Dr. Kimberly Budil
Director, Lawrence Livermore National Laboratory

Testimony before the Energy Subcommittee
U.S. House Science, Space and Technology Committee

February 12, 2025

Chairmen Weber and Babin, Ranking Members Ross and Lofgren, Members of the Subcommittee. Good morning and thank you for having me here today.

I am honored to speak to you on behalf of Lawrence Livermore National Laboratory (LLNL), a National Nuclear Security Administration (NNSA) laboratory and proud member of the Department of Energy's network of national laboratories.

S&T Leadership in a Competitive World

The U.S. Department of Energy (DOE) national laboratories are unrivaled strategic assets in the competition for global economic, technological, and military leadership. The mission-focused multidisciplinary workforce and world-class scientific facilities and capabilities of the national labs have been referred to as the crown jewels of the U.S. research and innovation ecosystem. Over the past 80 years, the national labs have successfully delivered solutions to critical national challenges, new ideas, world-leading science, and innovative technologies to benefit our nation and the world.

Today, we find ourselves at a critical time in history, with an evolving global security environment that presents new and unprecedented security challenges and emerging and disruptive technologies like generative artificial intelligence, dramatically accelerating the pace of discovery in science and technology (S&T). Sustaining U.S. competitiveness in this complex world requires a new approach—speed and innovation must be our focus. This is also a strategic moment for NNSA and its national security laboratories. Nuclear deterrence is a mainstay of U.S. national security and the need to modernize the nuclear deterrent—warheads, delivery systems, and infrastructure—is urgent given the new and expanded capabilities deployed by Russia, China, and North Korea. U.S. leadership in strategic areas of S&T is critical to both national security and economic competitiveness.

LLNL is playing a central role in the effort to rejuvenate the NNSA's nuclear security enterprise (NSE). We are the responsible nuclear design agency for two modernization programs—the W80-4 Life Extension Program and the W87-1 Modification Program—which are helping to drive the modernization of the production enterprise. NNSA faces stiff challenges in this effort. The NNSA labs, plants, and sites must deliver these capabilities on stressing timelines within budget while working to accelerate our efforts to better match the pace of the threat. Our Laboratory is pursuing innovative new partnerships within the

NSE and applying recent S&T advances to dramatically accelerate the pace of product development and scientific discovery.

The threats we face demand a more agile, responsive, and resilient S&T ecosystem. For this to happen, the national laboratories must strengthen partnerships, particularly with industry, to ensure the U.S. can be at the leading edge of scientific discovery, technology development, and manufacturing. In the words of our new Secretary of Energy, Chris Wright, “We must protect and accelerate the work of the Department's National Laboratory Network to assure and secure America's competitive advantage and its security.”

DOE laboratories provide leadership in many areas of S&T. High-performance computing (HPC)—particularly as it applies to scientific and engineering simulations of complex systems—is a vital strength. The national laboratories hold the three top spots in the Top500 list of the world’s most powerful supercomputers. This new generation of computers offers immense opportunities to both advance the state-of-the-art for modeling and simulation and harness the power of AI and machine learning to speed the cycle of learning dramatically. Opportunities abound for the laboratories to strongly support and provide innovative leadership in national efforts to accelerate scientific discovery, develop innovative new technologies, and transform manufacturing:

- *Capabilities*. The laboratories are multidisciplinary and well-suited for combining HPC simulations, AI and machine learning, experimental studies, and advanced manufacturing to drive potentially revolutionary changes in how we pursue science and develop new technologies.
- *Partnerships*. As federally funded research and development centers (FFRDCs), the laboratories are well-positioned to strengthen partnerships with industry to develop means to accelerate product delivery. These collaborations can help bridge the gap between what is “possible to do once” and what is “possible to affordably manufacture at scale.”
- *Innovation and investments*. Bridging the gap between invention and product has always been a challenge, often referred to as the “valley of death.” Catalyzing the national laboratories to accelerate scientific discovery and technological advances will require innovative approaches and strategic investments in infrastructure at DOE laboratories and sites.

Innovating and Accelerating Product Delivery within NNSA

Greater agility to bolster national security, support S&T leadership, and enhance economic competitiveness is urgently needed. Expediting design-to-product delivery requires a combination of innovation, streamlined processes, sustained investment, and effective partnerships. For the strategic modernization programs, our Laboratory has been vigorously pursuing novel materials and additive manufacturing (along with other advanced manufacturing methods) to modernize production of certain warhead components and materials and pioneer fundamentally new approaches to design and certification.

We have engaged NSE production agencies as partners to ensure that the technologies we design are adaptable to full-scale production. Investments in the Polymer Enclave at LLNL, where the application of novel direct-ink-write additive manufacturing tools was codeveloped with partners from the Kansas City National Security Campus, is an example of this new type of partnership to bring modern manufacturing techniques to NNSA production agencies. Such collaborations aim to speed the introduction of new technologies to make production faster and less costly, enable performance that otherwise would be unachievable, and reduce waste.

Another example is LLNL's Energetic Materials Development Enclave (EMDEC), where first-of-their kind technologies have demonstrated safe 3D printing of precision insensitive high explosive components. This work is being pursued in close partnership with the Pantex Plant to guide the development of their proposed High Explosive Synthesis, Formulation, and Production (HESFP) Facility. Plans are underway to expand EMDEC with pilot-scale manufacturing capabilities to scale up for production use. We have also proposed the Vertically Integrated Prototype Realization Enclave (VIPRE) complex, where advanced materials and manufacturing methods will be developed that can be quickly transferred to NSE and U.S. industry partners, enabling us to move seamlessly from developing novel materials through prototyping to scale-up and deployment. These leadership efforts to accelerate manufacturing have broad applicability. There are other examples of partnering to modernize and expedite concept-to-manufactured product—as well as scientific discovery—that I will later highlight.

Two of NNSA's flagship capabilities, the El Capitan supercomputer, installed in 2024, and the National Ignition Facility (NIF), which first achieved ignition and fusion burn in 2022, are located at LLNL. Both exemplify the importance of sustained, multi-year congressional support for investing in the core competencies and capabilities at the national laboratories. These two NNSA flagship capabilities are poised to make significant contributions to continuing U.S. leadership in S&T areas that are critical to national security and also offer potentially revolutionary means to accelerate product delivery and scientific discovery.

El Capitan—the World's Most Powerful Supercomputer

When the Stockpile Stewardship Program was launched in 1995, researchers set the ambitious goal of increasing computing power by a factor of 3,000 within a decade. By working in close partnership with U.S. industry over three decades, El Capitan—NNSA's first exascale supercomputer—is nearly 30,000 times faster than the initial goal. The path to exascale required not only developing new types of computing hardware and architectures but also reducing the power requirements for such a machine to achievable levels and upgrading our computing facilities to meet the power and cooling needs of these new systems.

A key foundation for El Capitan was DOE's Exascale Computing Project (ECP). Launched in 2016, the ECP enabled NNSA and DOE Office of Science (SC) researchers to work collaboratively with U.S. industry to overcome imposing technical challenges and deploy the exascale Aurora at Argonne National Laboratory and Frontier systems at Oak Ridge National Laboratory. The NNSA laboratories took the next step with El Capitan, working closely with industry partners to co-develop first-of-a-kind hardware, the required software ecosystem, and compatible scientific applications. With a peak performance of 2.79 exaFLOPs (2.79 quintillion calculations per second), El Capitan provides scientists and engineers a factor-of-20 improvement in modeling weapon performance in high-fidelity resolution and quantifying uncertainties.

Capabilities to routinely run large-scale 3D models are essential for sustaining an aging stockpile and certifying modernized weapon systems. El Capitan will also accelerate progress in inertial confinement fusion, enable discoveries in material behavior under extreme conditions, and support other critical national security missions. Importantly, exascale computing—in combination with AI and machine learning, precision additive manufacturing, and novel experimental capabilities—offers the potential of changing the way we think about the design of a new technology or autonomously guiding the next steps in a high-repetition-rate experimental campaign. An LLNL research team recently applied these tools to successfully "inverse design" a linear shaped charge. The engineering design process started with the desired performance and AI-guided HPC simulations refined an initial device design to optimize performance. Similarly, Laboratory researchers have developed an AI tool to guide the design of metal alloys to achieve desired performance. Other applications discussed below include the design of ignition targets for NIF and the design of antibodies to combat viruses.

The National Ignition Facility

Achievement of fusion ignition and energy gain at NIF in December 2022 was a historic event, an effort which began 60 years ago with the "big idea" of inertial confinement fusion (ICF). In the late 1970s, the Atomic Energy Commission began investing in a sequence of large lasers at the Laboratory as tools to study high-energy-density physics issues pertinent to weapons design while recognizing its long-term potential for meeting the world's energy needs. Success in ignition was the result of the hard work of the ICF community over many decades and benefited from key advances made in the last several years. The *Physical Review Letter* reporting the achievement listed more than 1,370 contributing researchers from 44 international institutions. NIF is a flagship facility for a vibrant ICF community. Since the initial success, five more NIF experiments have achieved energy gain, one with a record setting 5.2 megajoules (MJ) of energy and a gain of more 2.3 times the laser energy. This success was only possible with sustained support and investment in the facilities, diagnostic development and target design, and workforce development over the decades, and continued investment will also be critical to our success going forward.

Fusion ignition was not an end point—it is the beginning of our pursuit of high yield to explore the most extreme states of matter ever produced in the laboratory. Fusion producing experiments, which provide detailed information about complex underlying physics, are vital to meeting current and future needs for stockpile sustainment and modernization. They have given us exceptional insight into the science of nuclear weapons and provide a test bed for assuring the survivability of military systems in nuclear environments. Our planned activities to achieve higher fusion yields for nuclear security missions align closely with the needs to move forward in inertial fusion energy (IFE) research and development. Efforts include:

NIF Refurbishment. NIF began operations 15 years ago and has staged more than 4,500 experiments over this time. A multi-year sustainment plan has begun to carry out urgently needed refurbishments, recapitalization, and improvements to assure continued mission delivery over the next decade and beyond. Obsolete components and failing systems are being replaced, and efforts to harden critical equipment to tolerate the more extreme radiation environment produced in high-energy-yield shots are underway. In addition to sustaining NIF's outstanding performance, these efforts train the current generation workforce—many of whom are new to our Laboratory—about this unique and highly complex system.

Target design improvements. Through many improvements to mitigate damage to optics from high laser fluences, NIF can now operate at 2.2 MJ laser energy for fusion experiments, 20 percent higher than its initial design specifications. This additional energy can improve the performance of fusion ignition experiments, but it is clear that improvements in target design and manufacture are required to achieve higher fusion energy yields. The ICECap (Inertial Confinement on El Capitan) project has prepared LLNL to transform its approach to ICF target design optimization. It combines El Capitan's 2D and 3D simulations with machine learning to revolutionize digital design—with a focus on discovering the next generation of robust, high-yield ICF designs. LLNL researchers are also pioneering the development of an advanced additive manufacturing technology precise enough to 3D print NIF target capsules, which would accelerate the pace of experimentation and support pursuit of IFE.

NIF Enhanced Yield Capability (EYC). DOE's approval in September 2024 of a CD-0 for the EYC project formally recognizes NNSA's mission need to increase the laser's energy to 2.6 MJ from its current high of 2.2 MJ, making fusion yields greater than 30 MJ possible. EYC will enable researchers to probe weapons physics phenomena in ways that have never been possible, and experiments will also inform decisions about next-generation high-yield ICF facilities.

Inertial Fusion Efforts. With its flagship ICF facility and supporting expertise, our Laboratory provides the U.S. a unique opportunity to lead the world in IFE research. Building on the ignition successes, LLNL launched an institutional initiative in IFE in 2023. By leveraging decades of investment by NNSA in ICF and exploiting emerging technologies, this initiative seeks to provide leadership and pursue technical efforts in areas highly synergistic with our stockpile stewardship mission, and importantly, work with stakeholders to support the emerging public and private IFE landscape.

In December 2023, the DOE Office of Fusion Energy Sciences awarded a four-year, $16 million project to a multi-institutional team led by LLNL to accelerate IFE research. The IFE Science and Technology Accelerated Research for Fusion Innovation and Reactor Engineering (STARFIRE) Hub consists of members from seven universities, four U.S. national laboratories, one international laboratory, three commercial entities, one philanthropic organization, and three private IFE companies. IFE-STARFIRE is accelerating the demonstration of high-gain target designs, target manufacturing and engagement, and diode-pumped solid state laser technologies. In addition, in January 2025, the University of California Regents unanimously approved the University establishing the "Pacific CREST" Fusion partnership, which brings together the University of California, private companies like General Atomics, and LLNL and other laboratories to accelerate progress toward commercial fusion energy.

Innovations in support of "S&T on a Mission"

Our mission is to enable U.S. security and global stability and resilience by empowering multidisciplinary teams to pursue bold and innovative science and technology. Livermore was established as a "new ideas" laboratory to develop innovative solutions to the nation's pressing needs to advance nuclear weapons S&T. Our mission has evolved to include broader aspects of national security, always using our unique S&T capabilities to drive toward meaningful impact, providing solutions for important problems. To meet today's needs, we must become more agile and adaptable—not only through S&T innovation but also through taking bold, well-considered technical risks, seizing opportunities, and streamlining business practices.

Attracting and retaining a high-quality workforce is essential for LLNL's success. Staff are attracted to the Laboratory by the opportunity to work on important issues for the country and the prospect of challenging careers. Currently about 50 percent of our employees have five years or less service at the Laboratory, presenting both unique challenges and opportunities. We are adjusting to this changing workforce by focusing on employees' needs, providing frequent and actionable feedback on performance, assisting with career planning, setting clear technical and developmental goals, and supporting skills development. These new employees bring tremendous talent and energy along with new ideas but must also rapidly move up the learning curve for our important national security missions.

We are working to create a work environment that fosters innovative ideas and taking on the grand challenges that LLNL missions demand—and the workplace requires attention to aging and inadequate infrastructure to enable this effort. Our 20-year site development plan takes into account the need for greater opportunities for interactions, which spark innovation. In January 2025, DOE approved a CD-0 to begin planning for the National

Security Innovation Center (NSIC), a multi-building complex at the center of the Laboratory providing about 1,000 offices, additional classified space, and a replacement for a more than 60-year-old auditorium. The NSIC is vitally needed to improve office quality and capacity, foster collaboration, and increase staff retention. Today, our researchers are spread across our campus, working sometimes in trailers or facilities built in the 1950s or before.

Another area that requires considerable attention, particularly given heightened interest in protecting U.S. intellectual property, is the protection of taxpayer-funded research and development from foreign exploitation or exfiltration. LLNL maintains a Managed Research Environment that balances the risks and benefits of international scientific collaboration and engaging or employing foreign-born staff by carefully managing access to people, places, technologies, and information. The Managed Risk Environment consists of policies, procedures, tools (like DOE's S&T Risk Matrix) and infrastructure (like DOE's Counterintelligence (CI) program) that provide layers of security and protection enabling classified and unclassified research on sensitive technologies to occur at the same labs with unclassified basic research sometimes conducted in partnership with foreign entities and foreign nationals.

Given this Committee's keen interest in innovative research as relates to critical and emerging technologies, space science, and biotechnology, I wanted to share a few snapshots of how LLNL is contributing more broadly to U.S. national and economic security.

Artificial intelligence**. As highlighted through many cited examples, AI and machine learning are crucial tools** for addressing LLNL national security and science missions. We are widely applying AI and machine learning to increase the predictive power of simulation models, design new molecules for needs ranging from disease therapies to energetic materials, integrate complex multimodal data for national security decision support, and much more. For many applications, we use a cognitive simulation approach that combines state-of-the-art AI technologies with leading-edge supercomputing. Our Laboratory established an AI Innovation Incubator (AI3) to **advance AI for applied science at scale.** AI3 serves as a collaborative hub, working with experts across many domains and partnering with commercial entities, consortia, and academic institutions to expand the Laboratory's capabilities. Within the Laboratory, AI3 *provides leadership* in AI for applied science, *develops informed strategies* for mission-driven AI investments, and *coordinates investments* focused on exploring and developing AI.

Quantum computing. The Livermore Center for Quantum Science offers a state-of-the-art facility that connects researchers, capabilities, and development efforts, both internally and externally, to further quantum innovation and streamline collaboration. Recently, researchers installed a microchip containing 21 coupled superconducting qubits inside the center's Quantum Device and Integration Testbed. The microchip's implementation was a significant step toward developing larger qubit arrays and longer, more complex algorithms needed to execute quantum operations. LLNL has also made breakthroughs in reducing quantum devices' susceptibility to noise and hardware to achieve better performance. Researchers have also successfully developed miniaturized circulators—devices used to protect qubits from noise sources—that are 1,000 times smaller than previously achieved.

Biodefense and warfighter protection. For the Department of Defense (DOD), a LLNL-led, multi-institutional and interagency team is developing Generative Unconstrained Intelligence Drug Engineering (GUIDE) as a first-of-its-kind platform to accelerate medical countermeasure development to address known, unanticipated and engineered biological and chemical threats. Initially focusing on therapeutic antibody development to combat bacterial, toxin, and viral threats, GUIDE has reduced initial candidate discovery from years to weeks while significantly lowering developmental risk. GUIDE combines data, structural biology, bioinformatic modeling, and molecular simulations—driven by machine learning and HPC—to provide the DOD with a capability to rapidly design countermeasures preemptively and responsively. This effort also includes an automated rapid response laboratory, designed to rapidly synthesize and test candidate therapeutic molecules, again speeding the design-to-deployment cycle.

Human health. LLNL has also collaborated with Fredrick National Laboratory for Cancer Research and an industrial partner, BridgeBio Oncology Therapeutics, to apply our HPC and an LLNL-developed platform that integrates AI and traditional physics-based drug discovery to produce a breakthrough cancer drug—called BBO-8520. This drug aims to inhibit mutations of KRAS proteins—targets long considered "undruggable" by cancer researchers. In record time for this stage of development, the U.S. Food and Drug Administration cleared BBO-8520 for human trials in December 2023, with first dose in humans in June 2024.

Extreme ultraviolet lithography (EUVL) for next-generation microchips. A new research partnership led by LLNL aims to lay the groundwork for the next evolution of EUVL, centered around an LLNL-developed driver system dubbed the Big Aperture Thulium (BAT) laser. The LLNL-led project is a four-year, $12 million investigation that will test BAT laser's ability to increase EUV source efficiency by about 10 times when compared with carbon dioxide (CO_2) lasers, the current industry standard. This could lead to a next generation "beyond EUV" lithography system producing chips that are smaller, more powerful and faster to manufacture while using less electricity. LLNL's expertise in EUVL builds upon prior work with Sandia National Laboratories, Lawrence Berkeley National Laboratory, and private sector partners that was commercialized in the 2010s utilizing EUVL to create significantly smaller transistors on a chip—enabling the packing of more transistors into a smaller space and paving the way for advanced microchip designs with greater performance and energy efficiency.

Space satellite optics for national security and space science. LLNL's expertise in optical science and engineering of complex systems engineering has enabled development of cutting-edge telescope optics for small satellites. These innovations make space-based telescopes more compact, robust, and cost-effective, enabling new scientific discoveries and operational capabilities, and advancing both national security and space science. Laboratory researchers developed monolithic optics, where the primary and secondary reflectors are made from a single piece of fused silica. These optics are compact (1- to 10-inch diameters or larger) and robust to launch vibrations, which make them ideal for small satellites, and they are licensed for production. LLNL also developed the CODA family of optics in partnership with Corning. They are low-cost, aluminum telescopes that are easy to manufacture, enabling constellations of half-meter-class space telescopes. CODA optics are central to NASA's Pandora Small Satellite Mission, at a cost of $20 million. The mission, which is expected to launch within the next year, will study exoplanet atmospheres and stellar activity.

Concluding Remarks
Thank you, again, for offering me the opportunity to share how LLNL's multidisciplinary workforce collaborates with other DOE national laboratories, the NSE, industry, and others within America's S&T ecosystem to enable U.S. security and global stability by pursuing bold and innovative science and technology. Thank you for your continued support for our important work. I look forward to today's discussion.