major projects and experiments to maintain the United States' global leadership in the field.

Particle physics research probes from the smallest constituents of matter to the entire cosmos, in pursuit of the most profound questions of humanity. How did our universe come to be? How does it work? And why are we here? But investing in physics research goes beyond helping us understand such fundamental questions. We also push the boundaries of knowledge and develop technologies that improve lives.

The crosscutting nature of our research fosters applications beyond particle physics. Emerging technologies such as quantum science, artificial intelligence, and novel microelectronics find great synergy with our core HEP mission. This has engendered new frontiers well beyond their initial scopes. MRIs, proton therapy, X-ray lasers, and the World Wide Web have all resulted from particle physics research and collaboration. Continued investment in HEP, including in research, infrastructure, and people, are critical to driving major discoveries and new technologies in the future.

HEP is a powerful training ground that attracts and inspires young minds and helps build the best and most diverse STEM work force. HEP students and researchers develop state-of-the-art technologies, build tools to handle massive data, and cultivate the creativity to bring the imagined into reality, whether in HEP or in other STEM pursuits.

And particle physics is a global endeavor. We work with almost every country in the world, and our flagship projects are great examples of this collaboration. The 2014 P5 report recommended Fermilab to host the largest and most complex neutrino research program ever undertaken. The Long Baseline Neutrino Facility, or LBNF, will provide the infrastructure for the massive Deep Underground Neutrino Experiment, or DUNE, largest international scientific project on U.S. soil.

LBNF crews are now excavating caverns a mile underground at the Sanford Lab in South Dakota, while 1,400 DUNE collaborators from over 35 countries are building the cutting-edge detectors that will fill these caverns starting as early as 2024. LBNF/DUNE will be powered by Fermilab's new superconducting accelerator known as PIP–II, the first built with significant international contributions. In fact, together, LBNF/DUNE and PIP–II have attracted

more than $1 billion in in-kind contributions from international partners, including CERN, the European Particle Physics Laboratory, marking its first time investing in physics outside Europe. Twenty-one hundred U.S. scientists use CERN's Large Hadron Collider for their research. Since its startup, more than 2,000 scientific results have been published, including the Higgs Boson discovery in 2012. Ongoing LHC upgrades will enable scientists to unlock key questions in particle physics for decades to come.

LBNF, DUNE, PIP–II, and LHC upgrades are our highest priorities at Fermilab. The projects are proceeding well, and we are incredibly grateful to the Department of Energy for their support thus far, particularly in helping us to address the challenges of LBNF/DUNE and accelerating its schedule. Our international partners have seen the United States' ongoing commitment and investment in these efforts, and this has resulted in expanding contributions and our sustained global leadership in the field.

I thank the Members of this distinguished Subcommittee for your attention. Your continued support of the DOE Office of Science means we can continue to pursue our—the mysteries of the universe and improve lives, both here in the United States and around the world. Thank you.

[The prepared statement of Dr. Merminga follows:]

Testimony of

Lia Merminga, PhD
Director, Fermi National Accelerator Laboratory

Before the
U.S. House of Representatives
Subcommittee on Energy
of the House Committee on Science, Space, and Technology

On
Investigating the Nature of Matter, Energy, Space, and Time

Introduction

Distinguished members of the subcommittee, I am honored to speak with you about high energy physics. The views and words that I present here today are my own, on behalf of the HEP community. The research we do probes the smallest constituents of matter, the building blocks of our universe, in an attempt to do nothing less than address the most fundamental questions of humanity: How did our universe come to be? How does it work? And how do we fit in?

But investing in physics research goes beyond helping us understand the very world around us. On that quest, we also push the boundaries of knowledge and develop the technologies that directly improve our lives. Scientific collaboration in particle physics brought us the World Wide Web. Particle accelerators inspired medical technologies including MRIs. Antimatter allows us to detect cancers. Our work may sound like science fiction, but it is reality. Thanks to decades of efforts by dedicated particle physics researchers, we are now doing things once seemed impossible, like building quantum computers and sending particle beams hundreds of miles through the earth to study their oscillations.

There are many big questions around matter, energy, space and time left to answer, and the United States is a world leader in this research. But to continue leading the investigations into these big questions, we need sustained investment in our field's priorities, including our infrastructure, people and research programs.

It is an exciting time in physics: Before us, we see new knowledge, new applications and a vast, transformative potential for the future. We hope the U.S. can continue to lead the charge into the great unknown.

Basic research

Particle physics is a global endeavor. Sustained, long-term funding and international collaboration have led to major breakthroughs, such as the long-awaited discovery of the Higgs boson in 2012. Through the recommendations of the Particle Physics Project Prioritization Panel (P5), the United States has emerged as a leading force driving discovery on the most urgent scientific studies. New discoveries and world-leading science facilities supported by HEP have also inspired and attracted the next generation of talent in STEM careers and at DOE national labs.

Neutrino physics and LBNF/DUNE

The P5 report recommended that the Fermi National Accelerator Laboratory, or Fermilab — of which I am the director — lead the largest and most complex research program on neutrinos ever undertaken. Neutrinos are minuscule particles with surprising properties; they are ubiquitous and the most abundant matter particles in the universe, yet we know very little about them. What we *do* know is that they could hold keys to some of the biggest questions in particle physics, such as: Why is there matter in the universe? How do black holes form? How has our universe evolved?

Fermilab is uniquely suited to host the world's flagship neutrino facility and facilitate an international neutrino research program. The Long-Baseline Neutrino Facility (LBNF) will provide the infrastructure for the massive Deep Underground Neutrino Experiment (DUNE), the largest international scientific project on U.S. soil. LBNF crews are now excavating caverns a mile underground at Sanford Lab in South Dakota that will house enormous particle detectors.

Meanwhile, more than 1,400 DUNE collaborators from over 35 countries and 200 institutions are designing, building and contributing the cutting-edge detector technology that will fill these caverns in order to study these elusive particles. Among our international collaborators is CERN,

a Fermilab sibling laboratory in Geneva, Switzerland, home to the LHC. Notably, LBNF/DUNE marks the first time in its 60-year history that CERN is investing in a physics project outside Europe. Despite international partnerships and contributions and tremendous progress in constructing LBNF/DUNE, the project faces international competition. Japan is moving quickly on a competing project, known as Hyper-K, to build one of the world's largest neutrino experiments by 2027. The continued engagement and involvement of our international partners requires the U.S. to continue its commitments to HEP and meet project milestones to execute the best science and stay ahead of international competition.

PIP-II

LBNF/DUNE will be powered by an upgrade to Fermilab's accelerator complex known as PIP-II. The new superconducting particle accelerator is a testament to the global support for big physics research hosted in the United States. It is the first particle accelerator built in the U.S. with significant contributions from international partners, with major contributions from institutions in France, India, Italy, Poland and the United Kingdom.

Powered by the new accelerator, Fermilab will produce the most intense high-energy neutrino beam in the world, enabling the exploration of new physics. The unprecedented numbers of particles produced by the accelerator will help uncover theoretically predicted — but yet unobserved — phenomena that we expect are either incredibly rare or incredibly difficult to detect. The sheer numbers of particles will help draw out the subtle behaviors that would otherwise remain hidden.

In parallel, the high-power proton beams will enable muon-based experiments to search for new particles and forces at unprecedented levels of precision. Similarly, the proton beam power from PIP-II could drive a facility to support a diverse physics program. In fact, each experiment facilitated by the PIP-II upgrade provides new windows to the subatomic world.

The new machine supports Fermilab's leadership position in high energy physics, and, importantly, PIP-II's leading-edge design will pave the way for future advances in accelerator technology.

CMS and LHC

U.S scientists play an integral role in the success of research at the Large Hadron Collider at CERN. Department of Energy National Labs help design and build upgrades to the magnets at the heart of the accelerator through the LHC Accelerator Upgrade Program. Fermilab is the host lab for U.S. participation in the CMS experiment, which co-discovered the Higgs boson. (The U.S. contingent of CMS makes up nearly 30% of the collaboration.) Hundreds of collaborators across the United States are working on upgrades to the LHC experiments to handle increased amounts of data and information.

In addition to designing and building particle detector components, U.S. LHC collaborators develop machine learning and artificial intelligence algorithms to sift through petabytes of data to better understand the building blocks of matter. With the increasing involvement of machine learning and artificial intelligence in every facet of our lives, our contributions to these fields is of paramount importance to our continued leadership in the AI ecosystem.

Fundamental particles and forces

Recent measurements have put cracks in our theoretical framework for the subatomic world and may point the way toward exciting new discoveries. Results from Fermilab's Muon g-2 and CDF experiments as well as the LHC at CERN have generated thousands of headlines and captured global attention. For example, the Muon g-2 news earned over 3500 top-tier media mentions and more than 19B potential audience reach over several months, indicating the public's continued interest in fundamental physics and what it tells us about the world we live in. Muon g-2 and the LHC are gathering more data, and upcoming results have the potential to transform our understanding of the subatomic world. The Muon-2-electron conversion experiment at Fermilab is under construction and promises to probe the behavior of muons with unprecedented precision.

Using the cosmos as laboratory

Dark matter makes up about 95% of the mass of our universe yet it remains one of the greatest unsolved mysteries of science. Next-generation experiments in the U.S. will continue to home in on this invisible substance. Without a doubt, discovering what comprises this long-sought matter

will be a major milestone in physics history. Meanwhile, advanced telescopes led by the national labs are illuminating dark energy, the force behind what holds our universe together and that is responsible for space's accelerating expansion. Large-scale experiments such as the Large Synoptic Survey Telescope, Dark Energy Camera and Dark Energy Spectroscopic Instrument position the U.S. at the forefront of this research.

Emerging technologies

Because of the cross-cutting nature of research, scientists working in high energy physics can foster applications well beyond particle physics. Researchers use their ingenuity, techniques and skills to advance technologies in emerging areas such as quantum science, artificial intelligence, machine learning and microelectronics.

Quantum

With their expertise working with particles at the smallest scales, physicists are essential to developing quantum information science. HEP researchers are adapting tools from particle accelerators to extend the lifetime of quantum information and build quantum computers, which will have ramifications for fields as diverse as finance, medicine and national security. Fermilab leads one of the five DOE national quantum centers and is leading the way in quantum materials, computing, sensors and communication building toward a quantum internet.

Artificial intelligence and machine learning

The high energy physics community contributes to the growing fields of AI and ML, which underpin technologies in many industries, by advancing new technologies and using them to solve some of the most difficult problems in science. Scientists develop these tools to process and analyze the trillions of datapoints common in large physics experiments. They also expand these techniques to support the equipment itself, making smarter telescopes and self-driving particle accelerators. Additionally, HEP provides a unique role in the process of workforce development to the national AI ecosystem, collaborating with academia and industry partners and training an AI workforce with challenging scientific applications.

Microelectronics

Large-area detectors for high energy physics must operate reliably over the lifetime of the experiment in compact geometries and resource-constrained extreme environments, such as cryogenic temperatures. These restrictions have led the HEP community to develop custom microelectronics with complex in-pixel processing and reconfigurable data-driven architectures.

Over the last decade, Fermilab has successfully applied the concepts developed for high energy physics to other areas such as X-ray detectors for synchrotron sources and free-electron lasers. We are now developing deep cryogenic electronics for quantum systems, as well as on-chip machine learning for on-detector data processing.

The workforce of the future

High energy physics is a powerful training ground that attracts students and helps build the STEM workforce of the future. Fermilab is home to 114 postdoctoral researchers, 273 graduate students and 52 undergraduate students, and we reach more than 100,000 students a year through science education programming. Students and researchers at Fermilab design and build state-of-the-art technologies, glean insights from mountains of data, and develop both the creativity and know-how to bring the imagined into reality.

Fermilab also strives to attract the greatest diversity of talent. For example, Fermilab supports a broad array of fellowship programs for underrepresented minorities and groups in STEM in areas such as accelerator engineering, superconducting quantum materials and theoretical physics, to bring world-class research and development opportunities to a diverse group of young engineers and scientists. These physicists help us move toward the next discovery. And those who decide to transfer those skills into industry provide expertise found nowhere else.

Leading a global community

The timing of this testimony before Congress is especially important as scientists are now convening for Snowmass, the decadal planning exercise that outlines the future vision of particle physics research. The results of Snowmass will be used to develop the next 10-year P5 plan that prioritizes major projects and experiments to maintain U.S. leadership. Once again, the United States will have the opportunity to lead in cutting-edge research areas. We have the world-class

facilities, people, and research programs that will continue to thrive and deliver results, so long as we continue to invest in them. By showing our commitment to funding HEP, we marshal the best and brightest from around the world to join us in the quest to answer the universe's biggest questions.

Conclusion

I thank the members of this distinguished subcommittee for your time. Your continued support for the DOE Office of Science's High Energy Physics research program means we can investigate the mysteries of matter, energy, space and time — enabling the scientific discoveries that will define the future, increase knowledge and improve lives both here in the United States and around the world.

Lia Merminga

Lia Merminga began her tenure as director of Fermi National Accelerator Laboratory in April 2022. An internationally renowned accelerator physicist, Merminga previously led the Proton Improvement Plan II (PIP-II) project at Fermilab, an essential enhancement to Fermilab's accelerator complex that will provide powerful, high-intensity proton beams, enable the world's most intense neutrino beam to the flagship Long-Baseline Neutrino Facility and the Deep Underground Neutrino Experiment (LBNF/DUNE), and drive a broad physics research program.

Merminga has held major scientific leadership roles at SLAC National Accelerator Laboratory in California; TRIUMF in Vancouver, Canada; and the Thomas Jefferson National Accelerator Facility in Virginia. Merminga earned a bachelor's degree in physics from the University of Athens, in Greece, master's degrees in physics and mathematics and a Ph.D. in physics from the University of Michigan, in Ann Arbor. She is a Fermilab Distinguished Scientist, a fellow of the American Physical Society, and a graduate of the Department of Energy's Oppenheimer Energy Science Leadership Program. She has served on numerous international scientific committees and was one of the authors of the 2014 Particle Physics Project Prioritization Project (P5) plan.

Chairman BOWMAN. Thank you very much.

Next, we will have Mr. Yeck. And, Mr. Yeck, let's try to make it in 5 minutes.

TESTIMONY OF MR. JIM YECK, ASSOCIATE LABORATORY DIRECTOR AND PROJECT DIRECTOR FOR THE ELECTRON-ION COLLIDER, BROOKHAVEN NATIONAL LABORATORY

Mr. YECK. Chairman Bowman, Ranking Member Weber, and Members of the Committee, thank you for the opportunity to appear before you today. My name is Jim Yeck. I have participated in and led big science projects around the world, as noted in my introduction by Chairman Bowman.

I'm here today as Project Director for the Electron-Ion Collider, or EIC, a nuclear physics research facility being built at Brookhaven Lab in New York in partnership with Virginia's Thomas Jefferson National Accelerator Facility, and funded by the U.S. Department of Energy's Office of Science. I thank the Committee for authorizing the EIC as part of the *America COMPETES Act of 2022*.

Today, all our technologies and much of our economy depend on what we've learned about the atom and its orbiting electrons. Experiments on the behavior of electrons in the last century led to the development of batteries, semiconductors, smart materials, and more. With an EIC, we will be able to look inside the atom nucleus to image its constituents, the quarks and gluons. EIC experiments will reveal how the strong nuclear force drives interactions among completely massless gluons and nearly massless quarks to buildup the mass, structure, and properties of visible matter in the universe. Like the discoveries of the last century that power today's electronics-centered society, new discoveries about gluons could lead to the like technologies of tomorrow.

Tools we are developing for the EIC could also lead to new innovative accelerators for making and testing computer chips, killing cancer cells, and designing drugs and new materials; detector technologies for medicine and national security; and computational tools that can be applied to modeling climate change, global pandemics, even financial markets.

EIC planning has been underway for more than 2 decades. The nuclear science community and the National Academies consider its scientific promise to be timely, compelling, and worthy of investment. Our field has a strong track record of delivering on the goals laid out through this careful planning process and for delivering projects within budget.

As a Project Leader, my key ingredients of success include ensuring the project remains a priority of the science community, securing funding commitments, and establishing a strong role of the host funding agency and laboratory, appointing project leaders who enable the success of all stakeholders, encouraging collective ownership of problems and solutions, establishing realistic goals, making the most of the team's experience, and sustaining energy and enthusiasm over the decade required to construct the project. To make the EIC a reality, we need all of these ingredients.

I'm confident that we have the scientific and technical knowhow, the team, and other ingredients in place, but I'm concerned about the current funding realities. EIC construction cost estimates range from $1.7 to $2.8 billion. That investment will create thousands of jobs in construction, materials, and manufacturing in New York State, Virginia, and beyond, and hundreds of highly skilled technical jobs over the EIC's operational lifetime. Brookhaven Lab was selected as the EIC site in part to capitalize on the $2 billion-plus already invested in the Relativistic Heavy Ion Collider or RHIC, the only operating collider in the United States. RHIC and its team of talent will serve as a backbone for the EIC after RHIC's scientific mission is complete in 2025. Reusing components of RHIC and leveraging its highly trained work force with its decades of experience will reduce the overall EIC project costs and ensure the handoff of knowledge from today's scientists, engineers, and technicians to the next generation critical to building and operating the new facility.

But without several years of sufficient, dedicated funding to ensure a smooth transition from RHIC to EIC, we anticipate layoffs impacting those same individuals. To date, funding has been well below the levels required to keep the project on course and on budget. Funding constraints also affect our ability to attract the next generation of American physicists, technicians, and engineers and will compromise U.S. leadership and competitiveness in accelerator science and nuclear physics. And those constraints will also impact our international partnerships. Currently, a robust EIC user community of about 1,300 scientists from 250 institutions around the globe have been helping to develop the science program.

Finally, a word about education. Brookhaven Lab takes great pride in its internship programs with a 50/50 gender diversity mix and nearly 40 percent of our students coming from underrepresented groups. These populations are developing the diverse work force of the future. The EIC will be a unique resource for driving that progression.

I hope this testimony convinces you of the enormous value an investment in Electron-Ion Collider will deliver to our Nation and the need for sufficient funding to make it a reality. EIC will extend the frontiers of discovery, lead to benefits to science and society, and maintain our Nation's undisputed leadership and competitiveness in nuclear, accelerator, detector, and computational science, areas essential to economic advancement, national security, and technological development for decades to come.

Thank you, and I'm happy to take any questions.

[The prepared statement of Mr. Yeck follows:]

Hearing on High Energy Physics, Nuclear Physics, and Isotopes

Energy Subcommittee on the House Science, Space, and Technology Committee
Date, Time: Wednesday, June 22, 2022, at 10 a.m. (ET)
Speaker: Jim Yeck
Delivery: Spoken in person (condensed); Written submitted 10 a.m. June 17 (full version)

Chairman Bowman, Ranking Member Weber, and members of the committee, thank you for the opportunity to appear before you today to discuss the Electron-Ion Collider, nuclear physics, and the management of big science projects. My name is Jim Yeck. I have had the honor of participating in and leading big science projects around the world, including the Relativistic Heavy Ion Collider (RHIC) and the National Synchrotron Light Source II at Brookhaven National Laboratory, the U.S. contribution to Europe's Large Hadron Collider (LHC), the IceCube Neutrino Observatory in Antarctica, and the European Spallation Source (ESS). I continue to serve on advisory and review committees for other big science projects, and I am a lecturer for the U.S. Department of Energy's Project Leadership Institute.

I am here today as Project Director for the Electron-Ion Collider, a nuclear physics research facility being built at Brookhaven Lab on Long Island in partnership with Thomas Jefferson National Accelerator Facility in Virginia and funded by the DOE Office of Science. I will share with you how the EIC will extend the frontiers of discovery in nuclear physics and lead to benefits for science and society. In combination with other Office of Science user facilities for nuclear physics research, the world-leading, one-of-a-kind EIC will maintain our nation's undisputed leadership and competitiveness in nuclear, accelerator, detector, and computing science — areas that are essential to economic advancement, national security, and technological development — for decades to come.

First, a few words about Brookhaven Lab.

Brookhaven is a multi-purpose DOE Office of Science Laboratory with about 2,700 staff, located on Long Island in New York. Our mission, in simple terms, is to carry out discovery science and related technology development to address national needs. We do that by building large facilities beyond the capabilities of universities and industry, and then making them available to scientists across the country and around the world.

One of those facilities is the Relativistic Heavy Ion Collider, or RHIC, which collides atomic nuclei at nearly the speed of light to recreate the conditions of the early universe, enabling some 1000 researchers from around the world to explore fundamental properties of the building blocks of matter. Since coming online in 2000, RHIC—the only operating particle collider in the U.S.— has enabled surprising discoveries and opened

new areas of inquiry about nuclear matter—including discovering and characterizing a remarkable form of matter known as quark-gluon plasma and exploring the sources of proton spin. Over the next several years, RHIC will transition to the Electron-Ion Collider, the focus of my discussion today.

The EIC is a unique facility that will enable a new era of compelling science, expanding our knowledge of the inner workings of the atoms that make up nearly all visible matter in the universe. That's everything from galaxies and planets to the building we are in — and even you and me.

Today, all our technologies and much of our economy depend on what we learned in the last century about the atom — the positively charged nucleus and negatively charged electrons orbiting it. Those experiments revealed exquisite details of how electrons behave collectively, and ultimately led to the development of batteries, semiconductors, smart materials, all electronics, and more.

With an EIC, we will be able to look *inside* the nucleus to image its constituents, the quarks and gluons. The gluons are the particles that provide the "glue" that holds together the protons and neutrons of atomic nuclei while the quarks make up those particles. EIC experiments will reveal unprecedented insights into the collective behavior of gluons and the strong nuclear force — which creates the visible matter in the universe. We'll learn, for example, how the strong force drives interactions among completely massless gluons and nearly massless quarks to build up the mass, structure, and properties of visible matter.

Like the discoveries about the collective behavior of electrons in the last century, new discoveries about gluon interactions and the strong force will deepen our understanding of the world around us. And that understanding could potentially lead to the technologies of tomorrow.

This is a challenging field of science, with complex technological requirements. That's why it attracts the interest and efforts of thousands of the best and brightest scientists from around the world. Their contributions will extend the frontiers of discovery in nuclear physics while simultaneously sparking technological advances for science and society — in computing, electronics, energy, and medicine.

To give you some specific examples, the particle beam and detector technologies we are developing to explore the inner workings of atoms at the EIC could also lead to the next generation of:

- innovative accelerators for making and testing computer chips, killing cancer cells, and designing drugs, vaccines, and new materials for electronics;

Also:

- new isotopes for diagnosing and treating disease;
- detector technologies for medicine and national security;

- research relevant to protecting future astronauts and their electronics from harmful space radiation;
- and advances in exascale computing, data storage, distribution and data analysis that can be applied to modeling climate change, global pandemics, and even financial markets.

Planning for the EIC has been underway for more than two decades. The nuclear science community, through its most recent long-range planning activity, identified the EIC as the next major facility for the field. Then, through an extensive review process, the National Academies of Sciences, Engineering, and Medicine considered the scientific promise of the EIC and found it to be compelling and worthy of investment. These significant studies and assessments have laid the groundwork for moving ahead with the EIC with the backing of the entire nuclear science community.

The field of nuclear physics has a strong track record of delivering on the goals laid out through this careful planning process — and for bringing projects in within budget once they are launched. We also have a history of success in applying what we learn in ways that benefit society and our nation at large. We are the field that brought you nuclear medicine, medical imaging, particle accelerators for technology and cancer treatment. And from the EIC we anticipate unforeseen discoveries and applications as unimaginable as today's electronics industry was to the physicists of the early 20th Century.

Much of this success can be directly credited to the funding generously allocated by Congress to nuclear physics, including projects like the EIC. We are extremely grateful for that support — and that of the DOE Office of Science. We also understand the challenges that the country currently faces as Congress tries to decide how to best support our collective future. So I thank you again for the opportunity to share my views on what it takes for large science projects to succeed, along with some of the challenges we face when the budget profiles fall short of optimal. My goal is to find ways for us to work with all of you and with our valued partners at DOE to achieve our common goals.

Over the years, I have developed a list of key ingredients for the success of such big science projects. These include:

- Ensuring that the project remains a priority of the science community
- Securing funding commitments and establishing a strong role of the host funding agency and laboratory
- Appointing project leaders who enable the success of all stakeholders
- Encouraging collective ownership of problems and solutions
- Establishing realistic goals (in other words, valuing "experience over hope")
- Making the most of the available experience
- And sustaining the energy and enthusiasm of all stakeholders

To make the EIC a reality, we need all of these ingredients.

I am confident that we have the scientific and technical knowhow to build a world-class facility. We have an experienced project-management team that has successfully delivered complex facilities on time and within budgets. And we have a highly skilled workforce in place and very strong interest from the worldwide community of nuclear physicists eager to make use of the EIC. But I am concerned about current funding realities and their impacts.

Construction costs for the EIC are estimated in the range of $1.7–2.8 billion. That investment will create thousands of jobs in construction, materials, and manufacturing in New York State and beyond as we build the accelerator and detector components over the next 10-15 years — and hundreds of highly skilled, scientific, and technical jobs over the EIC's longer-term operational lifetime.

Part of the rationale for selecting Brookhaven Lab as the EIC site is to capitalize on more than $2 billion in investments in both unique infrastructure and the specialized workforce that built and currently operates the Relativistic Heavy Ion Collider (RHIC) — the facility that will provide essential accelerator systems as a backbone for the EIC. By adding new components for accelerating and storing electrons, cooling ions, and a range of other capabilities to this existing RHIC infrastructure, we will maximize the scientific impact of the new machine with significantly less investment than would have been required to build such a facility from a greenfield site.

Likewise, the team of scientific and technical experts currently operating RHIC are the result of more than 30 years of investment and specialized training. Their experience is essential for building the EIC, for growing our own diverse workforce, and attracting international partners. And because EIC is expected to operate well into the second half of this century, the handoff of knowledge between today's scientists, engineers, and technicians to the next generation will be critical.

The RHIC program currently makes up approximately a quarter of Brookhaven Lab's workforce and its annual budget. Providing the funding needed now to initiate the EIC project and move it forward *while RHIC completes its scientific mission over the next three years* is essential to ensure a smooth transition from one facility to the next. Without the necessary funding, that smooth transition will be at risk, creating a potential gap between the conclusion of the RHIC science program and the timely development of the EIC. That gap would result in layoffs, including the very talented staff capable of operating these sophisticated machines and advancing the science of the EIC.

The EIC project is therefore dependent on several years of sustained and dedicated funding to support EIC construction and the transition of the highly trained workforce from RHIC to the EIC. This funding will ensure that the EIC project is advanced enough at the time of the completion of the RHIC science mission to keep the staff critical to implementing installation of new EIC components — and the eventual operation of the new facility. To date, however, funding has been well below the levels required for an

optimally smooth transition, and below that required to execute the technically driven and most efficient construction schedule to keep the project on course and on budget.

A quick ramp up in EIC project funding while RHIC is still operating through FY2025 will allow the project to complete design work, start long lead procurements, and secure DOE CD-3 construction approval before the end of RHIC operations, and thereby maintain critical skilled workers for a smooth transition from RHIC to the EIC. Starting in FY2026, RHIC operations funds can be redirected to drive the EIC project to completion by the early 2030s.

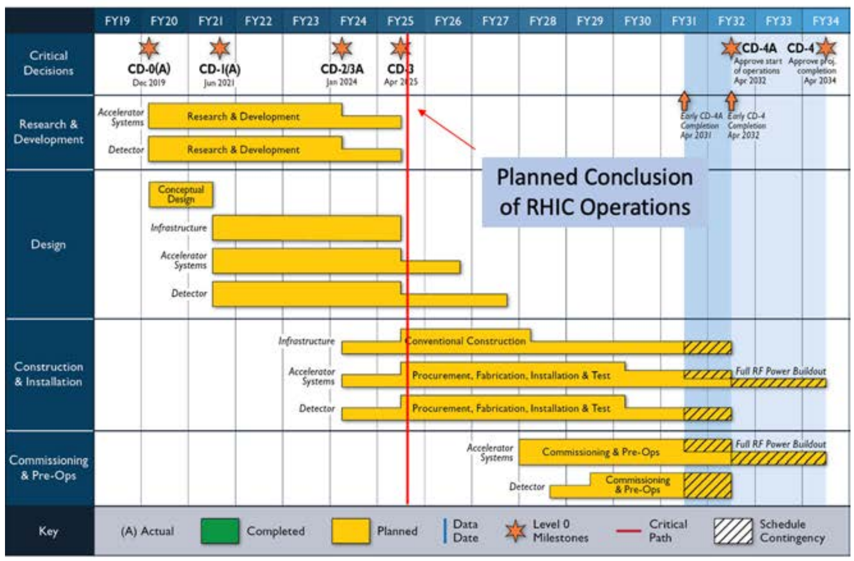

Figure 1. EIC Project Schedule

Significant funding constraints also affect the EIC project's ability to attract the next generation of physicists, technicians, and engineers, as well as international partners. If these future scientists and engineers don't bring their expertise to the U.S. and instead pursue projects in other nations, it will impact U.S. leadership and competitiveness in science and technology in general, and particularly in the critical fields of accelerator science and nuclear physics.

Currently, a robust EIC user community — about 1,300+ scientists from 250 institutions around the globe — has been helping to develop the EIC science program. These international collaborations of nuclear and accelerator physicists are developing advanced accelerator designs and sophisticated particle detector concepts to capture the data needed to turn EIC collisions into nuclear physics discoveries. Failure to adequately support the EIC project risks not just the international partnerships directly relevant to the EIC, but also international collaborators' confidence in U.S.-run projects in general, including DUNE, as well as the U.S. commitments made to overseas projects, such as at the Large Hadron Collider, which have been enormously beneficial to the advancement of U.S.-based scientists.

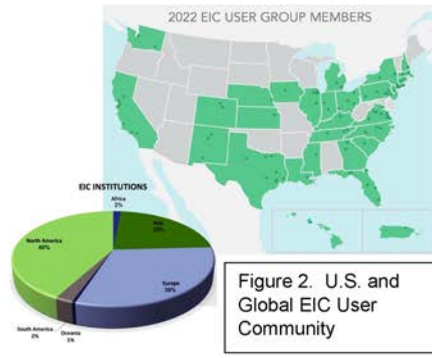

Figure 2. U.S. and Global EIC User Community

The accelerator complex at RHIC—and eventually the EIC—also supports DOE's Isotope Program and the NASA Space Radiation Laboratory. The Isotope Program produces key isotopes used to non-invasively image tumors in the body for diagnosis and monitoring of disease progression and response to treatment. One of the most promising is Actinium-225, which shows great promise in saving lives as an effective cancer treatment, even for cancers that have spread throughout the body. The NASA Space Radiation Lab uses the complex's particle beams to simulate cosmic radiation for experiments to better understand the risks astronauts would face on long-term missions, including journeys to Mars. The continuity of these activities also depends on the smooth transition from RHIC to the EIC.

Finally, a word about the educational impact of the EIC on our nation's young people, who represent our future. Brookhaven Lab takes great pride in its internship programs, including having attained a 50/50 gender diversity mix and drawing nearly 40 percent of our student class from underrepresented populations. These programs are developing the diverse workforce of the future. As the only particle collider of its kind in the world, the EIC will be a unique resource for driving that progression, providing educational opportunities for the next generation of engineers, technicians, and physicists needed to address a wide range of our nation's scientific and technological challenges. For example, students across the U.S. and around the world collaborating on EIC detector design will gain valuable hands-on experience designing, testing, and constructing sophisticated electronic components — and invaluable insight into large-scale science

collaboration and the international nature of physics research. These skilled workers may apply their expertise directly in the fields of accelerator and nuclear science, or across a wide range of disciplines where such skills are needed in jobs across the economy.

I hope this testimony has convinced you of the enormous value an investment in the Electron-Ion Collider will deliver to our nation — in terms of ground-breaking science, technological advances, opportunities for education and workforce development, and U.S. leadership in critical areas for decades to come, and that significant increases in project funding are needed now.

Thank you for your time today.

I'm happy to take any questions.

# # #

About Brookhaven National Laboratory

At Brookhaven, we focus on several different areas of science:

Nuclear and particle physics — research aimed at gaining a deeper understanding of matter, energy, space, and time. In nuclear physics, we operate the Relativistic Heavy Ion Collider, or RHIC, serving about 1000 users. The accelerator complex at RHIC also supports the production of critical medical isotopes and research into the effects of space radiation as noted above. And we also play a leading role in global particle physics experiments that push the limits of precision and expand our understanding of the cosmos, including the ATLAS experiment at the LHC and the Rubin Observatory.

Energy and climate science — leveraging our capabilities in advanced materials, catalysis, bioenergy, environmental systems, and climate science to put the U.S. on a path to a net-zero economy. These programs and others are supported by several DOE Office of Science user facilities, including the National Synchrotron Light Source II, the Center for Functional Nanomaterials, and the Atmospheric Radiation Measurement research facility — collectively serving thousands of users.

Advanced computer science, applied math, data science, and computational science — developing the infrastructure and algorithms to transform scientific discovery at Brookhaven's facilities and enhance its science programs.

Advanced and emerging technologies — leveraging strengths in instrumentation, magnets, accelerators, and laser science and technology

Applications — applying the results of Brookhaven's discovery science and technology to address emerging opportunities, including clean energy solutions, isotopes, national security solutions, and national emergencies.

About Thomas Jefferson National Accelerator Facility

Thomas Jefferson National Accelerator Facility (Jefferson Lab) is a U.S. Department of Energy Office of Science national laboratory. Scientists worldwide utilize the lab's unique particle accelerator, known as the Continuous Electron Beam Accelerator Facility (CEBAF), to probe the most basic building blocks of matter - helping us to better understand these particles and the forces that bind them - and ultimately our world.

In addition, the lab capitalizes on its unique technologies and expertise to perform advanced computing and applied research with industry and university partners, and provides programs designed to help educate the next generation in science and technology.

Managing and operating the lab for DOE is Jefferson Science Associates, LLC. JSA is a limited liability company created by Southeastern Universities Research Association.

Mr. Jim Yeck is the Associate Laboratory Director and the Project Director for the Electron-Ion Collider at Brookhaven National Laboratory. He has over 30 years of project director and project manager experience including recently serving as the Director General of the European Spallation Source from 2013-2016. He successfully led projects in both federal and contractor roles such as the DOE Project Manager for the Relativistic Heavy Ion Collider and the US contribution to the Large Hadron Collider, Project Director for the construction of the IceCube Neutrino Observatory, and NSLS-II Deputy Project Manager. Mr. Yeck is a member and serves as chair of numerous advisory committees for large projects supported by DOE, NSF, and international funding agencies and is a regular lecturer for the DOE Project Leadership since its inception in 2017. His academic training includes studies at University of Illinois (B.S. 1982), Northwestern (M.S. 1988), and the University of Pennsylvania.

Chairman BOWMAN. Thank you, Mr. Yeck.
And finally, we will have Mr. Guastella.

TESTIMONY OF MR. MICHAEL GUASTELLA, EXECUTIVE DIRECTOR, THE COUNCIL ON RADIONUCLIDES AND RADIOPHARMACEUTICALS

Mr. GUASTELLA. Good morning, Chairman Bowman, Ranking Member Weber, and Members of the Committee. I'm Michael Guastella, the Executive Director of the Council on Radionuclides and Radiopharmaceuticals. We're an association of companies that manufacture and distribute radioactive sources and medical isotopes here in the United States. Thank you for the opportunity to provide the Committee with our comments on the current supply of radioactive and stable isotopes.

Our supply chain issues have been the focus of several government efforts over the last 15 years to address the lack of a reliable and sufficient supply of domestic medical and industrial isotopes. And the recent invasion—Russian invasion of Ukraine highlight further these issues. The problem is significant. And my member companies are appreciative of the Committee's interest in these issues and our suggestions on what needs to be done.

I want to thank you, Mr. Chairman, and Ranking Member Weber, for your support and assistance over the last several years. Your Committee has recognized the importance of medical and industrial isotopes, and you have advocated for Federal policies that would ensure that our patients have the isotopes necessary for the diagnosis and treatment of disease.

Nuclear medicine involves the injection of medical radioactive isotopes and radiopharmaceuticals into a patient's body to diagnose and treat disease. Nuclear medicine is integral to the care of patients, and we estimate that there are 20 million nuclear medicine procedures performed annually for diseases such as cancer, heart disease, Parkinson's disease, and Alzheimer's disease.

Now, let me update the Committee on U.S. isotope supply challenges and opportunities. There are over 40 stable and radioactive isotopes that we have identified that are important for medical or industrial purposes, and that the United States relies largely on Russian companies to supply. For example, to serve U.S. patients, a significant portion of the molybdenum–99 supply chain relies on uranium–235 that is sourced from Russia. Several other isotopes sourced from Russia include stable isotope zinc–68, which is used for the production of therapeutic—the therapeutic radioisotope copper–67, gadolinium–153 for calibrating medical devices, and krypton–85 using industrial-sealed sources to measure thickness and density.

Various companies are currently developing reactor and non-reactor capabilities to help scale up domestic production of essential isotopes. However, these commercial activities may not be adequate to address the immediate risks to the radioactive and stable isotope supply chains posed by the Russian invasion of Ukraine and potential sanctions being considered on Russian suppliers by the United States and our allies.

DOE especially plays a critical role in producing and distributing isotopes needed in scientific research and for initial medical, clin-

ical development, and industrial purposes when there are not sufficient commercial incentives for production of such isotopes. CORAR and its member companies believe that, where commercially feasible, medical and industrial isotopes should be produced by the private sector. However, for a number of these isotopes where commercial domestic production has not been established or is not sufficient to meet U.S. medical and industrial needs, the DOE Isotope Program can potentially provide a bridge to ensure domestic supply.

CORAR would recommend that the Committee continue to support the DOE's research, development, and production activities. CORAR supports your Committee's work contained in section 311 of the *America COMPETES Act of 2022.* Provisions of the *COMPETES Act* will improve the mission of the DOE Isotope Program, including the establishment of a new Advisory Committee and the authorization of appropriations for the DOE Isotope Program to be used to support the new DOE isotope—the DOE Stable Isotope Production and Research Center, Radioisotope Processing Facility, and the Clinical Alpha Radionuclide Producer Project. However, the current level of funding supports project completion timelines that stretch to the early 2030's. CORAR encourages the Committee to consider accelerating the authorization of appropriation rate for the DOE Isotope Program that would allow these projects to be completed on an accelerated timeline, ideally over the next 4 to 5 years.

I thank you for the opportunity to testify today, and I would be pleased to answer your questions.

[The prepared statement of Mr. Guastella follows:]

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Michael J. Guastella, MS, MBA
Executive Director

June 22, 2022

Good morning, Chairman Bowman, Ranking Member Weber, and members of the committee. I am Michael J. Guastella, the Executive Director of the Council of Radionuclides and Radiopharmaceuticals, Inc. (CORAR). CORAR is an association of companies in the United States and Canada that manufacture and distribute radiopharmaceuticals, radioactive sources, and medical isotopes in the United States for therapeutic and diagnostic nuclear medicine and for industrial, environmental, and biomedical research and quality control.

Thank you for the opportunity to provide the committee with the perspective of the medical and industrial isotope industry. Our supply chain issues have been the focus of several government efforts over the last 15 years to address the lack of a reliable and sufficient supply of domestic medical and industrial isotopes and the recent Russian invasion of Ukraine highlights further these issues. The problem is significant, and my member companies are appreciative of the committees' interest in these issues and our suggestion on what needs to be done.

I want to thank you Mr. Chairman and Ranking member Weber for your support and assistance over the last several years. Your committee has recognized the importance of medical and industrial isotopes and you have advocated for federal policies that would ensure that our patients have the isotopes necessary for the diagnosis and treatment of disease. CORAR member companies greatly appreciate your support and your willingness to work with us.

What is Nuclear Medicine?

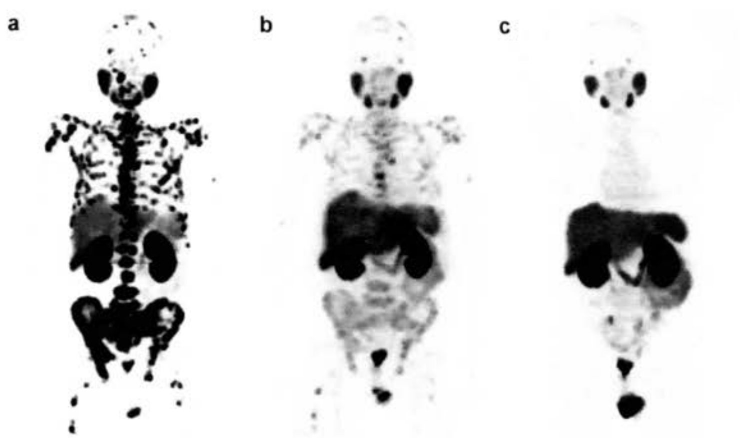
Nuclear medicine involves the injection of radioactive materials (i.e., medical radioactive isotopes, known as medical radioisotopes, and radiopharmaceutical drugs) into a patient's body for diagnostic or therapeutic procedures. These isotopes help provide detailed images of patients' organs, arteries, or certain cells, as well as assessing organ function. Nuclear medicine is integral to the care of patients with cancer, heart disease and brain disorders and offers not only structural images but allows physicians to see how the body is functioning and to measure its chemical and biological processes. To put the use of these isotopes and radiopharmaceuticals into perspective, today we estimate that there are approximately twenty (20) million nuclear medicine procedures performed annually in the United States as reported by the Society of Nuclear Medicine and Molecular Imaging (SNMMI).[1]

An area of rapid advancement in nuclear medicine is often referred to in some cases as Radiopharmaceutical Therapy (RPT). RPT is a novel therapeutic modality for the treatment of cancer, providing several advantages over existing therapeutic approaches. In RPT, radiation is systemically or

[1] Society of Nuclear Medicine and Molecular Imaging, http://www.snmmi.org.

locally delivered using radiopharmaceuticals that either bind preferentially to cancer cells or accumulate by physiological mechanisms.[2]

An example is provided below of the clincal response to Lu-177 PSMA-617 in a metastatic prostate cancer patient who had exhausted all standard treatment options.



Groener, D.; Baumgarten, J.; Haefele, S.; Happel, C.; Klimek, K.; Mader, N.; Nguyen Ngoc, C.; Tselis, N.; Chun, F.K.H.; Grünwald, F.; Sabet, A. Salvage Radioligand Therapy with Repeated Cycles of 177Lu-PSMA-617 in Metastatic Castration-Resistant Prostate Cancer with Diffuse Bone Marrow Involvement. Cancers 2021, 13, 4017. https://doi.org/10.3390/cancers13164017

The FDA approved Lu-177 PSMA-617 (Pluvicto®) for the treatment of advanced prostate cancer in 2022 and ^{177}Lu-DOTATE (Lutathera®) for the treatment of neuroendocrine tumors in 2018. In addition to the approved radiotherapies mentioned, we estimate that there are at least 85 clinical trials running to examine a variety of other RPT's based on medical radioisotopes such as copper-67 (Cu-67), actinium-225 (Ac-225), and lutetium-177 (Lu-177).[3]

In addition, oncology patients are benefiting from the development of Theranostics which integrates imaging and therapy using a radiopharmaceutical to characterize the cancer (diagnostic) and then deliver a precise treatment (radiotherapy). It is envisaged that Theranostics will become the 5th pillar of oncology – the other four pillars being surgery, radiation therapy, interventional oncology, and drugs (including chemotherapy and targeted therapies – biologicals and immunotherapy).[4]

The Problem

[2] Sgouros, G., Bodei, L., McDevitt, M.R. et al. Radiopharmaceutical therapy in cancer: clinical advances and challenges. Nat Rev Drug Discov 19, 589–608 (2020). https://doi.org/10.1038/s41573-020-0073-9

[3] https://www.clinicaltrials.gov/ct2/results?term=Lu-177+OR+Ac-225+OR+Cu-67&recrs=a&recrs=f&recrs=d&age_v=&gndr=&type=&rslt=&phase=4&phase=0&phase=1&phase=2&phase=3&Search=Apply

[4] Theranostics: The Fifth Pillar of Cancer Care, The Royal Australian and New Zealand College of Radiologist, Faculty of Radiation Oncology, Version 1.0 25 May 2021

Now let me update the committee on U.S. isotope supply challenges and opportunities.

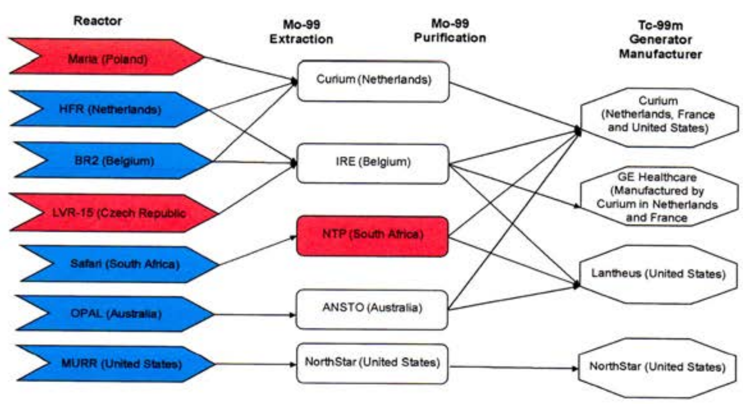
Lack of Domestic Supply

In the mid-1990s, the last U.S. commercially operated research reactor that produced fission based medical isotopes was closed and decommissioned leaving the U.S. without a domestic source of essential medical isotopes. Additionally, the U.S. government closed the stable isotope production facility in Oak Ridge National Laboratory in the late 1990s, leaving the U.S. largely dependent on foreign sources of such isotopes which are often used as target material for the production of radioisotopes. Few in the U.S. government focused on the loss of domestic production until 9-11 as the supply of many radioisotopes coming from abroad was temporarily cut-off due to the cessation of commercial flights into the U.S., echoed years later as commercial flights into the U.S. were halted in March 2020 at the start of the COVID-19 pandemic.

Dependence on Foreign Sources for Medical and Industrial Applications

There are over 40 isotopes that we identify in the list attached (Exhibit 1) to my testimony that are important isotopes for medical or industrial purposes and that the U.S. relies largely on Russian companies to supply as either raw materials or the isotopes themselves. Specifically, the Russian state corporation Rosatom (and affiliates) are critical suppliers of isotopes used in the U.S. for the manufacture of radiopharmaceutical drugs for U.S. patient care and industrial purposes. For example, to serve U.S. patients, a significant portion of the molybdenum-99 (Mo-99) supply chain relies on uranium-235 (U-235) sourced from Rosatom for either research reactor fuel or U-235 used for target fabrication in the Mo-99 production process.[5]

The majority of Mo-99 production is based overseas and handled by a series of long-established research reactors and processors in Europe, South Africa, and Australia. Six multi-purpose research reactors (excluding MURR[6]) and four Mo-99 processors (excluding NorthStar) supply approximately 95% of Mo-99 for patients in the United States[7]. The research reactors and processor filled in red below indicate points in the Mo-99 supply chain that we understand rely on Russian raw materials.



[5] National Academies of Sciences, Engineering, and Medicine Report on Molybdenum-99 for Medical Imaging; https://www.nap.edu/catalog/23563/molybdenum-99-for-medical-imaging
[6] University of Missouri Research Reactor
[7] https://www.nationalacademies.org/news/2016/09/new-report-examines-molybdenum-99-production-and-use

Mo-99 is necessary to produce technetium-99m (Tc-99m). Tc-99m, the most common medical isotope used in nuclear medicine procedures in the United States, is derived from molybdenum-99 (Mo-99), which has a half-life of 66 hours. Tc-99m based radiopharmaceuticals are used by nuclear medicine physicians and radiologists to diagnose diseases, such as heart disease and many forms of cancer, and to inform treatment plans. Of the 20 million nuclear medicine procedures performed annually in the United States, an estimated 15 million of these procedures utilize Tc-99m based radiopharmaceuticals.[8] For example, over 1 million doses of Tc-99m sestamibi, needed to diagnose coronary artery disease, were dispensed to Medicare beneficiaries in CY 2017.[9]

Enriched ytterbium-176 (Yb-176) is used for the production of Lu-177 and enriched zinc-68 (Zn-68) is used for the production of Cu-67 for therapeutic application. Both Lu-177 and Cu-67 are being used to develop the next generation of targeted radiopharmaceutical therapies that will enhance the treatment of disease, especially cancer, as described in the examples above. However, the enriched stable isotopes needed to commercialize these targeted radiopharmaceutical therapies are either sole sourced or predominantly sourced from Russia.

There are numerous other medical isotopes used in the diagnosis and treatment of various diseases that are sole sourced or predominantly sourced from overseas, including Russia. For example:

- Palladium-103 (Pd-103) is primarily used in early-stage prostate cancer treatment and a primary source of Pd-103 is Russia. Restrictions on access to Pd-103 will impact the ability of oncologists to treat patients.
- Xenon-133 (Xe-133) is produced overseas and shipped to the U.S. for the diagnosis of lung disease.
- Much of the iodine-131 (I-131) used to treat thyroid disease in the U.S. is sourced from overseas.
- Gadolinium-153 (Gd-153), and cobalt-57 (Co-57) are isotopes used in sealed sources, calibrating devices required for nuclear medicine cameras in order for medical isotopes to be measured accurately. Due to the half-life of these isotopes, hospitals need to replace sealed sources frequently and Russia is the sole source provider in the world of Gd-153 and the majority supplier of Co-57.

Please note that Exhibit 1 includes a number of isotopes produced through a supply chain heavily reliant on Russian production[10].

Industrial Applications

CORAR members supply industrial isotopes as well as medical isotopes and foreign supplied radioisotopes also play a crucial role in supporting U.S. oil and gas production – interruption of supply would quickly result in shortages and cause significant revenue losses to American energy sector producers.

- Radioisotopes such as iridium-192 (Ir-192) and selenium-75 (Se-75) assure operational safety in refineries and pipelines to test for corrosion, leaks, and cracks. Also, Ir-192, has medical applications for the treatment of cancer. Ir-192 is procured from two powerful high-flux reactors in Russia.
- Foreign produced americium-241 (Am-241) is used in the manufacture of smoke detectors. Russia is the largest source for Am-241with very limited amounts produced domestically since the late 1970s.

[8] US Department of Energy, https://www.energy.gov/nnsa/nnsa-s-molybdenum-99-program-establishing-reliable-supply-mo-99-produced-without-highly
[9] *Center for Medicare and Medicaid Claims data*
[10] Information available through Russian selling entities public websites

- Russian reactors also provide barium-133 (Ba-133), used in extraction and refining to separate oil, water, and gas. Ba-132 is an enriched stable isotope and is only available from Russia.

The Solution

CORAR members have been working for numerous years to develop a sufficient and reliable domestic supply of essential isotopes.

The U.S. Government recognized that essential medical procedures were postponed due to flight cessations post 9-11 with serious potential health consequences. Following 9-11, the American Medical Isotope Production Act of 2012 (AMIPA) was enacted. AMIPA has focused the U.S. Department of Energy (DOE) on the conversion from the use of highly enriched uranium (HEU) to low enriched uranium (LEU), and assisting in the development of a domestic medical isotope industry from non-HEU sources, which led to a close relationship between several CORAR member companies and the DOE in the government effort to aid in the development of a domestic supply of medical isotopes and to meet the needs of our researchers and drug developers for the next generation of medical isotopes. These public-private relationships include several awards of Cooperative Agreements with Government cost-share by the National Nuclear Security Administration (NNSA).

Considering the current need to enhance domestic production of other medical and industrial isotopes, the DOE leadership has been a supportive and a constructive partner through efforts of the Office of Science, Isotope Program (DOE Isotope Program). Unfortunately, current U.S. production of enriched stable isotopes and radioactive isotopes is not sufficient to meet domestic needs and highlights the U.S. reliance on Russia for a number of these isotopes.

To paraphrase the committee's question, "what foundational research would be relevant for isotope production and supply and what policies should the Congress and the Administration consider going forward?"

CORAR members believe that there are a few essential elements that would move us closer to a reliable domestic supply of isotopes and to reduce our dependence on Russia and other foreign suppliers. As a brief overview these elements are:

- Fully fund the proposed U.S. Stable Isotope Production and Research Center (SIPRC), the Radioisotope Processing Facility (RPF), and the Clinical Alpha Radionuclide Producer (CARP) projects and accelerate the appropriations for these three facilities.
- Retain the Committee's COMPETES provision establishing an advisory Committee for the DOE Isotope Program. CORAR is appreciative of the committee for already addressing this.
- When commercial production is adequate to satisfy U.S. demand, retain the language to continue to ensure that the DOE Isotope Program will preserve and appropriately allocate its resources by not competing with commercial isotope producers.
- When the DOE Isotope Program provides commercial isotopes to the domestic market, when commercial production is non-existent or insufficient to meet U.S. demand, ensure that the DOE Isotope Program is required to continue to satisfy the principles of full cost recovery for commercial isotopes.
- To increase flexibility for the DOE Isotope Program to identify opportunities to expedite domestic production of important medical and industrial isotopes currently sourced from Russia, include language that would allow the DOE Isotope Program to identify additional opportunities for Federal investment, including through potential public-private partnerships, as appropriate.
- Continue to support the DOE Isotope Program Research and Graduate training programs, through appropriated government grants and other government educational programs, to help fill the pipeline with knowledgeable and trained individuals in research, development, and commercialization to meet the current and future needs of the medical and industrial isotope industries.

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- Finally, in light of the Russian invasion in Ukraine, request that the administration institute a White House level supply coordinating effort to ensure that there is an interagency coordination to bring about an enhanced, reliable domestic supply of these essential medical and industrial isotopes.

CORAR supports your committee's work contained in Section 311 of the America Creating Opportunities for Manufacturing, Pre-Eminence in Technology, and Economic Strength Act of 2022 (America COMPETES Act of 2022). Provisions of the COMPETES Act will improve the mission of the DOE Isotope Program including the establishment of a new Advisory Committee to provide expert advice to help define the nation's isotope needs and help identify opportunities to increase domestic isotope production. Also, CORAR acknowledges that the authorization of appropriations for the DOE Isotope Program includes escalating authorization through 2026 that should be used to support the new DOE SIPRC, RPF, and CARP projects. However, this level of funding supports project timelines that would have the SIPRC and RPF facilities completed in the early 2030s. CORAR encourages the committee to consider accelerating the authorization of appropriation rate for the DOE Isotope Program that would allow these projects to be completed on an accelerated timeline (ideally over the next four to five years).

CORAR wants to emphasize that the DOE Isotope Program plays a critical role in producing and distributing isotopes needed in scientific research and for initial medical clinical development, as there are not sufficient commercial incentives for production of such isotopes. However, CORAR and its member companies believe that where commercially feasible, medical, and industrial isotopes should be produced by the private sector. Several companies are currently developing reactor and non-reactor capabilities to help scale up domestic production of essential medical radioisotopes such as Mo-99, I-131, and Xe-133. In addition, private sector projects are underway to increase domestic supply of actinium-225 (Ac-225), Lu-177, and Cu-67 for targeted radiotherapies. CORAR believes that when diverse commercial production sources can meet U.S. demand, the DOE Isotope Program should exit the market for such isotopes, consistent with the mission of the DOE Isotope Program.

CORAR is aware of additional opportunities being explored by industry stakeholders in North America to augment the domestic supply of essential medical and industrial isotopes such as the use of current nuclear power reactors as neutron sources for isotope production. The Canada Deuterium Uranium (CANDU) commercial power reactors are currently being used for certain medical isotope production in Canada. For example, BWXT Medical has publicly disclosed that they will be using the Ontario Power Generation (OPG) Darlington Nuclear Generating Station to produce the medical isotope Mo-99.[11] Also, ITM Medical Isotopes GmbH has publicly stated that they are using Bruce Power Reactors to produce the therapeutic radioisotope Lu-177[12]. Both OPG and Bruce Power reactors utilize CANDU design technology which provides unique capabilities to irradiate targets for isotope production that commercial reactors in the U.S. don't currently possess.

However, these commercial activities may not be adequate to address the immediate risks to the radioactive and stable isotope supply chains posed by the Russian invasion of Ukraine and potential sanctions being considered on Russian suppliers by the U.S. and its allies.

Any U.S. Government sanctions on Rosatom, or its subsidiaries (and affiliates), will significantly disrupt the supply of many of our essential medical and industrial isotopes. For a number of those isotopes where commercial domestic production has not been established or is not sufficient to meet U.S. medical and industrial needs, the DOE Isotope Program can potentially provide a bridge to ensure domestic supply. To better prepare the DOE Isotope program to meet the isotope needs of U.S. health care and industry, CORAR supports accelerating the completion timelines of both the RPF, SIPRC, and CARP projects mentioned above.

[11] https://www.bwxt.com/bwxt-medical/news/2020/09/24/OPG-and-BWXT-Make-Significant-Progress-in-Production-of-Life-Saving-Medical-Isotope-at-Darlington-Nuclear-Generating-Station

[12] https://itm-radiopharma.com/news/press-releases/press-releases-detail/bruce-power-and-isogen-set-first-critical-milestone-for-exclusive-irradiation-service-provided-to-itm-for-its-production-of-no-carrier-added-lutetium-177-201

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Accordingly, CORAR wants to thank the committee for the opportunity to highlight these issues and commends the committee for your work to date and encourages the Committee to continue to support the DOE's research, development, and production activities.

I thank you for the opportunity to testify today, and I would be pleased to answer any questions.

Respectfully Submitted,

Michael J. Guastella

Exhibit 1

Medical Isotopes	Stable	Isotope Details
Actinium-225 (Ac-225)		Cancer treatment
Cobalt-56 (Co-56)		Calibration standard
Cobalt-57 (Co-57)		Medical Imaging
Cobalt-60 (Co-60)		Cancer treatment and medical product sterilization
Cobalt-60 (Co-60)		Cancer treatment and medical product sterilization
Cesium-137 (Cs-137)		Cancer treatment, Thickness gauging, flow dectection
Cadmium-112 (Cd-112)	Stable	Target material for In-111 production
Erbium-168 (Er-168)	Stable	Production of Er-169 used for radiation synovectomy
Gadolinium-153 (Gd-153)		*Medical Imaging Quality Control Source (SPECT)*
Germanium-68 (Ge-68)		PET imaging, cancer treatments
Iodine-131 (I-131)		Therapy for hyperthyroidism and thyroid cancer
Manganese-54 (Mn-54)		Calibration standard
Nickel-64 (Ni-64)	Stable	Target material for Copper-64 production which is used for cancer diagnosis
Palladium-103 (Pd-103)		Treatment for Prostrate Cancer
Rubidium-85 (Rb-85)		*Cancer treatment, target for Sr-82*
Ruthenium-106 (Ru-106)		*Brachytherapy for treatment for ocular melanoma*
Thallium-203 (Tl-203)	Stable	Target material for Thallium-201 production used in heart imaging.
Tin-112 (Sn-112)	Stable	Cancer diagnosis of brain , liver kidney tumors
Molybdenum-98 (Mo-98)	*Stable*	*Target material for Mo-99 production*
Molybdenum-100 (Mo-100)	*Stable*	*Target material for Mo-99 production*
Rhenium-185 (Re-185)	Stable	Production of Re-186 for cancer treatment
Samarium-152 (Sm-152)	Stable	Production of Sm-153 used in cancer treatment
Strontium-90 (Sr-90)		Cancer treatment
Uranium-235 (U-235)		Research reactor fuel and irradiation targets for Mo-99 production
Ytterbium-176 (Yb-176)	Stable	Production of non-carrier added Lutetium-177 for cancer treatment
Yttrium-88 (Y-88)		Medical diagnostics, LED's
Xenon-124 (Xe-124)	Stable	Production of Iodine-123 and Iodine-125 radioisotopes for imaging and cancer treatment
Xenon-133 (Xe-133)		Production of Xe-133 for evaluation of pulmonary function and lung imaging
Zinc-67 (Zn-67)	Stable	Target material for Ga-67 and Cu-67 production
Zinc-68 (Zn-68)	Stable	Target material for Ga-67 and Cu-67 production

Please note: highlighted italic isotopes are single sourced from Russia.

Industrial Isotopes	Stable	Isotope Details
Americium-241 (Am-241)		Oil/Gas exploration
Barium-133 (Ba-133)		Oil/Gas exploration
Barium-132 (Ba-132)	*Stable*	*Target Material to US DOE for Ba-133 production*
Cadmium-109 (Cd-109)		*Metal analysis/lead in paint*
Cerium-139 (Ce-139)		Used in Metal production
Helium-3 (H-3)		*Oceanic transient tracer, fuel for nuclear fusion reactions*
Iridium-192 (Ir-192) Disks		Industrial Radiography
Iridium-192 (Ir-192) Disks		Industrial Radiography
Krypton-85 (Kr-85)		*Radioactive tracer, Arc discharge lamps, exit signs*
Polonium-210 (Po-210)		Static remover
Selenium-75 (Se-75)		Industrial Radiography
Tellurium-122 (Te-122)	Stable	Target material for I-122 gamma imaging
Xenon-124 (Xe-124)	Stable	Instrumentation for radiation detection

Please note: highlighted italic isotopes are single sourced from Russia.

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Michael J. Guastella Bio

Michael J. Guastella is the current Executive Director of the Council on Radionuclides and Radiopharmaceuticals, Inc. (CORAR). CORAR is a Washington DC based trade association that represents developers, manufacturers, and distributors of radiopharmaceuticals and radioisotopes used in healthcare, the life sciences, and industry.

Michael has approximately 30 years of experience in the radiopharmaceutical and nuclear medicine industries. Prior to CORAR, Michael worked in the nuclear pharmacy industry with both Syncor International Corporation and Cardinal Health for 18 years holding a number of leadership positions in both marketing, product development, sourcing, and supply chain management. As Vice President of the Nuclear Pharmacy Business of Cardinal Health he led the marketing, product development, and innovation teams.

While working in industry, Michael served on the CORAR Board of Directors for ten years and has held other industry leadership positions including Co-Chairman of the CORAR Healthcare Policy Committee. Michael received his B.S. and M.S. degrees from the University of California Los Angeles (UCLA) and received his MBA from the Anderson School at UCLA.

Chairman BOWMAN. At this point, we will begin our first round of questions. The Chairman now recognizes himself for 5 minutes.

My first question goes to Mr. Yeck. It's for you as the Director of—the Project Director of the Electron-Ion Collider, which is funded and supported by the DOE Office of Science Nuclear Physics Program and located in my State of New York. I understand from your testimony that research at this facility will not only continue to advance our fundamental understanding of matter and reality but could also pave the way for further breakthroughs in medicine, electronics, advanced computing, and much more. Can you please elaborate on how the Electron-Ion Collider is envisioned to contribute to maintaining our country's leadership and innovation in these and other critical technology areas?

Mr. YECK. Thank you. One of the features of the Electron-Ion Collider is that it's an extremely challenging and complex machine, which requires innovations in accelerator physics. And the result that we're pursuing in performance parameters that push the envelope in terms of the energy of the collisions, the luminosity, the polarization of the beams. All of these techniques have been used in the past to benefit other fields. So it's basically the development of accelerator science and technology which is motivating the interest of collaborators around the world. And the detector technologies are also quite challenging. And if history is any guide, as was discussed earlier in other testimony, this is made available to these other fields. Thank you.

Chairman BOWMAN. Thank you. Dr. Berhe, can you comment on this as well?

Dr. BERHE. Yes, I agree with Mr. Yeck that, you know, the Electron-Ion Collider represents an important—and thank you, first of all, for your question, Congressman. And, as I said, I agree with Mr. Yeck on the importance of this incredibly exciting facility that the science community is looking forward to. And I also agree that even though some of these research questions that the facility might address might be more fundamental, there are significant advances and benefits that we can look forward to from these facilities. And I think it's a really good reason why there is a widespread support for this facility and the science that it will enable across the board in the Office of Science.

Chairman BOWMAN. Thank you. My next question is for Dr. Greene. Thank you for your testimony. Here on the Science Committee, we have delved deep into how to better involve students in STEM around the country, from K to 12, to the university and graduate level.

In your written testimony, you state that the American education system has failed to teach science effectively. You go on to say that, as a society, we are too focused on what science can do for us instead of valuing science for how it can change the way we understand and see the world. Can you describe this educational failure? How can we here on the Science Committee and in Congress in general address that problem?

Dr. GREENE. Yes, thank you for the question. Briefly put, we focus in the classroom on teaching kids the details of science so that they can regurgitate it back on an exam so we can evaluate them. But science is not simply the details. Science is the big ideas,

as we've already heard in the testimony from many on the panel today. And if you can take a kid out to the stars and reveal to them the wonders of the cosmos and the wonders of life and the wonders of mind, this can inspire them to want to learn the details.

So I think there needs to be a fairly significant shift in the way that we teach science to the young and the way we bring adults and families into the scientific enterprise because, ultimately, what we're doing is continuing a journey that our species has been on for thousands of years. And we have, as a species, tried to understand ourselves and the cosmos, and it's perhaps the most exciting of adventure stories.

So what we need to do is extol science as something vital to life and fun, the ability of scientists to go out into the world and spread the message of how these ideas can help us shape our place in the universe.

Chairman BOWMAN. Thank you very much. I yield back the balance of my time and now recognize Mr. Weber for 5 minutes.

Mr. WEBER. Thank you, Mr. Chairman.

We can all agree that isotopes are strategic commodities that are essential to the Nation's economic, scientific, medical treatments, industry, national security is not negotiable or replaceable. Therefore, I'm extremely concerned about DOE's solution or dare I say the lack thereof to the instability of isotope supply chain resulting from the Russian aggression in Ukraine.

So Dr. Berhe, welcome once again here. We'll give you one of the hard questions first. I'll ask you. What exactly is DOE's short-term outlook here, and do you believe that the Department's plan to build both a Stable Isotope Production and Research Center and a Radioisotope Processing Facility will be quick enough and sustainable enough in the long term to avoid the short—the supply shortage that is already appearing absolutely inevitable?

Dr. BERHE. Thank you, Congressman, for that question. I agree with you that the importance of isotopes is clear, as was elaborated by my colleagues on the panel and the urgency of this matter is also very, very clear. One thing I could say is the fact that contingency planning for scenarios like what we're experiencing right now actually started at the DOE about 5 years ago, so we've been anticipating and planning for something like this and disruptions. And, as a result, we've been able to actually speed up production in facilities that are existing, but also are continuing to push for newer facilities to come online as soon as possible. And we appreciate the bipartisan support that we've received from your Committee on this area.

And as, you know, it was discussed earlier, the two Stable Isotope Facility, as well as the Radioisotope Production Facility that are in construction, are going to be very critical for helping us address the needs.

I want to be clear also about the fact that this is an extremely technically challenging area, so there's not going to be any very, very quick fixes in the matter. But I think, as has been demonstrated in the last several months, the DOE facilities and the personnel involved in this work and the partnerships that we have with both universities and the industry have been able to limit the impact of the supply chain disruptions because of Russia's invasion

of Ukraine. And we'll continue to work with the Congress, as well as these different stakeholders, to make sure that we address these issues.

In the short term, there might be some challenges, obviously. But I think continuing to receive support for these upcoming facilities will definitely help us bring them online faster in the timelines that hopefully can alleviate even more significant——

Mr. WEBER. Well, let me ask you two questions to follow up with that, Doctor. And that is No. 1. If that process was inevitable 5 years ago, where are we in that process, No. 1? And the second question is, how long are you on loan from the university?

Dr. BERHE. Well, to answer your first—second question first, I'm in this position for—you know, I'm a Presidential appointee, so—but I think—rest assured, though, this is not about me or one person, right? Obviously, there's a program and dedicated staff with DOE.

Mr. WEBER. Is there an administrator to that process?

Dr. BERHE. Yes. Yes, there is——

Mr. WEBER. Who is that?

Dr. BERHE. There is a program—Joann Gallon—Gillian—sorry——

Mr. WEBER. OK.

Dr. BERHE. The last name, I'm butchering it a little bit. But Jehanne Gillo is the Program Manager for Isotopes. And I should also mention that the scientific community in this area has been very invested, as you heard. They're trying to set up their own advisory committee actually outside NP and continuing——

Mr. WEBER. And if I may interrupt, and that answer, do we think that we have to build a facility like this each time or could we get the private industry on board as quickly as possible, have them taking this over?

Dr. BERHE. I think, as has been demonstrated, there's multiple different pathways that could be followed in the long term. Obviously, many of us have been engaged in the short term trying to address with the facilities that we already have and ones that have been planned and are currently under construction. But there are obviously possibilities around the world to do this in different ways.

Mr. WEBER. OK, thank you. I appreciate that.

Mr. Chairman, I'll go ahead and yield back.

Chairman BOWMAN. Thank you.

The gentlewoman from Oregon, Ms. Bonamici, is now recognized.

Ms. BONAMICI. Thank you so much, Mr. Chairman, Chairman Bowman, and Ranking Member Weber, and thank you for our witnesses for being here this morning.

I'm honored to be selected as a Member of the Conference Committee tasked with negotiating a bipartisan innovation package. And as part of the House-passed version of this legislation, the Science Committee included a provision authorizing nearly $1 billion over 5 years to establish a development, demonstration, and commercialization program at the Department of Energy to strengthen our global competitiveness in the field of microelectronics. The House-passed bill would establish microelectronics science research centers to address the foundational challenges in design, development, and manufacturing.

So the district I represent in northwest Oregon is often referred to as the Silicon Forest. It's particularly affected by innovation in microelectronics. Thousands of my constituents and more than 40,000 Oregonians currently work in the semiconductor industry.

So I want to ask Dr. Merminga, in your written testimony you note that Fermilab was a leader in advancing science and technology that drive advancements in microelectronics capabilities. So will you please expand on the interplay between the DOE's High Energy Physics Program and microelectronics development and offer your perspective on why our national labs are uniquely positioned to accelerate progress in advanced microelectronics research and development?

Dr. MERMINGA. Thank you very much for this question. So Fermilab experiments create massive streams of data at very high rates. Just to give you an idea—excuse me—the data generated per second in just one large collider physics experiment like the LHC is equivalent to the average internet traffic across North America. Now, in order to monitor these data and make decisions about what events to read out, the readout must be located on the detectors themselves. So this creates naturally a need for microelectronics code design, which is a prerequisite to allow us to interpret and monitor the data that we produce in our large-scale particle physics experiments. It's part of our business.

In addition, our applications of microelectronics have additional cutting-edge requirements, for example, cryogenic operation, ultralow power consumption, and radiation hardness. It turns out industry now is interested in all of these challenges. Their requirements are easier than ours. We have more stringent requirements. And industry is very interested in working with us to codevelop a lot of these capabilities.

To give you an another idea, we were the first laboratory in the complex to put AI on a chip. And so advances now——

Ms. BONAMICI. Dr. Merminga, I'm sorry to cut you off, but I want to get a couple other questions in and I don't have much more time.

Dr. MERMINGA. Sure.

Ms. BONAMICI. I'm sorry to cut you off. I want to ask Dr. Berhe, briefly, how can basic research fields like high-energy physics and nuclear physics more effectively support work force issues and help our U.S. high tech industries? And if you can summarize and then I want to ask, Dr. Greene, thank you for your work, how can we better communicate the importance of what we do to the general public?

Dr. BERHE. Thank you, Congresswoman. So this is a very important area for me personally and the Department and the Administration. And we are currently actually working on a comprehensive plan that would allow us to support a diverse, dynamic work force that we could develop and support right here in the United States so that we are, you know, providing the best training possible for the scientists that will go on to make the discoveries of the future, but also the work force that will be needed for these highly technical industries out there.

And you know, both the HEP and NP programs, for example, support a significant part of the training of the skilled work force in these areas, and so providing the support, being very intentional

about recruitment, being intentional about also—oh, OK, sorry, the buzzing sound—being very intentional about the training, recruitment, and retention of staff and—is a very important priority area and that's how we think it's—this is going to work. Thank you.

Ms. BONAMICI. Thank you. Dr. Greene?

Dr. GREENE. So in 13 seconds I would simply say that public engagement is cheap. So with a little bit of funding, you can have an army of scientists who are out there talking to the public and getting the public excited about these key ideas.

Ms. BONAMICI. I appreciate that and appreciate all your efforts to bring science to the people of this country and the world. Thank you, Mr. Chairman. I yield back.

Chairman BOWMAN. The gentleman from Indiana, Mr. Baird, is now recognized.

The gentleman from California, Mr. Obernolte, is now recognized.

Mr. OBERNOLTE. Thank you very much, Mr. Chairman. And thank you to all the witnesses. This has been a fascinating hearing.

I'd like to continue the line of questioning that Ranking Member Weber had started. Like him, I am very concerned about the supply chain issues that have arisen in our radioisotope production. Mr. Guastella, I found in your written testimony some of the things that you had to say about that extremely interesting. You had pointed out that it's possible to use commercial power reactors as neutron sources for the creation of radioisotopes, but you also pointed out that, currently, power reactors in the United States lack the technology to irradiate a target, which is really what you'd need to make this work.

So a number of us here on the Committee have been vocal advocates for next-generation nuclear, both fission and upcoming fusion, but the—you know, really, as we confront the problem of global climate change and decarbonization, nuclear energy is probably at this point the cleanest energy that mankind knows how to produce. And, you know, we think it's gotten a bad name. Next-generation nuclear has amazing promise and much lower failure modes.

So as you see these next-generation nuclear programs and the modular reactors come on board, is there a possibility for some synergy of designing in the technology to be able to create these radioisotopes as we develop these new reactors?

Mr. GUASTELLA. Well, Congressman, thank you for the question. And yes, as you've acknowledged, some of the power reactors in Canada, generally CANDU (Canada Deuterium Uranium) reactors, are using—they're using the power reactors as neutron sources for moly production, as well as lutetium–177, which is a beta-emitting isotope. The current power reactors in the United States, unfortunately, generally don't have the same type of technology that allows them to irradiate these targets while they're online.

We have one member TerraPower, a Bill Gates company, who was looking at a next generation, a small modular reactor. They're going to test it in Wyoming. As far as I know—and we've asked this question—TerraPower does not plan to include medical isotope production into their mission and into the design of the reactor. I'm not aware of any of the other projects right now that are including medical isotope production, unfortunately, but——

Mr. OBERNOLTE. What would be the technical barriers to be able to—to adding that kind of capability?

Mr. GUASTELLA. To be honest, I'm not quite sure. We can certainly look into that a little bit more and maybe provide a response as a question for the record. But in asking TerraPower, who is looking at actinium–225 production in partnership with the DOE, they've basically said the design of their reactor does not allow right now for the—a production of medical isotopes, but not sure of some of the other projects that are currently in development.

Mr. OBERNOLTE. Do you know if any other countries are planning on building in this technology? It just seems like an incredible missed opportunity if we're having the supply chain pressure not to take advantage of the fact that we're deploying this next-generation technology currently?

Mr. GUASTELLA. Yes. Well, as far as next-generation technology, I'm not aware. Obviously, there are projects in Europe right now, research reactor projects that are on the books right now and with the design of medical isotope production as part of their mission. So there are some projects. I'm not aware of any—of the next-gen small modular reactor projects involving medical isotope production at this time.

Mr. OBERNOLTE. Well, thank you. Well, let me ask you, Dr. Berhe, is this something that your department is pursuing, perhaps talking with the Office of Nuclear Energy as you interface between the Radioisotope Program and this upcoming technology?

Dr. BERHE. Thank you, Congressman, for that question. We all agree that this is an important area. It's also fast-moving in terms of the technical advances that are happening. And I think your—the point that you make is an important one, and the Isotope Program at DOE Office of Science continuously works with the nuclear energy side of the house and other stakeholders to figure out what is—what other things that we should be thinking about because it's not just a production program, right? It's also a research and development program so that we are thinking ahead about what are the new technologies that we're developing. So in consultation with the scientific community and the different stakeholders, they are continuously assessing what needs to be the next goal that we target.

And just to mention one, the Radioisotope Production Facility at Oak Ridge National Lab that's, you know, in development will actually have capacity to add a number of the isotopes that we currently source from Russia that are produced on a reactor, and obviously will help accelerate the availability of a number of radioisotopes that are critical, including in the medical field.

Mr. OBERNOLTE. Thank you. I see I'm out of time. but I'd like to encourage you to continue to have those discussions because it would certainly be a missed opportunity if we didn't build that capability into the new commercial power reactors that are in development.

Thank you, Mr. Chairman.

Chairman BOWMAN. The gentleman from Pennsylvania, Mr. Lamb, is now recognized.

Mr. LAMB. Thank you, Mr. Chairman. I wanted to start off with a question for Mr. Yeck about the facility being built at Brookhaven. I was wondering if you could kind of compare that for

us to similar facilities around the world if they exist in direct comparison. In other words, you know, how urgent is it for us to complete and maintain that facility in order to maintain an edge over competitor nations, or are we merely matching them by building the facility at Brookhaven?

Mr. YECK. Yes, thank you for the question. So the EIC, when it's constructed, will be a unique facility in the world. And there's worldwide interest in the realization of the facility. It's been a priority, obviously, in the United States but also in the European community, and participation is encouraged.

There is potential competition. I mean, China is interested in building an electron-ion collider. They've made plans. We're ahead. We have a unique opportunity, as I mentioned in my testimony, with the successful conclusion of the RHIC program, which will end in 2025, with a work force that can be mobilized immediately into the construction work of the EIC. The timing here is absolutely critical. We cannot lose these people. We need these people in addition to our partnerships and collaboration with Jefferson Lab and other laboratories and universities. So the timing is now for the realization of the Electron-Ion Collider, and it will maintain U.S. leadership in this field with creating a facility that will have international interest and participation. Thank you.

Mr. LAMB. I appreciate that. Thank you.

And, Dr. Behre, to kind of enlarge that to all 28 of the user facilities under your purview, can you maybe update us on the the overall state of those 28 in comparison to the portfolio of other nations? And has that changed over time? Like in other words, are we pulling ahead? Are other nations catching us in terms of the concrete user facilities that we have?

Dr. BERHE. Thank you, Congressman, for the question. I think it's fair to say that the United States remains one of the strongest, you know, kind of nations with respect to the user facilities that we have, the capabilities that—and the science that they enable. And many of the research programs that enable and support the facilities remain one of the strongest, anywhere, really.

But I think it's important also to acknowledge that there are in fact nations out there, as we just heard, that are, you know, also making similar investments in their institutions. And so there is competition coming down the pike. I think that's widely acknowledged. But continuing, I think, efforts to support these facilities is—I think, again, it will ensure that the United States remains preeminent on top of our—you know, on top of the field across many areas. These user facilities, as you mentioned, there are many, they're diverse, they're some of the most renowned in the world in the areas of research that they enable, and they remain important priority areas that are supported and have widespread support by the Office of Science.

Mr. LAMB. I agree. Thank you.

And Dr. Greene, last question for you. You know, you've referenced several times some of the really important scientific and particularly physics discoveries of the 20th century. And, you know, my limited knowledge of that story is that a lot of the most important characters started off in Europe and found refuge in the United States around the time of World War II and made many

other discoveries here as a result. Do you think that we are still seen around the world as a refuge and a destination of that type? And are these investments we're talking about today critical to our ability to continue that way?

Dr. GREENE. Yes, I think we're definitely still seen as a center of forefront research and a place where scientists who aspire to great things will want to spend time here at American universities, at our national labs, and so forth.

But, you know, I think the the more important lesson to my mind is that science is a worldwide effort. Sure, it's important for American competitiveness, we want to be the leaders and so forth, but ultimately, the questions that we're asking transcend national boundaries. And if I was going to use one model for the way the world could be a better place, we scientists, we speak to each other across national boundaries. It doesn't matter where you're from. What matters is the work that you do, the contributions that you make, the insight that you provide. And that, to me, is an inspiring message that really transcends national considerations and is a global concern that should drive us all.

Mr. LAMB. Thank you very much, Mr. Chairman. I yield back.

Chairman BOWMAN. Thank you. The gentleman from Indiana, Mr. Baird, is now recognized.

Mr. BAIRD. Thank you, Mr. Chairman. And my question goes to Dr. Yeck. You know, Purdue University is in my district, and it's just one of the institutions that have participated in research with the Relativistic Heavy Ion Collider. So I appreciate your testimony and your update on the Electron-Ion Collider, the EIC. So here's my question. You noted in your testimony that funding for the EIC has been well below that is required for most efficient construction models and schedules. How would such delays impact academic users in institutions anticipating the use of the EIC facility? Dr. Yeck?

Mr. YECK. Thank you. Yes, thank you for the question. The impact is profound. I mean, the delays and the realization of the EIC result in a gap as there are many users involved, as you mentioned, from your district that are involved in the science of the Relativistic Heavy Ion Collider and are planning for the science that will come with the Electron-Ion Collider. And so the plans that we've laid out and the funding plans that are proposed minimize the gap between the conclusion of RHIC operations and the start of operations and the data-taking with the Electron-Ion Collider. This is an issue that the plans have addressed. That funding is clearly identified what is needed to minimize that gap. And so I think it is—the answer is it's profound. I mean, we need to move forward on the EIC now so that we can move the people that are interested in the science into the program in as graceful a way as possible. Thank you.

Mr. BAIRD. Well, thank you. And Dr. Merminga, a number of news stories in recent months have featured concerns about—and it's along the same vein of this last question—about the progress of the LBNF and DUNE, so including the cost in recent years, extended completion times, and the decision to split this project into subprojects. So in your new role, how do you plan to reassure international and institutional partners regarding Fermilab's and the

Department's commitment to completing this project in a timely and cost-effective manner?

Dr. MERMINGA. Thank you very much for this question, and thank you for the opportunity to set the record straight. The splitting in phases was something that was envisioned in the 2014 P5 report originally. It is not a recent development. LBNF and DUNE, the DUNE experiment was going to—came in two phases. Phase 1 was the installation of two detectors in the first South Dakota sight and beam power from PIP–II equal to 1.2 megawatts. And then phase 2 was the installation of the remaining two detectors in South Dakota and increasing the beam power to 2.4 megawatts. That was originally conceived.

Now, the LBNF experiment is proceeding on track. The first side excavation is already more than 30 percent, the excavation complete. Eight hundred thousand tons of rock is being excavated right now. And furthermore, delays would be very, very detrimental to the project. However, a couple of months ago, the Office of Science reaffirmed their commitment in front of our international partners in a funding—international funding agency forum their commitment to LBNF and DUNE and announced a new funding profile that increases funding in 2024 to 2027 and allows completion of the project in early 2031, 2 years compared to the earlier profile, 2 years earlier, and in alignment with the original P5 expectations.

So the way I'm going to convince the communities who are doing—still—were—the science is profound from LBNF and DUNE. We are managing the cost. The cost has been stable to around $3 billion since 2019. We are delivering the project on schedule, and we're accelerating in order to win the competition as well.

Mr. BAIRD. Thank you very much. I appreciate the witnesses and their expert testimony. I yield back.

Chairman BOWMAN. The gentlewoman from North Carolina, Ms. Ross, is now recognized.

Ms. ROSS. Thank you, Chairman Bowman and Ranking Member Weber, for holding this hearing and to all of our witnesses for joining us.

What's clear from the witness testimony today is the far-reaching impact of particle and nuclear physics research. And I'm proud to say that my district is home to the world's first nuclear reactor used for teaching, research, and public service at the North Carolina State University School of Engineering. Nuclear engineers at NC State University are at the forefront of research on neutrino detection to advance nuclear nonproliferation, food irradiation—you guys are going to have to help—irradiation to prevent the transmission of pathogens, and nuclear forensics and medical imaging. That work and the work of researchers at academic institutions across the country is more important than ever as we face both energy shortages and the ever-present potential for nuclear conflict.

So, Dr. Greene, as the only panelist today representing an academic institution, what are your thoughts on the interplay between the research community and these large-scale experiments funded in the range of hundreds of millions to billions of dollars? And how do you think the Federal Government can better nurture relationships with our academic institutions, as well as improve partnerships with universities, national labs, and international projects?

Dr. GREENE. Great, thank you. Thank you for the question. There's an enormously fruitful interplay between the national labs and academics at universities. Ever since I was a graduate student, the number of my colleagues both as students and then when I was a faculty member as well, who freely move between the university and various of the national labs. That's a commonplace occurrence. There are many graduate students at a given university, including my own, who spend most of their time at a national lab where their thesis work is part of the laboratory's work, part of the undertaking of that facility.

So I think it's a very fruitful interplay between the two. And it's a vital one because, look, the charge of a university is different from the charge of a national lab. We're seeking to both educate broadly, as well as be a research institution. Managing a large-scale facility is usually not within the purview of most universities, so I think it's a very symbiotic relationship between the labs and the academic universities in America. Thank you.

Ms. ROSS. Thank you very much. And Dr. Merminga, I understand that one of the areas of cutting-edge research in nuclear nonproliferation is the use of antineutrino detectors to monitor nuclear power plants from long distances. And North Carolina State University's Dr. John Mattingly is part of the team of researchers working on this potentially game-changing research. Could you speak a bit to the promise of this approach and other novel approaches to nonproliferation research?

Dr. MERMINGA. I'm sorry, I don't think I can speak to this.

Ms. ROSS. OK. Anybody else?

Dr. MERMINGA. I will get back to you though.

Ms. ROSS. Does anybody else on the panel know anything about nonproliferation research? OK. Well, then I'll move to my last question, and hopefully, Dr. Merminga, you can speak to this. I was recently in Japan, which is moving rapidly on a competing project known as Hyper-K, which is similar to LBNF/DUNE. Can you briefly comment on the difference between the scientific approaches favored by LBNF/DUNE versus Hyper-K?

Dr. MERMINGA. I'm very happy to speak about this, and thank you for the question. So Hyper-K is an experiment that aims at similar scientific goals as the DUNE experiment. However, it follows fundamentally different approaches. Simply put, DUNE brings together exceptional capabilities due to the following key characteristics of the facility and the experiment. And I will draw the difference between DUNE and Hyper-K. These experiments are called long baseline experiments because the distance—because of the long distance between the source where neutrinos are produced and where they are being detected at the far side. So for DUNE, the distance is 1,300 kilometers and for Hyper-K is 295 kilometers. Furthermore, the DUNE experiment is going to be—to have the most intense beam of neutrinos ever built in the world. Already the Fermilab complex delivers today the most intense beam of neutrinos with nearly 900 kilowatts of beam power today. And for DUNE, we're going to go to 1.2 megawatt, eventually to 2.4 megawatt. And importantly, this beam of neutrinos is wideband. It has a wide band of energies that covers the oscillation spectrum. And

the neutrino oscillations is a key scientific objective of these experiments.

Ms. ROSS. Thank you very much.

Dr. MERMINGA. And third——

Ms. ROSS. I see my time has expired. And, Mr. Chair, I yield back. But thank you so much for that explanation.

Dr. MERMINGA. OK. Thank you.

Chairman BOWMAN. The gentlewoman from Michigan, Ms. Stevens, is now recognized.

Ms. STEVENS. Our Chair strikes again, an amazing hearing on investigating the nature of matter, energy, space, and time. Five amazing witnesses. I cannot believe what we are hearing, the quiet murmurs of the Science Committee ringing across the universe. One testimony alone from Dr. Berhe, neutrinos, quote, "Neutrinos may hold the key to why matter exists at all in the universe, as opposed to nothing," quote, "a broad range of the epochs of the universe," end quote, in your testimony. That alone is just absolutely remarkable. And we could spend all day with every one of you, so thank you so much for your expertise and your time.

We are certainly in a competitive moment. My colleague referenced our work in microelectronics and the chip shortage and supply chain disruptions, but this is broader, this is more international, and this is, dare we say, universal. So in terms of what we're looking at with—and my—you know, there's just so much to unpack here. But in terms of what we're looking at with isotopes—and this is of importance to us in Michigan—we've got this new isotope research lab, the FRIB (Facility for Rare Isotopes Beams) that—the Department of Energy's Michigan State University Facility for Rare Isotope Beams. And just last month, everyone was all together, and we certainly want to talk about the importance of these programs. But I actually—I would like to hone in, you know, in the testimony of Dr. Berhe, you were talking about how we compare with Russia, and how the war in Ukraine is impacting our abilities, and that the U.S. and Russia are the only two in this type of space. How do you feel as though we are measuring up today as it relates to the pandemic, a war, inflation, access to materials? And let me let me pause on that question. I'm going to come back and ask about CERN as well. Thanks.

Dr. BERHE. Thank you, Congresswoman Stevens. I definitely share your excitement about the importance of this area and the questions. And also, you know, I think everybody shares your excitement about the FRIB facility that was newly opened in—at Michigan State University, which I might say is my alma mater, too.

So to kind of answer your question about where do we stand in terms of, you know, kind of the—our ability to produce and supply these isotopes, though, I think it's fair to say we are in a much better place now than we would have been if we didn't have a lot of the contingency planning in place, but I think this problem is pretty widespread and, unfortunately, affects not just us, but it basically affects the whole world, as a lot of the isotope supply systems had been concentrated in Russia for a long period of time.

But right now, you know, again, even though we're not expecting—and we're pretty—everybody's pretty clear about the fact that

there are no quick fixes, the—there's actually quite a lot of improvements that have been made. There are roughly, for example, 31 radioisotope supply chains in which the United States had dependence on Russia, and 19 of them are—have experienced some disruptions. But of those, the DOE Isotope Program has developed capabilities to produce 19, and another 11 of them are at various stages of development. So that says that we're doing OK, but we're continuing—we're going to have to continue to work on this.

Ms. STEVENS. Well, in Mr. Guastella's group, which is talking about this association of companies in the U.S. and Canada and what we manufacture, you know, I do Manufacturing Monday. Every Monday, I go to a small manufacturer and geek out with them. That and this Committee will keep you sane in the Congress in these polarized times. But we signed a trade deal, as you know, we renegotiated NAFTA (North American Free Trade Agreement). Are you seeing us—are you seeing that help us—helping us compete in terms of what we're talking about here? Obviously, we've got a global, you know, race going on here. But is that benefiting some of the work in the space that your association is focused on with radionuclides and radiopharmaceuticals?

Mr. GUASTELLA. Well, thank you for the question. The—most of the radio isotopes—and I'd say well over 90 percent are sourced either from Europe, Russia, South Africa, Australia. And we do obviously work with Canada, some of our member companies, obviously work with manufacturers in Canada. The actual impact of the trade agreement I can't speak to, but I can say that we've had a long relationship with organizations in Canada. And in fact, we have some organizations within CORAR that are based in Canada. So we have a nice cross-relationship between the two countries.

Ms. STEVENS. A fantastic border and a fantastic part of our supply chain and thank you. With that, I'll yield back, Mr. Chair.

Chairman BOWMAN. The gentleman from Illinois, Dr. Foster, is now recognized.

Mr. FOSTER. Thank you, Mr. Chair, and to our witnesses. I—first, I'd like to echo my congratulations to Dr. Berhe and to Dr. Merminga on your new roles. And I'd like to thank the Chairman and the Ranking Member for their opening statements, which articulated very clearly the strong bipartisan support, both for the flagship Department of Energy facilities that are essential to maintaining U.S. leadership in fundamental science, and the DOE's contributions to immediate concerns like medical isotopes.

We've also been very encouraged recently to hear President Biden lament the fact that the R&D intensity, the fraction of GDP (gross domestic product) that we devote to R&D has dropped precipitously from its historic levels. So at a time when our Nation's GDP is growing strongly, faster than inflation, fixing that should mean significant real increases in the research budgets of DOE's Office of Science and should in fact be growing even faster than our GDP.

But when we see the budget proposals, both from the Administration and from our Appropriations Committees, which for many accounts do not even cover inflation, we realize how far short of the mark we're falling, and perhaps gain some insight into the mecha-

nisms that have promoted the short-term thinking that got us into this situation that really is putting our scientific leadership at risk.

Now, as a Member of the House Science Conference Committee on the *COMPETES Act,* I'm confident that we will be authorizing a budget envelope to begin restoring R&D intensity to historic levels, but these must be followed through by appropriations. You know, for example, Dr. Berhe, in your testimony you wrote in depth about the DOE national lab infrastructure and some of the needs of the network of labs that Office of Science oversees.

Last year, Senator Luján and I introduced the *Restore and Modernization Our National Labs Act,* which authorizes $30.5 billion in funding for the National Laboratories to address this critical shovel-ready backlog of overdue infrastructure repairs and improvements. I was very pleased that we were able to include this legislation in the *America COMPETES* bill as an amendment and hope that it survives the Conference Committee.

So, Dr. Berhe, could you speak a little bit about how funding to—specifically directed at laboratory infrastructure would assist your ability to prioritize and execute the series of projects that really are essential to maintain a healthy enterprise?

Dr. BERHE. Thank you very much, Congressman Foster. I first would like to start by thanking you and the Committee for the support that we've received in this area. As you've articulated very well, we all agree that the—maintaining the infrastructure and the facilities and operations at the national labs is critical for the science that we conduct. It's also critical for us to be able to, again, train, recruit, and retain the next generation of scientists that will take on the next challenges, both in—you know, in research as well as in industry.

So, you know, we're constantly evaluating the needs in consultation with the national labs and figuring out how to prioritize, obviously, the infrastructure projects that cannot wait that will lead to even bigger problems if they're not addressed or ones that are urgent, so figuring out basically all the ways that we have at our disposal to balance the different—many different competing needs.

But I think we're all on the same page about the need to address infrastructure and facilities ops, and all very, very supportive of have you all as partner, as we address the—as we seek more support and funding to address these challenges, which I think are extremely important. And——

Mr. FOSTER. Thank you. And Dr. Merminga and Mr. Yeck, could you just describe briefly what it's like being a project manager of something where—in a laboratory where there's a big backlog of overdue infrastructure repairs, and that a lot of these infrastructure repairs get offloaded onto your project and making your project look more expensive than it might otherwise have to be? It's—I'm sure it's a universal experience, and so if you could start—we'll start with Dr. Merminga.

Dr. MERMINGA. Thank you, Mr. Foster. I must say that, as the Project Director of the PIP–II project, we were very fortunate to have some GPP projects, general——

Mr. FOSTER. Infrastructure.

Dr. MERMINGA [continuing]. Infrastructure projects.

Mr. FOSTER. Infrastructure projects.

Dr. MERMINGA [continuing]. That were complementary and necessary for the PIP–II project to advance. And so these were executed, were mostly funded by the SLI (Science Laboratories Infrastructure) program and were executed in time—on time, and so that was very helpful for us.

Mr. FOSTER. Yes, and my time is up, but I would get—Mr. Yeck, if you'd just acknowledge that you've had comparable experiences in managing projects, I'd——

Mr. YECK. Yes.

Mr. FOSTER. Thank you. My time is up. Yes, Mr. Chairman, if it was feasible, I'd be interested in another round of questions if the witnesses and our time can accommodate.

Chairman BOWMAN. So I'm going to ask—I'm going to begin another round of questions if that's OK with the witnesses. Thank you very much. Yes, just—yes. So I'll start. And my question is for Dr. Greene.

Dr. Greene, your expertise is in the area of research called string theory, which hundreds, maybe even thousands of physicists around the world are currently studying. If proven, it could fulfill Einstein's dream of having a theory of the universe, a set of mathematical formulas that explains all of our physical laws. But is such a theory even provable? Are there extremes of nature that we can never achieve and examine up close to test these theories?

Dr. GREENE. Yes, thank you for the question. Indeed, your summary is correct. There are many of us in America and around the world who are trying to realize the dream that Einstein initially articulated of a single set of mathematical laws that would govern the entire universe, the big, the small, and everything in between. So it is a hugely ambitious undertaking. Remarkably, we have a theory on the table, the one you mentioned, string theory. That may be the theory that Einstein was looking for, but the key question you ask is, is it testable? And we don't know. As of today, our technology and our understanding is probably too limited to be able to specify a test that could establish the theory right or refute it. But that's what research is all about. We are working intensely on the mathematical aspects of the theory to try to bring our understanding to a point where we can make predictions that perhaps some of the machines that we're hearing about on the panel might one day be able to test.

So we would not be working on the theory if it were somehow fundamentally philosophically unprovable, but it's a challenge to prove a theory that manifests its distinct characteristics at enormously high energies and incredibly small distances. So the answer probably is best summarized as not yet, but hopefully in the future.

Chairman BOWMAN. Thank you so much. I now yield to the Ranking Member, Mr. Weber, for a question.

Mr. WEBER. Oh, gosh, that was quick. Thank you. I appreciate that. I can answer a part of that last question. That is, as long as I do what my wife says, things add up. And if I don't, not so much. That's the most important answer for me.

Mr. Guastella, in your written testimony, you state that your organization's members support private sector production of important isotopes. What are some of the major barriers to the domestic commercial production—this is going to be kind of a three-part

question—of important medical and industrial isotopes for which we currently rely on other countries or DOE production? What are some of the major barriers to domestic commercial production of those? What suggestions do you have for the DOE Isotope Program for encouraging and supporting private-sector production, No. 2? And then No. 3, does it concern—should we be concerned—in earlier testimony, one of the things about the EIC, for example—or ECI—I can't read my own hen scratch—was that it was motivating the interest of collaborators all around the world. Do we trust that? How do we vet them? How do we know that they're not here just to steal our information? And I'll yield to you?

Mr. GUASTELLA. Well, Congressman Weber, thank you for the question. First of all, Dr. Berhe has mentioned on a few occasions that the technology can be somewhat complicated and certainly capital-intensive. So I would say with some of the newer isotopes, and depending on the opportunities, if you will, for commercialization, those can create barriers. And that's why in certain instances industry has relied on the DOE Isotope Program, and the DOE Isotope Program has been a great, great partner.

Mr. WEBER. Let me ask something real quick. Does the NRC (Nuclear Regulatory Commission) get involved in that process that you're describing?

Mr. GUASTELLA. Absolutely. And we deal with not only the NRC, but the FDA (Food and Drug Administration), the DOT (Department of Transportation), international organizations like the IAEA (International Atomic Energy Agency). So when you're talking about manufacturing and transporting radioactive materials, obviously, you have to satisfy regulations from all those regulatory bodies.

I mean, we have several suggestions that I've included in our testimony, one mentioned earlier, and that is fully fund the Stable Isotope Production and Research Center and the Radioisotope Processing Facility. The DOE, from my understanding, is in desperate need of additional processing capabilities, and having those facilities come online sooner rather than later would be very important to increase the ability to have those isotopes produced in the United States.

Also came up a——

Mr. WEBER. But there are entities in your group that stand ready, willing, and able to get onboard with that if that becomes a possibility.

Mr. GUASTELLA. Absolutely. I think, though, that kind of leads to my response in the second part of your question, and that is kind of to introduce, if you can, opportunities to expedite production commercially. And that may be in providing public-private type opportunities. Now, I understand right now that the DOE Isotope Program is not part of their mission. But public-private funding opportunities in the future could accelerate the introduction of commercial production of some of these isotopes that we're relying on Russia right now. So that would certainly be another opportunity.

You know, another thing I would mention is what I hear sometimes is that the importance of isotopes may not be fully realized through the government and the Administration. And we've also

suggested and requested that the Administration institute a White House-level supply coordinating effort. We found that to be very successful when we had issues with molybdenum. Molybdenum is an important isotope. The daughter isotope of molybdenum is technetium–99, which basically is used in about 80 percent of all nuclear medicine procedures. And the DOE obviously was very involved in helping to move toward domestic production of moly, but we found that the coordination within the Administration and the OSTP (Office of Science and Technology Policy) was also helpful and brought to light a number of issues that needed to be addressed as we were moving toward domestic production.

Mr. WEBER. I'm running out of time. Thank you, Mr. Chairman. I'm going to yield back. And unfortunately, I have another meeting that I have to leave for. Thank you so much.

Mr. GUASTELLA. Thank you.

Chairman BOWMAN. Thank you. The Chair now yields to Ms. Stevens from Michigan.

Ms. STEVENS. Thank you. As it pertains to CERN and our collaboration with the European Organization for Nuclear Research—and this is also the Large Hadron Collider that we've all been reading about for the balance of a decade and recognizing as the world's largest and highest energy particle collider—I was just actually wondering if any of you could shed some light on how that collaboration is going? How prominent is the United States in that collaboration? How much will we receive from that collaboration and its benefits? Why is it located in Europe and not the United States for the kids watching at home? Yes, Dr. Merminga, we'll start with you.

Dr. MERMINGA. Thank you very much. So I would say CERN is our most important partner in high-energy physics in the United States right now. As you know, particle physics is—the experiments and the facilities and infrastructure are of such great scale that in order to realize our collective ambition worldwide, we have split, if you like. And so Europe has the energy frontier with a Large Hadron Collider. and the United States participates in great numbers in those experiments at the LHC, as well as we participate in the upgrades to the LHC, both the accelerator——

Ms. STEVENS. And who's paying for that? Is it moneys to your agency or how is that being supported?

Dr. MERMINGA. DOE is supporting the upgrades to the LHC. And at the same time, CERN is contributing to our DUNE experiment because the neutrino science is in the United States. And our aspiration with the completion of LBNF and DUNE is that the Fermilab and the United States becomes the world center for neutrino science. And CERN for the first time in its 60-year history is investing in infrastructure into DUNE. And in fact, they're contributing the two cryostats for the two detectors that will go in South Dakota for the DUNE experiment. And they're paying for this, so it's truly a reciprocal relationship. And—yes.

Ms. STEVENS. Yes. Go ahead, Dr. Berhe.

Dr. BERHE. I would completely agree with Lia on this point. Both at CERN and the—you know, the ongoing projects at LBNF/DUNE, they're both collaborative in that the United States contributes financially to making the CERN experiments happen, but our sci-

entists in turn get a huge part of the benefit and they get to participate and be, you know, leaders in the science in the areas of CERN. And once, you know, the LBNF/DUNE is realized and it's completed, then the European scientists will also be important partners here in the United States. And this field, as you've heard, is a very highly international, multidisciplinary—collaborations are what makes it possible.

Ms. STEVENS. Yes. And so we just want Fermi to have the same attention that, you know, CERN is getting in many respects. I mean, we want to be seen as the leader. And it appears from both of your responses that we have the human capital, we have the trained and ready scientists who we can send over to CERN. You know, we've spent a lot of time on this Committee—and I'm a Subcommittee Chair for Research and Technology on, you know, our scientific research enterprise, our STEM education work force, making sure we're not leaving our own talent behind. But some of that is so dependent on these global exchanges, right?

And so, you know, if we've got people going over there, they've got folks coming over here—and let's just—again, for the folks watching back home—and obviously, it should be everyone's homework to read these testimonies because they're brilliant—but what are we getting out of that partnership? I mean, how is this going to impact industries of scale or even our economy as it's appropriate to ask? Because it's not just research for research sake. I mean, this has got wide-ranging applications into how we live, conduct business, transport ourselves, and on if I'm right. Yes.

Dr. MERMINGA. I just wanted to say, in addition to training our work force, we're getting—as I mentioned earlier, AI on a chip was first tried for the CMS (Compact Muon Solenoid) detector, which is a detector of the LHC. And so microelectronics also originate from research in order to sort out data collected by the LHC and quantum computing as well. So a lot of these advances have then societal applications.

Ms. STEVENS. Yes, yes. Yes——

Dr. MERMINGA. Transfer to technology.

Ms. STEVENS. Thank you.

Dr. BERHE. Yes, as both Dr. Merminga, as well as Dr. Greene and others have spoken to, we get a lot of benefits from these fundamental science experiments. They may be curiosity-driven, trying to understand the fundamental processes and nature of matter and other issues. But eventually, we get sometimes even benefits that we didn't even realize they're going to be possible, right, benefits that are byproducts of the—you know, the scientists working on the process itself.

But I think we don't even have to go far, as Dr. Merminga just explained. We've already realized a lot of benefits for society, for, you know, for industrial applications and others. And I think the field is rich. We will only continue to benefit going forward.

Ms. STEVENS. Right. Well, and, Dr. Greene, too, we appreciate you being here. You are right in the room with us and it's—look, this is just so exciting. It's really wide-ranging. And I think even to the point about where we're going with nuclear, you know, there's, again, energy benefits. And so we can come back on more hearing topics on this front. Our Chair is totally focused on these

subject matters. And I think in terms of it's budget season, and how we're funding our agencies and making sure your work is funded, this couldn't be more timely.

So with that, Mr. Acting Chair, I'll yield back. Thank you.

Mr. FOSTER [presiding]. Well, thank you. And as Chair pro tem of this Committee, I will now recognize myself for the final 5 minutes of questions here.

You know, I've always found that Congress understands well the near-term needs like, you know, supply chain, medical isotopes, and things like that. We have a lot of trouble understanding the—you know, the benefits of fundamental research that are harder to explain and the payoff is much longer term. Dr. Merminga, you sit on the—stand on the shoulders of giants at your laboratory, Dr. Wilson, Lederman, Peoples, Witherell, Oddone, Lockyer. But your first predecessor, you know, your—you know, Dr. Wilson, the founder of Fermilab, when he was pressed by a Senator in front of a Committee many decades ago about of what use the research—the fundamental research that's done at Fermilab is, that—you know, what exactly does Fermilab's research have to do with national defense? He responded with some—with a response which I think which echoes today. So when he was asked what is it that Fermilab's research has to do with national defense, say, or whatever the question of the day is, do you recall his answer?

Dr. MERMINGA. Absolutely. It has nothing to do with national defense, but it makes the country worth defending.

Mr. FOSTER. That's right. And that is the correct answer. It's also important to remember that when we think about the the difficulties of international collaboration, Robert Wilson always was proud that in the depths of the cold war when Fermilab was founded, when, you know, Russian soldiers were shooting antiaircraft missiles at American pilots in Vietnam, we—at the same time, one of the first experiments that was conducted at Fermilab had Russian collaborators. And the—you know, so it's a two-edged sword. We have to be very careful to protect our real national interest, but the benefits of international collaboration are not just the dollars that come in to experiments.

Mr. Yeck, is there a significant international interest in the Electron-Ion Collider?

Mr. YECK. Yes, thank you. The user community, which was formed in 2016 and now reaches over 1,300 members from 250 institutions, is about half U.S. and half worldwide. And so there's significant interest—and they together developed a report on the planned science that the EIC can deliver and how best to deliver it with the detectors. It's fully international. So I would say the EIC will be an international facility. Thank you.

Mr. FOSTER. Yes, Dr. Merminga?

Dr. MERMINGA. I'd like to also add a couple of more points on this. As you said correctly, to my opinion, it's the benefits from international collaboration go—are a lot more than just the monetary benefits, in-kind contribution to the facility. We've—in the case of PIP–II and LBNF/DUNE, we really gathered from around the world the world's best experts in the corresponding technologies. And those experts contribute their expertise, their capabilities, their own facilities in their own countries, to develop infra-

structure that's going to be housed in U.S. soil, on U.S. soil, to enhance our scientific infrastructure here in the United States.

And I'd like to point out that Fermilab has taken international collaboration to the next level through the recent LBNF/DUNE and PIP–II with more than $1 billion in contribution, as I mentioned earlier. Thank you.

Mr. FOSTER. Thank you. And, Dr. Greene, I will be asking you a question for the record about the implications of Wick rotations on lattice gauge theories, which always seemed to me to just fundamentally alter the locality and causality of these theories because of the—trying to hide the granularity from—after the Wick rotation. And so I'll be asking you about that.

But more immediately, you know, you and I both struggle with the difficulty of explaining complex science in simple terms to the public and particularly doing that without simplifying it too much so that it makes this—your scientific friends cringe at the oversimplification. Could you say a little bit about what you found the effective techniques for that is? Because it's crucial.

Dr. GREENE. Yes, I think you're absolutely right, and thank you for the question. It is part of the art of trying to find the right language, the right visual metaphors for communicating some of the most abstract of ideas to the general public. And you don't want to turn your explanation into a cartoon or a caricature. The goal is to find the core understanding and find a bridge between the unfamiliar and the familiar so you can cross that bridge and bring these insights to the general audience.

And if I was going to give one lesson learned, it would simply be this. If we teach and communicate science as a narrative, as a story, as a human endeavor, not just the cold, hard facts that make it into the textbook, not just the equations, but if we give the narrative of discovery so that you see the human part of the journey, then the drama of scientific adventure comes across in a sparklingly clear way. And I find that that's the most powerful way of inspiring the general public with these ideas.

Mr. FOSTER. Thank you. And as someone who brings, you know, all the charisma of the typical physicist to this job, I really appreciate it when an artist like yourself gets involved in this. Thanks much. I will yield back to the Chairman.

Chairman BOWMAN. Thank you. Before we bring the hearing to a close, I want to thank our witnesses for testifying before the Committee today. The record will remain open for 2 weeks for additional statements from the Members and for any additional questions the Committee may ask of the witnesses.

The witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 11:47 a.m., the Subcommittee was adjourned.]

Appendix

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Lia Merminga

U.S. high energy physics (HEP) research pursues extremely difficult scientific questions about the first moments of the Big Bang and the fundamental nature of matter, energy, space, and time. Because of these challenges, HEP scientists are early adopters and developers of emerging technologies and often the first to deploy them at larger scale, using the unique infrastructure and capabilities of the Department of Energy (DOE) national labs. Some examples:

- HEP scientists gearing up for the Large Hadron Collider were the first to fully execute distributed high throughput computing at a global scale, and later Fermilab experts helped U.S. commercial cloud providers Google and Amazon develop competitive capabilities in this area.
- More recently DOE HEP scientists were the first to develop cryogenic microelectronics at large scale for the DUNE experiment, and those same scientists are now collaborating with Microsoft on broader applications.
- DOE made large investments in infrastructure and expertise for superconducting materials and devices needed for HEP particle accelerators, which enabled the world-leading capabilities of the Superconducting Quantum Materials and Systems Center (SQMS), a DOE national quantum information science (QIS) research center led by Fermilab with multiple industry partners.
- The HEP challenge of detecting dark matter is fueling rapid advances in the development of quantum sensors, including for the Quantum Science Center (QSC), a DOE national QIS research center led by Oak Ridge National Laboratory.
- HEP particle detectors already deploy timing systems with a thousand times better precision than commercially available, and this capability was recently transferred to a quantum teleportation network connecting Fermilab and Argonne – a key step towards a Quantum Internet.
- U.S. HEP scientists working with U.S. industry developed, and are now deploying, the world's most advanced "Artificial Intelligence (AI) on a chip", a million times faster than commercial systems.

As these examples show, U.S. HEP enabled by the mission-driven capabilities of the DOE national lab system is a natural leader in multiple emerging technologies of strategic importance to the nation and to U.S. industrial competitiveness.

Responses by Mr. Jim Yeck

Electron-Ion Collider Directorate

Brookhaven National Laboratory

ATTACHMENT #2

"Investigating the Nature of Matter, Energy, Space, and Time"

Answers to Questions for the Record from Jim Yeck

Associate Laboratory Director and Project Director for the Electron-Ion Collider

Brookhaven National Laboratory

Submitted by Chairwoman Eddie Bernice Johnson

International Competitiveness in Science and Technology

The Department of Energy leads or significantly contributes to interagency initiatives in several emerging and crosscutting areas, such as quantum information science, artificial intelligence, high-performance computing, and microelectronics. Increasing our investment in these areas is critical to maintaining U.S. economic competitiveness and national security, and the high energy physics, nuclear physics, and isotope programs all support research in these areas.

- DOE obviously is not the only agency supporting research in these areas, but why do you think the Department is uniquely positioned to lead in them?

Re: Complex high-energy and nuclear physics experiments funded by the Department of Energy often track millions of subatomic particles. These experiments have pushed the evolution of both detector electronics and computing technologies in ways that have and will continue to spill over to benefit society at large. DOE is the agency with the most experience, expertise, and motivation to develop these tools.

For example, the detectors used in high-energy and nuclear physics experiments are made of many different kinds of interconnected electronic sensors, some of which operate in extreme environments (including extreme cold and with a need to be resistant to damage from radiation). If not for the electronics designed for physics, we might not have the medical imaging technologies and sensors for national security applications we currently rely on today. As the data needs of nuclear and particle physics evolve, so will the technologies needed to track and discern among different types of particles. At the Electron-Ion Collider, for example, we are working to develop new application-specific integrated circuits (ASIC) chips to collect the signals for the different detector components, as well as super thin tracking detectors with dramatically improved resolution and components that can efficiently detect photons (particles of light) with high-resolution timing. In addition to improving and streamlining detection for particle physics experiments, this technology has the potential to significantly improve the resolution of images obtained by positron emission tomography (PET scanning) used for

medical imaging. Continuing evolution in chip technology will also likely lead to faster and higher-precision microelectronics for a range of other applications in medicine, industry, and national security.

Likewise, the large datasets of these experiments have pushed the envelope in terms of computing architectures and data analysis techniques. For example, the supercomputing architecture first developed to model the complex interactions of quarks and gluons (the particles that make up protons and neutrons of atoms) led to the development of the IBM "Blue Gene" chip used in many generations of supercomputers. The world's first internet was built by high-energy physicists seeking a new way to share their data.

Future experiments, including those at the Electron-Ion Collider, will drive the development of new data-sharing paradigms, as well as tools for monitoring and optimizing experimental equipment in real time. The experiments will also drive further advances in data-processing and analysis tools, including new ways to use machine learning and artificial intelligence.

The powerful tools we develop to quickly sort through large datasets to drive our discoveries will also find applications in addressing other data-intensive challenges, including modeling climate change, tracking global pandemics, and optimizing performance of the nation's electric grid.

Isotope Supply Chain Impacts

The world is experiencing supply chain impacts like never before, largely due to the devastating conflict in Ukraine. Members on this Committee watch supply chain issues closely, as any shortages can have significant and lasting negative impacts on science and technology research, among other things. I'd like to talk about supply chain impacts on nuclear isotopes. Nuclear isotopes are used for a variety of reasons in the United States, ranging from cancer treatments to battery development to food irradiation. And the DOE Office of Science's Isotope Program is a huge supplier of these isotopes. I understand from DOE that many of the isotopes that this program supplies are currently at risk of a shortage or experiencing a shortage because of supply chain issues, and specifically, because we depend on Russia directly or indirectly for the supply of many of our nation's critical isotopes.

- Mr. Yeck, can you explain how the Electron-Ion Collider plans to contribute to the nation's domestic isotope supply?

  Re: The operations of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) directly benefit the Isotopes Program. RHIC operations and scientific program are supported by the DOE Office of Nuclear Physics. The DOE Office of Science's Isotope Program is responsible for the incremental cost. This would be the same during Electron-Ion Collider (EIC) operations. The isotopes program at BNL is a consequence of the accelerator infrastructure and expertise supported by DOE and developed over many decades. The synergies with the EIC include technical subject matter experts, common technologies, and shared infrastructure. The development and implementation of Artificial Intelligence and Machine Learning in EIC facility operations will also benefit the DOE Isotope Program.

Responses by Mr. Michael Guastella

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Executive Director

August 18, 2022

BY EMAIL: alexa.bishopric@mail.house.gov

The Honorable Eddie Bernice Johnson
Chairwoman
Committee on Science, Space, and Technology
2321 Rayburn House Office Building
Washington, DC 20510-6301

Re: CORAR Response to Questions from Chairwoman Eddie Bernice Johnson

Dear Chairwoman Johnson,

The Council on Radionuclides and Radiopharmaceuticals, Inc. (CORAR) appreciates the opportunity to provide responses to the Questions for the Record submitted to Mr. Michael Guastella (CORAR Executive Director) on July 25th. These questions were submitted as a follow-up to the June 22, 2022 Hearing: *Investigating the Nature of Matter, Energy, Space, and Time*. CORAR is an industry association of firms that manufacture and distribute diagnostic and therapeutic radiopharmaceuticals, radionuclides, and other radioactive products primarily used in medicine, research, and industry.

The following sections provide CORAR responses to the questions from Chairwoman Johnson:

Question 1:

Mr. Guastella, as the executive director of the Council on Radionuclides and Radiopharmaceuticals, will you elaborate on the many uses of isotopes?

Radioactive and stable isotopes have extensive use in both health care and industry. In nuclear medicine, medical isotopes and radiopharmaceutical drugs are injected into a patient's body to diagnose and treat disease. For example, the most common medical radioisotope used in nuclear medicine procedures in the United States is technetium-99m (Tc-99m) used by nuclear medicine physicians to diagnose diseases, such as heart disease and many forms of cancer, and inform treatment plans. The second most frequently utilized medical radioisotope is fluorine-18 (F-18), used in positron emission tomography (PET) imaging. The F-18 medical radioisotope has been used for the past 20 years with approximately two (2) million PET scans done annually in the

U.S.[1] Other important diagnostic medical radioisotopes used in nuclear medicine include gallium-68 (Ga-68) and copper-64 (Cu-64) used in newer precision diagnostic PET drugs for the diagnosis of prostate cancer and neuroendocrine tumors. Also, there are a number of legacy medical radioisotopes used in nuclear medicine, including thallium-201 (Tl-201), used in heart imaging, iodine-123 (I-123) used in thyroid imaging, and xenon-133 (Xe-133) used in lung imaging.

In order for single photon emission computed tomography (SPECT) and PET imaging cameras, used in nuclear medicine, to function correctly and accurately, each camera requires a calibrating device, known as a sealed source. To ensure clinical accuracy, cameras are calibrated every day they are in use. Sealed sources are made from germanium-68 (Ge-68), cobalt-57 (Co-57) and gadolinium-153 (Gd-153). Due to the relatively short half-lives of these radioisotopes, nuclear medicine departments need to replace sealed sources frequently.

As I mentioned in my June 22, 2022 testimony to the Subcommittee on Energy, medical radioisotopes are also used by physicians to treat disease. A workhorse radioisotope that has been used to treat thyroid disease is iodine-131 (I-131). Currently, there is rapid advancement in an area of nuclear medicine referred to as radiopharmaceutical therapy (RPT). RPT combines a radioisotope with a cell-targeting molecule (e.g. small protein or monoclonal antibody) into a radiopharmaceutical specific to certain types of cancer cells or biological processes. When injected into the patient's bloodstream, the radiopharmaceutical travels to and delivers radiation directly to disease sites[2]. Promising radioisotopes used in RPT include alpha emitting astatine-211 (At-211), actinium-225 (Ac-225), radium-223 (Ra-223), and bismuth-213 (Bi-213). In addition, beta emitting radioisotopes such as copper-67 (Cu-67) and lutetium-177 (Lu-177) are being used in RPT.

In my June 22nd testimony, I provided an example of the approved Lu-177 PSMA-617 radiopharmaceutical (Pluvicto®) for the treatment of advanced prostate cancer and Lu-177 DOTATATE (Lutathera®) for the treatment of neuroendocrine tumors. In addition to these approved radiotherapies, we estimate that there are at least 85 clinical trials running to examine a variety of other RPT's based on medical radioisotopes such as copper-67 (Cu-67), actinium-225 (Ac-225), and lutetium-177 (Lu-177).[3]

Radioisotopes have important applications for U.S. industry. Iridium-192 (Ir-192) and selenium-75 (Se-75) assure operational safety in refineries and pipelines to test for corrosion, leaks, and cracks. Americium-241 (Am-241) is used in the manufacture of smoke detectors. Nickel-63 (Ni-63) is used in explosive detectors at airports and in narcotic detectors. Promethium-147 (Pm-147) is used in nuclear batteries, thin film measurement instruments, light sources, and luminous paints. Californium-252 (Cf-252) is a neutron source used to start nuclear reactors, detect impurities in cement, and calibrate radiation detection devices. Finally, plutonium-238 (Pu-238) is used as a heat source as a well as a power source for satellites.

In addition to radioisotopes, there are a number of enriched stable isotopes used to produce medical and industrial radioisotopes. These stable isotopes include ytterbium-176 (Yb-176) used to produce Lu-177, zinc-68 (Zn-68) used to produce Cu-67, molybdenum-98 (Mo-98) and

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[1] https://imvinfo.com/pet-ct-drives-pet-scan-volume-new-heights/

[2] http://www.snmmi.org/Patients/About/content.aspx?ItemNumber=14792&navItemNumber=14793

[3] https://www.clinicaltrials.gov/ct2/results?term=Lu-177+OR+Ac-225+OR+Cu-67&recrs=a&recrs=f&recrs=d&age_v=&gndr=&type=&rslt=&phase=4&phase=0&phase=1&phase=2&phase=3&Search=Apply

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molybdenum-100 (Mo-100) to produce molybdenum-99, nickel-64 (Ni-64) used to produce Cu-64, and barium-132 (Ba-132) to produce Ba-133 used in extraction and refining to separate oil, water, and gas.

Question 2:

In your testimony, you describe how the recent Ukraine-Russia conflict has highlighted supply chain issues that have existed for a few decades. Will you elaborate on the urgency of this issue, and offer any solutions you think the federal government can pursue to help address it?

In my June 22nd testimony, I provided information on over 40 isotopes, used for medical or industrial purposes, that the U.S. relies largely on Russian companies to supply as either raw materials or the isotopes themselves. Specifically, the Russian state corporation Rosatom (and affiliates) are critical suppliers of isotopes used in the U.S. for the manufacture of radiopharmaceutical drugs for U.S. patient care and industrial purposes.

The Ukraine-Russia conflict has created disruptions to the radioactive and stable isotope supply chain for U.S. manufacturers due to a number of reasons including air space restrictions to Russian aircraft enacted by the U.S. and its allies. In addition, sanctions on Russian banks enacted by the U.S. and its allies as well as actions by non-government entities, such as shippers and freight forwarders who refuse to accept Russian products, have created delayed and missed isotope shipments. These disruptions are particularly problematic to U.S. healthcare and industry because of the fragility of the radioactive and stable isotope supply chain due to (1) short shelf life for the quickly decaying radioisotopes; (2) high barriers to entry for new suppliers, and (3) a limited number of suppliers. Please note that previous supply chain disruptions have resulted in rationing of care to U.S. patients.

With regard to solutions, CORAR believes the federal government can pursue a number of options to ameliorate the supply chain issues described above and increase domestic production of critical radioactive and stable isotopes, I will reiterate several of our suggestions provided in my June 22nd testimony:

- Fully fund the proposed U.S. Stable Isotope Production and Research Center (SIPRC) and the Radioisotope Processing Facility (RPF).
- Retain the Committee's COMPETES provision establishing an Advisory Committee for the DOE Isotope Program. CORAR is appreciative of the committee for already addressing this.
- When commercial production is adequate to satisfy U.S. demand, retain the language to continue to ensure that the DOE Isotope Program will preserve and appropriately allocate its resources by not competing with commercial isotope producers.
- When the DOE Isotope Program provides commercial isotopes to the domestic market, when commercial production is non-existent or insufficient to meet U.S. demand, ensure that the DOE Isotope Program is required to continue to satisfy the principles of full cost recovery for commercial isotopes.
- To increase flexibility for the DOE Isotope Program to identify opportunities to expedite domestic production of important medical and industrial isotopes currently sourced from Russia, include language that would allow the DOE Isotope Program to identify additional opportunities for Federal investment, including through potential public-private partnerships, as appropriate.

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- Continue to support the DOE Isotope Program Research and Graduate training programs, through appropriated government grants and other government educational programs, to help fill the pipeline with knowledgeable and trained individuals in research, development, and commercialization to meet the current and future needs of the medical and industrial isotope industries.
- Finally, in light of the Russian invasion in Ukraine, request that the administration institute a White House level supply coordinating effort to ensure that there is an interagency coordination to bring about an enhanced, reliable domestic supply of these essential medical and industrial isotopes.

Question 3:

In your testimony you describe how the nation's supply of isotopes is greatly affected by events that disrupt the commercial flight industry, such as 9-11, the COVID-19 pandemic, and now the Ukraine-Russia conflict. Why is this?

Radioisotope and stable isotopes are shipped daily to the U.S. in passenger aircraft mainly from Russia, Europe, South Africa, and Australia. With the disruptions in passenger aircraft flights between the U.S. and these countries during 9-11, COVID-19, and currently due the Ukraine-Russia conflict, industry has experienced delays and missed deliveries of isotopes. In response, U.S. manufacturers and distributors continue to evaluate alternatives to mitigate the current air transport restrictions caused by sanctions and other non-government actions. In addition, delayed deliveries are particularly problematic for manufacturers and distributors of radiopharmaceuticals and radioisotopes because of the significant loss of material due to radioactive decay (for example Mo-99 has a sixty-six (66) hour half-life and Tc-99m has a six (6) hour half-life).

Question 4:

Will you explain the need for [the U.S. Stable Isotope Production and Research Center and Radioisotope Processing Facility], and how they each address unique issues?

The U.S. Stable Isotope Production and Research Center (SIPRC) is designed as a 54,000-square-foot building and will be built on Oak Ridge National Laboratory's (ORNL's) main campus. Current stockpiles of stable isotopes are being depleted, and the U.S. has no existing domestic broad-scope enrichment capability without this future facility. SIPRC will expand U.S. capabilities to enrich stable isotopes for medical, industrial, research, and national security uses through significant expansion of electromagnetic separation and gas centrifuge capabilities. This will allow the DOE Isotope Program to produce enriched stable isotopes like ytterbium-176 (Yb-176), used for Lu-177 production, Mo-98 and Mo-100, both stable isotopes used for domestic Mo-99 production, silicon-28 (Si-28), being evaluated for quantum computing applications[4], and many others. CORAR believes that full funding should be provided to allow for completion of this facility in the next four to five years.

The Radioisotope Processing Facility (RPF) will augment the capabilities of the High Flux Isotope Reactor (HFIR) at ORNL, and allow the U.S. to significantly expand domestic radioisotope production. The 40,000-square-foot facility will use modern, modular hot cells to

[4] https://www.nist.gov/news-events/news/2020/01/spotlight-silicon-28-quantum-computers

provide flexibility for future needs. The DOE Isotope Program proposes that completion of the RPF will make possible the domestic production of radioisotopes including iridium-192 (Ir-192), lutetium-177 (Lu-177), and strontium-89 (Sr-89) which are used in cancer treatment. As with SIPRC, CORAR believes that full funding should be provided to allow for completion of this facility in the next four to five years.

Respectfully Submitted,

Michael J. Guastella

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