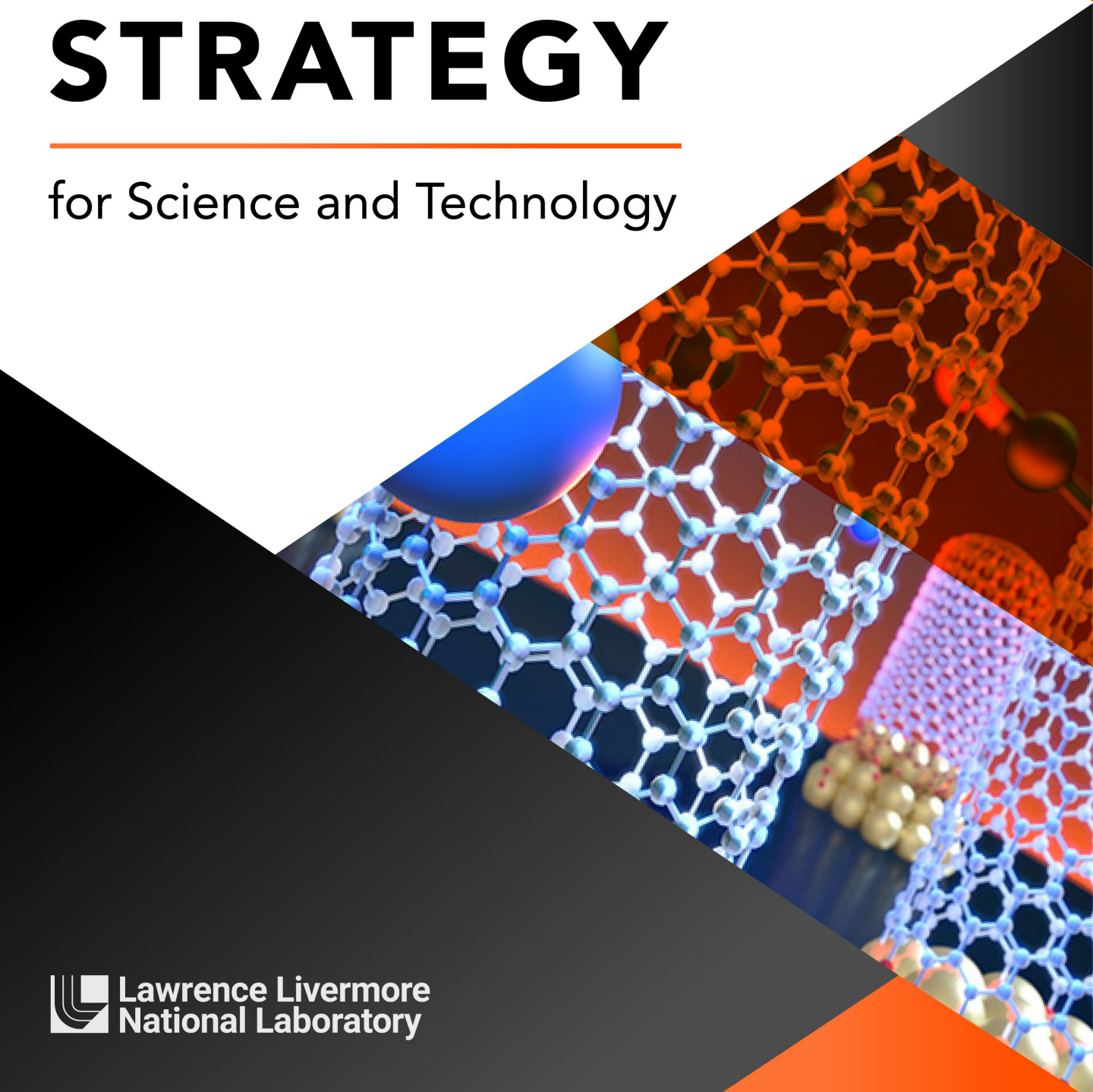
2023

INVESTMENT STRATEGY

for Science and Technology



Lawrence Livermore National Laboratory

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LLNL is chartered to develop, support, and employ world-leading scientific capabilities in support of a set of national security mission responsibilities. These foundational capabilities include talented and multidisciplinary staff, premier facilities, and core scientific competencies. These foundations enable progress and the translation of innovations into impact in an increasingly dynamic world.

The Laboratory conducts fundamental research to improve our understanding of the natural world, creates technologies that drive innovation and the economy, and delivers solutions to address national security challenges.

LLNL's *Investment Strategy for Science and Technology* describes our approach for the strategic support of the quality, health, and sufficiency of the Laboratory's scientific and technical foundations. The document provides a strategic framework for strengthening our science; deliberation and goal setting; attention to the broader mission and technological context; allocation of internal resources; selection of priority areas for attention; and assessment. This approach to science and technology investment is one part of the Lab's overall leadership strategy.

Preparation of LLNL's *Investment Strategy for Science and Technology* is led by LLNL's Deputy Director for Science and Technology. The strategy is updated annually to reflect evolving mission needs and scientific understanding. This document outlines the strategic context for internal investments in Livermore's scientific and engineering enterprise including our significant research resource: the Laboratory Directed Research and Development (LDRD) program. This document can be a resource for principal investigators as they consider and propose research projects aligned with internal investment priorities.

PATRICIA FALCONE
LLNL Deputy Director for Science and Technology

Science and Technology on a Mission

Lawrence Livermore National Laboratory (LLNL) was founded as a "big ideas" lab, a place where innovative science and technical solutions to the nation's most difficult security challenges are created. We continue this and live by our motto, "Science and Technology on a Mission," by pushing the frontier of what is or might be scientifically and technically possible.

Outstanding and innovative mission delivery requires talented and committed staff, state-of-the-art facilities and equipment, and robust partnerships with colleagues at other laboratories, universities, industrial firms, nonprofits, and government organizations. These factors have been essential to the Laboratory's many achievements and continue to be indispensable for the Laboratory's vital mission responsibilities and the advancement of science and technology (S&T).

The 2023 *Investment Strategy for Science and Technology* is organized differently than in previous years. Reflecting the guidance of Laboratory Director Kim Budil and the strategic planning efforts of her leadership team over the past year, this document outlines updated Laboratory mission and vision descriptions, the establishment of new Mission Focus Areas (MFAs), and the use of a more formal goal setting approach using Objectives and Key Results (OKRs). It broadly describes the types and nature of investment decisions and the desired outcomes over a three-to-five-year time horizon as a result of those decisions. Overall, the strategy describes science and technology challenges from a mission perspective and looks ahead to where pushing the boundaries of new science, technology, and innovation could lead. And, consistent with previous year's documents, the priorities for this year's LDRD program investments are described to support the call for LDRD research proposals for FY24.

This document opens with a bird's-eye view of LLNL in **Section 1**, highlighting our mission and vision statements. **Section 2** breaks down our crucial mission-driven commitments and introduces the Objective and Key Results process. **Section 3** focuses on the Laboratory's Science and Technology Enterprise and introduces our "S&T Mobilizers"—our people, our facilities, and our Core Competencies—the critical elements at LLNL that are the foundations for our mission-driven work. **Section 4** presents the set of internal funding sources at LLNL and describes how each source supports continued excellence in research and development. Support of our S&T Mobilizers by external sponsors is also highlighted. **Section 5** explains the process and importance of regular investment portfolio review and the use of metrics, since building sustainable success relies on monitoring results. **Section 6** looks ahead to the future state of the Laboratory's S&T portfolio and the evolving contributions of our S&T Mobilizers.

I hope you find this document informative and enlightening as it offers new transparency on how strategic science and technology investment decisions are made. We are grateful for the ability to make strategic investments that sustain Lawrence Livermore National Laboratory as a national resource for innovative solutions to tough, important national security challenges. And we are determined to use these investments to keep the Laboratory an exciting and meaningful place to work for top-flight scientists and engineers.

P. K. Falcone

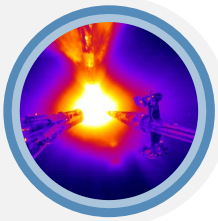
Section 1: LLNL Overview

One Mission, Many Domains. Lawrence Livermore National Laboratory serves a wide variety of national security missions through the application of science and technology, and our enduring domain of nuclear deterrence. Established in 1952 at the height of the Cold War to advance nuclear science and technology, we recently celebrated seventy years of addressing the challenges of strategic deterrence and non-proliferation in an increasingly complex geopolitical environment. Continuing federal support for our defining responsibility has enabled the Lab to provide the nation state-of-the-art facilities, world-class competencies, and a talented workforce, fostering our reputation as a global resource for questions of deterrence and stockpile stewardship.

Through that lens of national security, we've transformed many of the tools and approaches that were brought to bear on our original national security mission into capabilities to meet the pressing issues of our time. We apply cutting-edge science and technology to achieve breakthroughs in enterprise resilience and counterterrorism, defense and intelligence, energy security and climate resilience, and research and development to produce fundamental science discoveries and faster innovation cycles.

Section 1.1: Mission and Vision Statements

Our Mission: LLNL's mission is to enable U.S. security and global stability and resilience by empowering multidisciplinary teams to pursue bold and innovative science and technology.



Our Vision: We fearlessly and relentlessly pursue big ideas to solve the most important security challenges facing the nation and the world.

Who We Are: Our inclusive teams bring together exceptional scientific, technical, administrative, business, and operational experts to accomplish our important missions.

Section 2: LLNL's Mission

LLNL's mission is to enable U.S. security and global stability and resilience by empowering multidisciplinary teams to pursue bold and innovative science and technology.

For more than 70 years, Lawrence Livermore National Laboratory has applied science and technology to make the world a safer place. 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.

The Laboratory strengthens the United States' security by developing and applying world-class science, technology, and engineering that enhances the nation's defense, reduces the global threat from terrorism and weapons of mass destruction, and responds with vision, quality, integrity, and technical excellence to scientific issues of national importance.

In support of our crucial mission-driven commitments and keeping an eye on emerging threat and technical opportunities, we apply cutting-edge science and technology to achieve breakthroughs in a wide variety of research areas.

S&T is embedded in *everything* we do.

Section 2.1: Mission Areas

Mission Areas

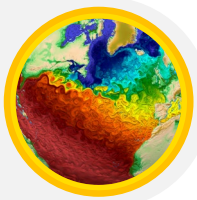
Major domains of mission responsibility

LLNL is a national security laboratory with a "nuclear core." Our defining and core responsibility includes nuclear weapons, nuclear deterrence, and nuclear security. The scale, mix, and objectives of our mission programs have changed over the years. Today, we continue to work to ensure the safety, security, and reliability of the U.S. nuclear stockpile, to perform the Annual Assessment, and to lead life extension and modification efforts for weapon systems. In addition, we continue working to understand adversary capabilities and intentions, to meet the challenges of nuclear proliferation and terrorism, to understand and prevent cyber threats, to capture the benefits of advanced technologies, and to characterize and create adaptive strategies for global issues such as climate change, access to space, and regional conflict.

It is useful to describe the Lab's work on today's national security challenges in four large Mission Areas: nuclear deterrence, threat preparedness and response, climate and energy security, and multi-domain deterrence. While the Mission Areas differ in size (nuclear deterrence is the largest Mission Area), each one includes significant work at a range of technology readiness levels from basic research through prototype or deployment, each has a history of major mission and science contributions, and each enriches and draws from the Lab's Core Competencies. In all four Mission Areas, we count on our talented workforce to think bigger—to have big ideas; new ideas. Through their exceptional work in preeminent areas of science, the Lab's influence doesn't stop at our country's borders—our innovations make the world a better place to live.

Nuclear Deterrence: develop and apply scientific insight and engineering prowess needed to assure the safety, security, and reliability of the U.S. nuclear stockpile in an ever-changing threat environment and enable the modernization and transformation of the NNSA production enterprise.

Threat Preparedness and Response: provide unique capabilities and innovative solutions to stem the proliferation of nuclear, chemical, and biological weapons of mass destruction, understand adversary capabilities and anticipate adversarial actions, and support response and consequence mitigation of natural and man-made threats.



Climate and Energy Security: advance understanding of the global climate system, develop technologies to reduce accumulation of greenhouse gases, and pursue the domestic production and supply of affordable, clean, and increasingly carbon-free energy delivered across a secure and sustainable infrastructure.

Multi-Domain Deterrence: create a global strategic advantage through innovative technologies, strategies, and analyses to bolster escalatory and defensive capabilities across the full spectrum of domains including strategic defense, conventional strike, space, cyber, and technological competition.

Section 2.2: Mission Focus Areas

Mission Focus Areas

Current, targeted challenges addressed via focused cross-Laboratory efforts

As a part of the 2022 Laboratory strategy update process, Director Kim Budil solicited her leadership team to consider a range of ongoing mission program areas and some of the most salient national and global challenges for which science and engineering together with Laboratory program delivery approaches might be able to render significant service. The intent was to select a small number of areas and to explore potential solutions employing more comprehensive and adaptive governance approaches.

Ultimately, four new Laboratory "Mission Focus Areas" (MFAs) were selected by the leadership team as inaugural experiments. This pilot effort was structured to more explicitly engage the full breadth of Laboratory capabilities, to proactively engage key partners in these topical areas, and to have senior managers cooperatively oversee the work efforts. Each Mission Focus Area is based on a set of existing capabilities and program contributions, each has a set of Senior Management champions, and each is structured for maximum impact. Unique work programs have been established in each Mission Focus Area that exploit existing technical expertise, take advantage of deep mission knowledge, and employ decision-informed analyses to inform policy options.

The four Mission Focus Areas receive special management attention, but they represent just a part of the larger set of important ongoing programs that constitute a Mission Area. By putting Laboratory capabilities and experts at the core of this pilot effort, Mission Focus Areas enrich LLNL's mission contributions by accelerating credible solutions for national security and global stability.

Stockpile and Enterprise Transformation accelerates the advancement of the sophisticated enterprise of laboratories, facilities, and people ensuring confidence in the nation's nuclear deterrent. Bio Resilience counters natural and man-made biological threats by leveraging LLNL's unique competencies in high-performance computing, advanced biotechnology and bioengineering. Climate Impacts and Resilience couples capabilities in materials science, carbon cycle and subsurface research, and climate simulation to mitigate greenhouse gases and predict climate impacts at scale. Integrated Deterrence and Technology Competition addresses operational and strategic needs by converging with and reinforcing a full range of defense strategy capabilities.

Stockpile and Enterprise Transformation

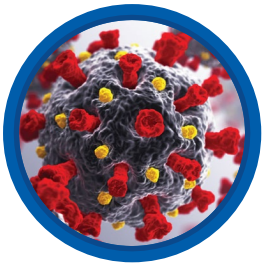
Accelerate resiliency of enterprise

Enhance collaborative partnerships

Produce next-gen ST&E

Leverage world-class workforce

Bio Resilience



Analyze, assess, and predict threats

Develop countermeasures and therapeutics

Establish integrated computational-experimental platforms

Climate Impacts and Resilience

Reduce greenhouse gas accumulation via advanced technology

Inform climate strategy through high-fidelity models

Assess and mitigate national security impacts

Integrated Deterrence and Technology Competition

Strengthen integration across national security objectives

Analyze adversary capabilities

Integrate cross-domain analysis and technology solutions

Each of the four Mission Focus Areas is outlined in greater detail in Section 6.

Section 2.3: Retirement of Mission Research Challenges

Mission Research Challenges

Science-supported aspects of LLNL's mission

Over the past several years, the Laboratory's *Investment Strategy for Science and Technology* highlighted particular areas of interest called Mission Research Challenges. With the advent of MFAs, this construct has been retired. In the future, the Lab's support of and interest in ST&E in these areas will continue, just primarily under the auspices of the four Mission Areas.

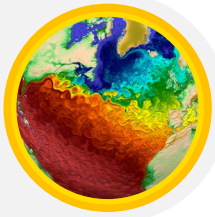
Each Mission Research Challenge will primarily be supported under these Missions:

Nuclear Deterrence

- Nuclear Weapons Science
- High Explosive Physics, Chemistry and Material Science
- Nuclear Threat Reduction

Threat Preparedness and Response

- Nuclear Threat Reduction
- Biological and Chemical Countermeasures
- Forensic Science



Climate and Energy Security

- Energy and Resource Security

Multi-Domain Deterrence

- Directed Energy
- Cybersecurity and Cyber-Physical Resilience
- Quantum Science and Technology
- Science of Materials in Hypersonic Regime Conditions
- Space Science and Security

Section 2.4: LLNL's Mission Structure

The Laboratory counts more than 8,000 employees across the country: no matter what team, division, program, or directorate they belong to, they all contribute to our vital national security mission. By acting as good stewards of all available resources—time, effort, knowledge, and taxpayer dollars—we continue to enhance and adapt our core mission to changing national needs and priorities.

LLNL's mission is to enable U.S. security and global stability and resilience by empowering multidisciplinary teams to pursue bold and innovative science and technology.

Section 2.5: Lab-Wide Objectives and Key Results

Laboratory leadership adopted **Objectives and Key Results (OKRs)** as a management framework in 2022 to advance science innovation and operations excellence and enable to us to fulfill mission deliverables. OKRs foster collaboration, connectivity, and help organizations reach aspirational goals. Lab-wide OKRs were finalized in the summer of 2022 and provide clarity on near-term priorities. The guiding principles or "North Stars" for each of the four organizational elements will remain unchanged over the next several years, but the Objectives and Key Results will be updated at a regular cadence. As OKRs are introduced at the directorate, divisional, and program level, Laboratory staff will have more visibility and better understand how their work contributes to and supports LLNL's mission.

- **North Star:** guiding principle that anchors how we do our work
- **Objective:** what we seek to achieve
- **Key Result:** defined, measured progress towards achieving the objective

Mission and Program Delivery

North Star: Be the "game-changing" lab delivering innovation and transformational solutions to the biggest national security challenges.

Objective: (1) Demonstrate schedule credibility in delivering our W80-4 and W87-1 scope; (2) Implement an integrated roadmap for Mission Focus Areas (MFAs) to ensure alignment and impact.

Science and Technology

North Star: Perform foundational and applied Research & Development (R&D) that will have strategic impact in areas of national importance.

Objective: Update the S&T roadmap to advance capabilities essential to LLNL's future success over the next decade.

Workforce

North Star: Transform the Lab's culture and reimagine workforce experiences to meet current needs and ensure future success.

Objective: Improve the employee experience to increase engagement, enhance productivity, and reduce attrition.

Operations

North Star: Establish LLNL as a model 21st century federally funded R&D center (FFRDC), that is responsive, agile, adaptive and poised to enable workforce and mission success.

Objective: Modernize operations, processes, and systems in order to accelerate execution, prioritization, decision making, and resource allocation.

Section 3: Science and Technology Enterprise at LLNL

The guiding **North Star** for the Laboratory's science and technology—perform foundational and applied R&D that will have strategic impact in areas of national importance—requires processes and procedures to maximize enterprise quality and drive resource allocation decisions. As the entity charged with stewardship of the Laboratory's S&T enterprise and guided by the relevant North Star, the Office of the Deputy Director for Science and Technology (DDST) is responsible for executing Objective L3:

Science and Technology

North Star: Perform foundational and applied Research & Development (R&D) that will have strategic impact in areas of national importance.

Objective: Update the S&T roadmap to advance capabilities essential to LLNL's future success over the next decade.

This vital Objective comes with four Key Results, a mix of accessible and "stretch" goals:

- **Key Result 1** (due by 11/30/22): Develop a new S&T framework clarifying the role & intent of its components.
- **Key Result 2** (due by 12/31/22): Define the measures of success for the new LLNL S&T roadmap.
- **Key Result 3** (due by 1/31/23): Establish the priorities of the S&T roadmap for the next 5-10 years incorporating the new MFA requirements.
- **Key Result 4** (due by 1/31/23): Deliver 2023 LLNL *Investment Strategy for Science and Technology* informed by the updated framework and roadmap.

Fulfillment of Key Result 1 is detailed in Section 3.1: Science and Technology Framework. Pictured on the next page, the S&T Framework provides an overview of the DDST Office's strategic outlook. Actions undertaken for the good of the scientific enterprise in the framework's four elements are described in the charter listed in each element segment: "Advance LLNL's core scientific, technology, and engineering expertise to ensure leading-edge capabilities are available to fulfill LLNL's national security missions by relying on our talented staff, Core Competencies, and state-of-the-art facilities to conduct diverse research activities that are regularly assessed to make scientific innovation available for disciplined execution."

Delivery of Key Result 2 is detailed in Section 5—examining formal review processes and leveraging existing elements to ensure our S&T Portfolio is aligned with our enduring missions. Key Result 3 involves a more thorough understanding of how MFAs are supported by internal investments, a process that the Laboratory's senior management team will continue to develop in 2023. Guided by the elements detailed throughout this document, the creation of the *Investment Strategy for Science and Technology* fulfills Key Result 4.

By adopting OKRs as a management strategy, Livermore continues to harness science, technology, and operational excellence to help secure a reliable, safe, and resilient nation.

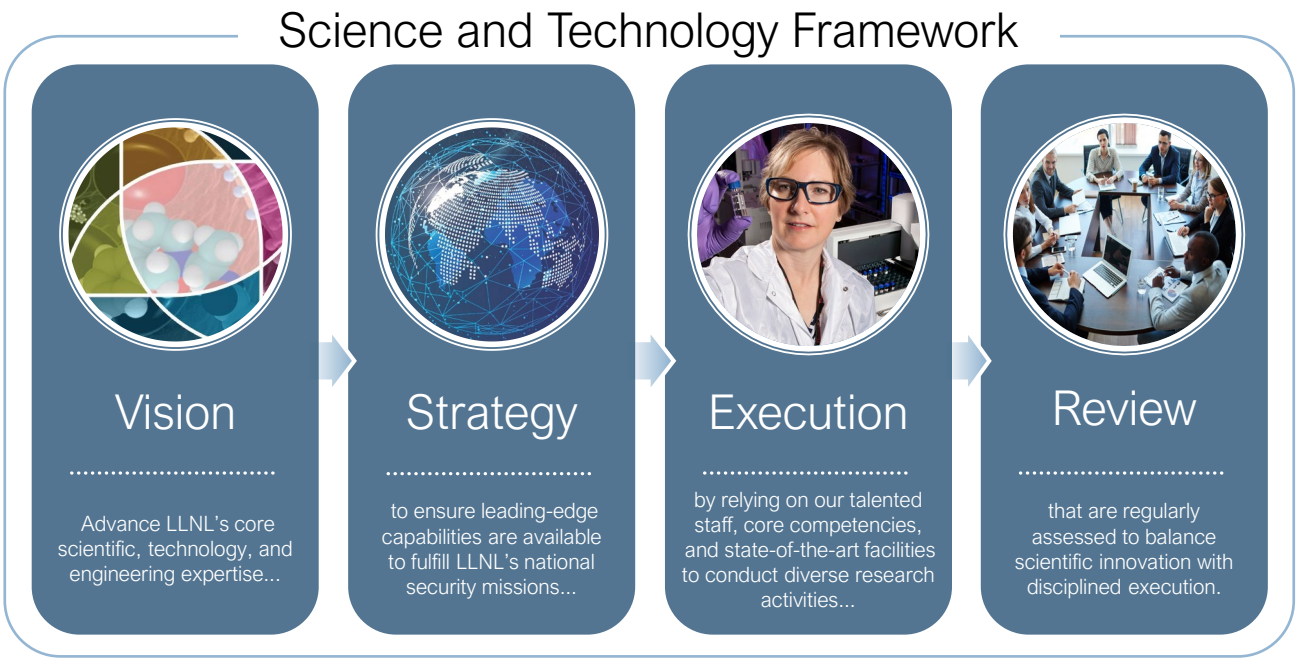
As the OKR process advances, LLNL can more efficiently capture plans for continued growth.

Section 3.1: Science and Technology Framework

A new framework for investments in the Lab's S&T enterprise was requested in the 2022 Laboratory strategy and planning sessions and incorporated into the OKRs. Each Key Result can be mapped to a pillar:

- The Science and Technology Framework at the bottom of this page delivers on **Key Result 1**, outlining four pillars of our S&T Framework. **Vision** also echoes the Laboratory's mission statement: "bold and innovative R&D" and the ambitious challenges within our mission.
- **Key Result 2** requires defining metrics, matching our assessment of internal investments in the **Review** pillar.
- **Key Result 3** speaks to the office's priorities for the next 5-10 years, an example of **Vision**.
- This document's creation fulfils **Key Result 4** and maps to the **Strategy** component of the S&T Framework, which also includes how we prepare and support emerging science through Institutional Initiatives (formerly called Director's Initiatives) and MFAs and how we rebalance internal funding to respond to national needs and emerging challenges and opportunities. Our S&T Mobilizers, further detailed in Section 3.1, are an extension of the **Execution** pillar.

The Framework below is a broad look at the DDST Office's strategic outlook: we've created, nourished, and grown our three S&T Mobilizers to serve us well in delivering on our mission, as illustrated within the **Vision** and **Strategy** pillars. We also respond to emerging science challenges through the MFAs and Institutional Initiatives, which draw upon internal investments and S&T Mobilizers for a fixed amount of time. **Execution** involves tracking milestones and deliverables against scope, budget, and schedule—and is outside the purview of this document. The **Review** pillar signifies our ability to update plans, respond to changes in technology and the national security landscape, and then make judicious funding decisions.



Section 3.2: S&T Mobilizers

LLNL's Science and Technology enterprise has three constituent parts referred to as S&T Mobilizers: **talented staff, Core Competencies,** and **state-of-the-art facilities.** Each part of the enterprise is addressed in the Science and Technology Framework, while the importance of our S&T Mobilizers is stressed throughout this document. This section examines each S&T Mobilizer closely in its current form, and a future-minded evolution of the S&T Mobilizers is outlined in Section 6.

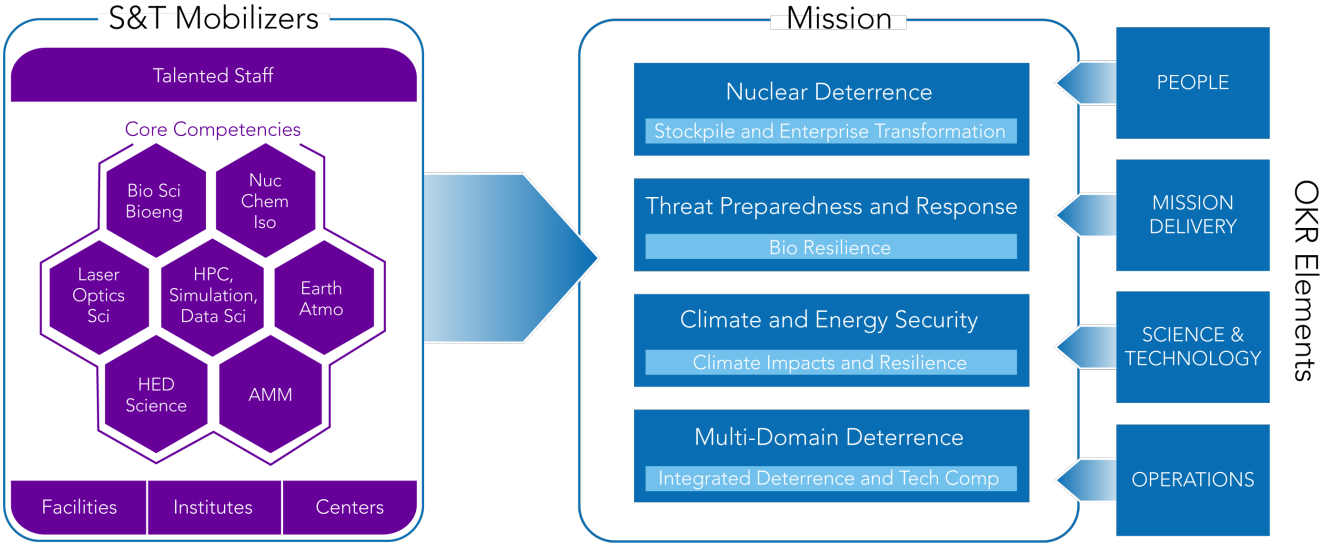
Our workforce is at the heart of everything we do, from training postdocs to be LDRD principal investigators to developing thought leaders by having them run a Center or Institute and form academic partnerships through shared Facility capabilities. Centers, Institutes, and Facilities also serve as organic recruitment pipelines, drawing motivated staff and inspiring innovative collaborations. Through thriving Core Competencies, researchers conduct impactful R&D that positions them among the world's experts in their chosen field.

Talented Staff

Core Competencies

State-of-the-Art Facilities

S&T Mobilizers work together as a combined set of skills, tools, and resources to underpin our mission-driven work. Mission delivery requires talented and committed staff, state-of-the-art facilities and equipment, and robust partnerships with colleagues at other laboratories, universities, industry, nonprofits, and government organizations. These factors have been essential to the Laboratory's many achievements and continue to be indispensable for the Laboratory's vital missions and the advancement of S&T. As illustrated below, the OKR process and S&T Mobilizers are focused on mission success to advance scientific discovery.



Section 3.3: S&T Mobilizers—People

People

Supporting and engaging our current and future staff members

Livermore's talented staff is its key asset. The Laboratory's many scientists and engineers bring their knowledge, expertise, and experience to address national security mission challenges. They do so with extreme curiosity and a drive to uncover knowledge and better understand how things work with a continuously improved set of tools and approaches. Staff work individually, in multidisciplinary teams, and with partners at other laboratories, universities, and other institutions. Examples of investments that support people are listed below in two categories: investments that support individual skills and effective teaming, and those that support effective collaborations.

Skill Development:

Career Development: Training, workshops, presentations, webinars, and conferences are a few of the many ways we ensure that our thousands of talented researchers, operations staff, and creative professionals advance their individual skillsets.

Postdoctoral Scholar Training: LLNL employs >400 postdoctoral scholars; they are a valued cohort of our research community. During their tenure, postdocs conduct research publishable in peer-reviewed journals, develop scientific expertise in their field of research, present their research at national and international meetings, and learn how to be successful professional researchers. LLNL supports their professional development with resources, targeted training, and events such as the annual Research SLAM! competition.

IDEA (Inclusion, Diversity, Equity, and Accountability) and Culture: Laboratory leaders are committed to creating an environment where the diverse talents, perspectives, ideas, backgrounds, and life experiences of all employees are respected. We believe this gives rise to the most innovative ideas and fosters our ability to take on and solve the grand challenges that our mission demands.

Library/Archives: The LLNL Research Library and its talented staff are key supporting resources for accessing the global research archive and preserving LLNL scientific and technical information.

Partnering and Engagement:

Academic Engagement Office (AEO): The Academic Engagement Office fosters collaborations and partnerships between Laboratory researchers and the academic community. The team provides students and faculty at K-12 schools, community colleges, vocational schools, universities, and post-doctoral programs with research assignments, work-study opportunities, and educational activities.

Innovation and Partnerships Office (IPO): This team serves as a focal point for LLNL engagement with industry. Through technology commercialization, encouraging entrepreneurship, and Laboratory business development activities, the IPO office advances the development and commercialization of scientific discoveries. With input from programs and disciplines, the IPO identifies new economic opportunities and solutions and transfers those to the private sector through licensing or partnerships for the benefit of the U.S. economy.

Science Education: LLNL's Science Education program offers a wide variety of experiences to students and teachers. From workshops on molecular biology and robotics to summer camps empowering women in STEM, a multitude of options exist to spark scientific discovery and leadership in students and teachers alike. The Discovery Center at LLNL provides insight into our state-of-the-art research programs for visitors of all ages.

STEM Pipeline: Laboratory initiatives and programs help attract, develop, and retain high-caliber employees. Sustaining an end-to-end high-caliber workforce pipeline continues to be an important focus, from recruiting new talent and mentoring career development to recognition of career achievements.

S&TR: *Science & Technology Review* is published eight times a year to communicate our S&T accomplishments in support of national security. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

Section 3.4: S&T Mobilizers—Core Competencies

Core Competencies

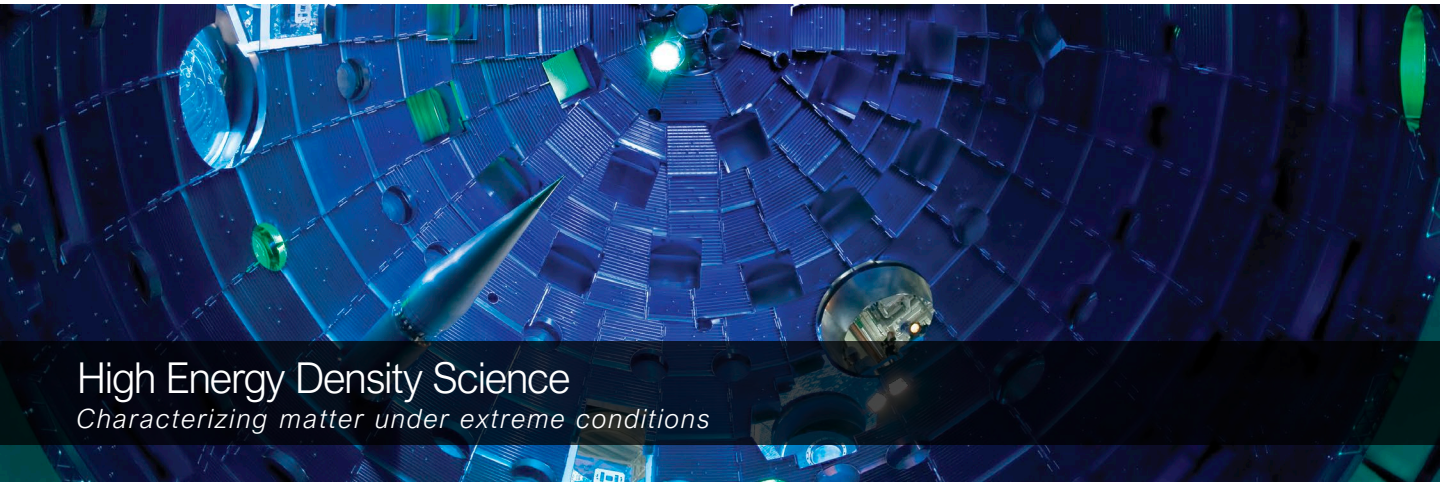
Applying our unique capabilities to today's biggest challenges

Core Competencies are areas of special capability or expertise in which LLNL is recognized as a national—and often world—leader. From basic research to applied science and engineering, we leverage core competencies to understand, respond, and adapt to pressing issues. The seven core competencies are continually strengthened through cutting-edge research and collaborations with other government organizations, industry, and academia.

Mission relevance: Core competencies inform S&T research—from the experimental design process to application—that underpins our mission of national security and global stability. Continuing investments in these areas help sustain Livermore as the nation's "big ideas laboratory" that provides innovative solutions to the most challenging national security problems as well as transformative S&T advances in the nuclear weapons and biosecurity mission areas.

Each of the seven Core Competencies is outlined in greater detail in the following pages.

Section 3.4: S&T Mobilizers—Core Competencies



High Energy Density Science

Characterizing matter under extreme conditions

Description:

Livermore is an international leader in high energy density (HED) science, studying matter at conditions of extreme temperature or pressure or under the influence of a strong force such as an intense laser, particle beam, or radiation. In pursuit of its national security missions, Livermore has continually advanced HED science starting in the 1950s with the design of nuclear weapons and extending to today's pursuit of fusion energy and the interpretation of astrophysical observations ranging from black holes to the birth of galaxies.

Mission Relevance:

Developing the science to predict, control, and exploit burning fusion plasmas is particularly important to stockpile stewardship and fusion energy. Maintaining the nuclear weapons stockpile in the absence of nuclear testing requires HED models of extraordinary fidelity that are made possible by Livermore's suite of powerful supercomputers.

Scientific Underpinnings

- On December 5, 2022, a team at LLNL's National Ignition Facility (NIF) conducted the first controlled fusion experiment in history to reach ignition, or energy breakeven, meaning it produced more energy from fusion than the laser energy used to initiate the fusion reaction. This historic, first-of-its kind achievement will provide unprecedented capability to support NNSA's Stockpile Stewardship Program and will provide invaluable insights into the prospects of clean fusion energy.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.4: S&T Mobilizers—Core Competencies

High-Performance Computing, Simulation, and Data Science

Leveraging the world's most powerful supercomputers

Description:

High-performance computing (HPC) has always been a defining strength of the Laboratory. State-of-the-art simulation applications that run efficiently on the world's most advanced computers is the integrating element of science-based stockpile stewardship and critical to many other national security needs. These extraordinarily realistic and reliable science and engineering simulations allow modeling and simulation to assume an equal role with experiment and theory. In data science, we're creating the capabilities to recognize patterns in massive amounts of information in order to understand and predict the behavior of complex systems.

Mission Relevance:

Use of the most advanced computers is the integrating element of science-based stockpile stewardship and has been behind breakthroughs in all of the Laboratory's principal Mission Areas. Livermore's flagship supercomputer is Sierra, a next-generation system focused on predictive applications to sustain the nuclear deterrent. Mission-related areas of continued focus include providing leadership through technology transitions and computing paradigm shifts; developing and applying higher fidelity, realistic, and reliable science and engineering simulations; and creating scalable capabilities to manage and recognize patterns in big data.

Scientific Underpinnings

- Livermore hardware and software experts are preparing for El Capitan, an exascale computing system that will be capable of at least two quintillion (or two million trillion) calculations per second.
- Continued development of new computer architectures as well as vertically integrating hardware and software, multiphysics applications, and data science analytics so they run seamlessly at exascale.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.4: S&T Mobilizers—Core Competencies

Advanced Materials and Manufacturing

Revolutionizing the design-build-test cycle

Description:

The Laboratory's Core Competency in Advanced Materials and Manufacturing integrates precision engineering, chemistry, materials science, manufacturing expertise, and high-performance computing to produce innovative materials for stockpile stewardship, global security, and energy security. A key contributor to our strength in this area is additive manufacturing (AM), which enables the production of materials with new structural, thermal, electrical, chemical, and photonic properties.

Mission Relevance:

Innovative materials with tailored properties are used across a broad range of mission applications, including energy storage; advanced optical materials used in high-intensity laser systems; quantum materials; and components that can function effectively in extreme environments. Advanced Materials and Manufacturing allows finished and validated components to be produced in weeks and months instead of the years needed for conventional manufacturing. Through leverage of the Advanced Manufacturing Laboratory and the Polymer Production Enclave, a set of growing partnerships with industry and research institutions will further boost our ability to realize mission-critical capabilities at scale.

Scientific Underpinnings

- Composite materials with the ionic conductivity needed to increase voltage, storage capacity, and thermal stability—providing new options for fast-charging, lightweight batteries.
- Additively manufactured transparent ceramics with customized composition and structure, optimized for use as laser-amplification media—including waveguides, laser rods with end- and side-cladding, and thin disks with tailored gain profiles.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.4: S&T Mobilizers—Core Competencies

Biosciences and Bioengineering

Protecting the nation by countering current and future biological threats

Description:

The Laboratory's biological research program supports cutting-edge research to deliver transformative biological solutions for the security needs of the nation. Bringing together state-of-the-art capabilities and partnerships in quantitative biology, computing, and precision measurement, this Core Competency integrates "big data" and predictive simulation capabilities to deepen understanding of biological complexity, enable more precise predictions of health risk, and accelerate the development of countermeasures, therapeutics and vaccines. Extending biological models to include climate and ecology research, LLNL researchers provide innovative solutions for biofuels, carbon storage in soils, and biomining of critical minerals. They also develop bio-enhanced manufacturing processes for biomaterials.

Mission Relevance:

Researchers work at the interface of biology, engineering, and the physical sciences to address mission-related challenges in biosecurity, human health, and clean energy. World-class capabilities in genomics, bioinformatics, bioengineering, implantable systems, toxicology, and bioanalytical science helps keep our country safe from natural and man-made biological threats.

Scientific Underpinnings

- Laboratory bioscientists are accelerating drug discovery and development by combining physics-based modeling and simulation platforms with machine-learning algorithms.
- LLNL researchers designed the Lawrence Livermore Microbial Detection Array, a pangenomic platform for rapid detection of more than 12,000 microorganisms within a day.
- LLNL's nanoparticle-based vaccine delivery platform advances vaccine development for human health and biosecurity pathogens.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.4: S&T Mobilizers—Core Competencies

Earth and Atmospheric Science

Assessing and mitigating human influences on climate

Description:

This Core Competency combines expertise in earth and atmospheric science with high-performance computing, artificial intelligence, and machine learning to meet national security, energy security, and environmental security needs. Expertise in atmospheric science is central to study climate change, climate adaptation, renewable-energy systems, and atmospheric chemistry, transport, and dispersion.

Mission Relevance:

LLNL has developed world-class capabilities in subsurface modeling of the behavior of rocks under loading, the propagation of seismic energy, and the movement and reaction of subsurface fluids—physical processes that underlie important national security, carbon management, and energy applications. LLNL is also developing capabilities to predict anticipated climate response at the spatial and temporal scales required for adaptation, with emphasis on national security and critical infrastructure.

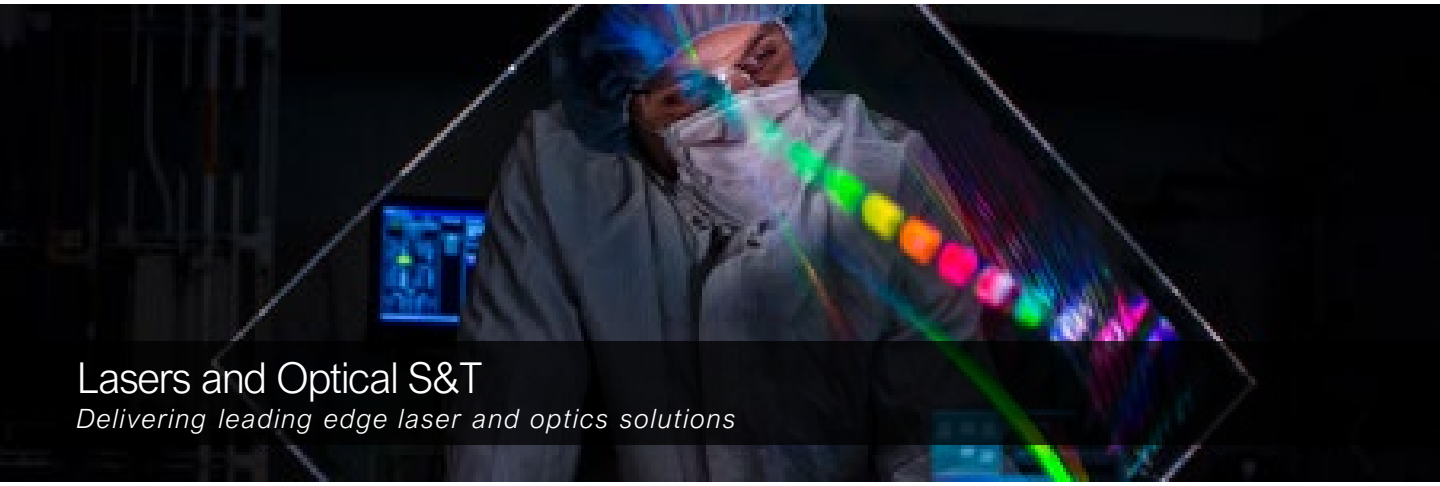
Scientific Underpinnings

- Using the Energy Exascale Earth System Model (E3SM) as the template, an LLNL-led research team has developed a powerful high resolution new global atmosphere model: the Simple Cloud-Resolving E3SM Atmosphere Model (SCREAM). The model's high resolution is important for accurately resolving coastal areas and mountainous regions and for capturing convective clouds, which are a leading source of climate change uncertainty.

- Livermore's leadership in earth and atmospheric science is exemplified by the National Atmospheric Release Advisory Center (NARAC). NARAC provides essential data to government decision makers in the event of hazardous atmospheric emissions, such as the Fukushima radioactivity release in 2011 and forest fires in the Chernobyl Nuclear Plant exclusion zone in Ukraine in 2020.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.4: S&T Mobilizers—Core Competencies



Lasers and Optical S&T

Delivering leading edge laser and optics solutions

Description:

Livermore researchers have designed, built, and operated a family of increasingly complex laser facilities that have successively broken world records in laser energy, power, and brightness. The Laboratory has long-standing expertise in systems engineering and laser construction and operations, which are complemented by international leadership in photonics science and technology, optics and optical material science, laser-material interactions, and laser system simulations. Livermore scientists designed, built, and operate the National Ignition Facility (NIF), the world's largest and most energetic laser, which demonstrated fusion ignition in a laboratory for the first time in 2022. The team also designed and built the world's highest average power petawatt laser for the European Union's Extreme Light Infrastructure (ELI) science facility in 2017, as well as advanced laser technologies for the DOD in support of our integrated deterrent.

Mission Relevance:

Livermore developed laser and optical solutions advance science and national security missions for the nation. In support of stockpile stewardship, the NIF remains an invaluable tool for exploring high-energy-density regimes not accessible by other experimental facilities. NIF experiments provide key insights and data for simulation codes used in mission-centric weapon performance assessments.

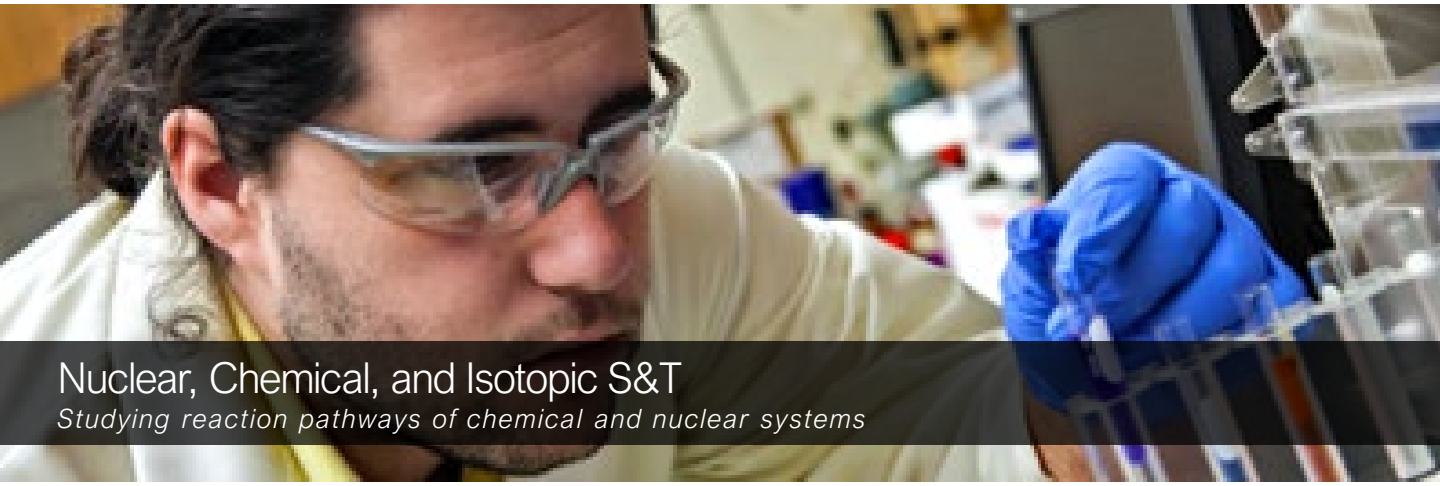
Scientific Underpinnings

- Featured as the cover story of *Advanced Optical Materials*, LLNL researchers reported a significant advance in broadband antireflective (AR) coatings applied to optics using nanostructure metasurface technology.

- With a September 2021 shipment of optical filters, Livermore researchers enabled the Vera C. Rubin Observatory to start imaging the southern sky in 2024.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.4: S&T Mobilizers—Core Competencies



Nuclear, Chemical, and Isotopic S&T

Studying reaction pathways of chemical and nuclear systems

Description:

Nuclear science and technology has been a defining strength of Livermore since its inception. These programs also serve to further neutrino science, the search for dark matter, cosmochemistry, and properties of the heaviest elements. Livermore is an international leader in chemical and isotopic analysis, with basic science and national security programs supported by the Center for Accelerator Mass Spectrometry (CAMS) and the Forensic Science Center (FSC). CAMS has hosted over 1,000 faculty and student visitors, resulting in over 300 Ph.D. and master's degrees over the past 26 years.

Mission Relevance:

Nuclear S&T is essential for sustaining an aging nuclear weapons stockpile and integral to missions in nuclear event forensic analysis, threat reduction, and safeguards.

Scientific Underpinnings

- The Forensic Science Center is one of only two U.S. laboratories to be internationally certified for identifying chemical warfare agents. Its researchers are developing innovative new forensic techniques, including a revolutionary technique using hair instead of DNA to identify individuals.

- In 2011, the IUPAC confirmed the name Livermorium for element 116. Livermorium (atomic symbol Lv) was chosen to honor Lawrence Livermore National Laboratory and the city of Livermore, Calif. A group of researchers from the Laboratory, along with scientists at the Flerov Laboratory of Nuclear Reactions at JINR, participated in the work carried out in Dubna on the synthesis of superheavy elements, including element 116.

The 3–5-Year Vision for this Core Competency can be found in Section 6.3

Section 3.5: S&T Mobilizers—Facilities, Centers, and Institutes

Facilities, Centers, and Institutes

Exquisite experimental capabilities and discipline-oriented organizational units

Description:

LLNL's facilities, centers, and institutes promote cross-disciplinary collaboration to magnify our impact on national security and global challenges. In incubators of innovation across the Lab, specialized capabilities drive science, technology, and engineering breakthroughs. LLNL institutes and centers fulfill a wide variety of needs across the Laboratory's campus. Science and technology investments provide some support for multi-programmatic efforts for many of these entities, while mission program investments make the largest investments in these facilities. These infrastructural resources engage staff from multiple directorates to carry out research, to partner with external research communities, and to build pipeline activities that educate and attract students and collaborators. These entities maintain physical and organizational infrastructure for research in shared spaces. Investments also support an annual process that prioritizes and acquires multiprogrammatic scientific instruments.

Mission Relevance:

Centers and institutes link complementary resources to continue our mission-driven work while remaining accessible to external collaborators. Some focus on the research frontiers in a particular discipline, and others are built on the shared perspectives of researchers aligned for a common application. These entities promote cross-disciplinary collaboration to magnify our impact on national security issues and global challenges. The Laboratory's facilities house the most energetic laser in the world, powerful supercomputers, and other premier tools that support a depth and breadth of research activities.

Key Facilities

- Advanced Manufacturing Lab
- Contained Firing Facility
- Electron Beam Ion Trap
- Forensic Science Center (FSC)
- High Explosives Applications Facility (HEAF)
- Jupiter Laser Facility (JLF)
- Livermore Computing Complex
- National Atmospheric Release Advisory Center (NARAC)
- National Ignition Facility (NIF)
- Optical Fabrication and Processing
- Polymer Production Enclave
- Select Agent Center
- SKYFALL

Discipline-Oriented Institutes and Centers

- Center for Accelerator Mass Spectrometry
- Center for Applied Scientific Computing
- Center for Bioengineering
- Center for Design and Optimization
- Center for Engineered Materials and Manufacturing
- Center for Global Security Research
- Data Science Institute
- Energetic Materials Center
- Glenn T. Seaborg Institute
- High Energy Density Science Center
- High Performance Computing Innovation Center
- Laboratory for Energy Applications for the Future
- Nondestructive Characterization Institute
- Space Science Institute

Section 3.6: Office of the Deputy Director for Science and Technology

On behalf of the Laboratory, the Office of the Deputy Director for Science and Technology (DDST) executes these investments in the Lab's science and technology enterprise. It works to ensure Livermore's world-renowned S&T research excellence balances innovation with disciplined execution, and multidisciplinary teamwork with individual initiative. The combination of mission focus and S&T excellence is central to the Laboratory's strategic vision.

The key functions of the DDST Office are to:

Invest: *Coordinate internal investments to keep the Lab's research activities and staff at the forefront of science and technology*

- Laboratory Directed Research and Development (LDRD)
- Institutional Strategic Support (ISS)
- Institutional Science Capability Portfolio (ISCP)
- Licensing and Royalty (L&R)
- Development and training opportunities

Partner: *Growing relationships among mission-driven partners*

- Academic Engagement Office (AEO)
- Innovation and Partnerships Office (IPO)
- Science Education
- Engagement with the broader science policy community
- Commitment to international partners

Communicate: *Explaining our research approaches and outcomes to staff, sponsors, partners, and the community*

- *Investment Strategy for Science and Technology*
- Performance Evaluation and Management Plan (PEMP) and assessments
- *Science and Technology Review* (S&TR)

Enable: *Ensure our scientists and engineers are supported with tools and programs to exercise and grow their capabilities*

- Awards and recognitions
- Postdoctoral program support
- Principal Investigator (PI) training
- Proposal Development support
- Library resources

By guiding internal investments and overseeing the integration of science and technology expertise and resources with the Laboratory's programmatic Mission Areas, the DDST Office supports, strengthens, and enhances premier S&T across a range of disciplines.

More information about many of these functions can be found in Section 3.3

Section 4: Support of Science and Technology

The support of LLNL's science and technology enterprise relies on external funding and guidance from a variety of sponsors. The largest and most important sponsor is NNSA/Defense Programs, who provides significant support for all of our S&T mobilizers. LLNL brings its technical competencies to the full suite of DOE missions and engages in activities to support the Department and its national laboratories while providing synergy to our core NNSA mission.

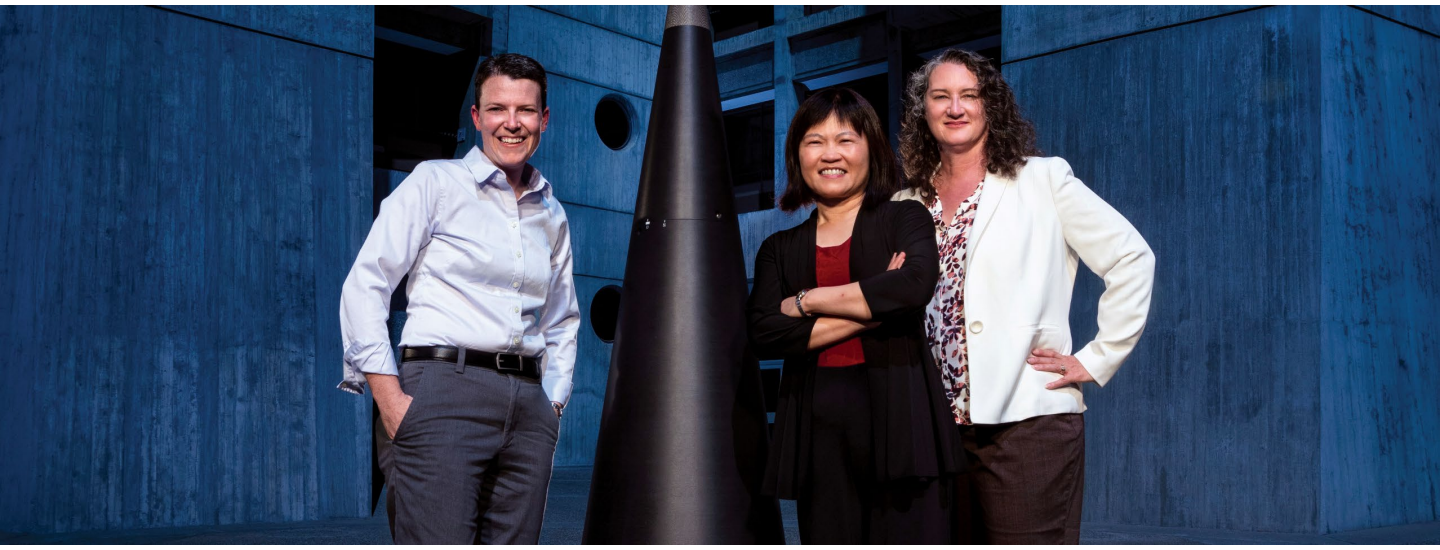
Many non-NNSA mission areas require expertise, unique capabilities, and facilities that exist at the Laboratory. These Strategic Partnership Projects (SPPs), often conducted in partnership with other laboratories, serve to strengthen and broaden the science and technology expertise necessary for NNSA work. The non-NNSA DOE projects can be sponsored by other U.S. government agencies, industry or academia, and spin back new ideas and knowledge into NNSA programs, and they attract and help support top-notch researchers that contribute to a healthy, vibrant Laboratory.

In addition to externally funded work guided by sponsors, LLNL also makes significant internal investments to create new capabilities, pursue leading-edge R&D, and ensure our S&T Mobilizers can address NNSA's mission and respond to emerging challenges.

Section 4.1: NNSA Defense Program Science

Through the Stockpile Stewardship Program (SSP), NNSA's Defense Program (DP) has made dramatic advances in experimental and computational capabilities to gain tremendous insights into the science and engineering of operational nuclear weapons. These technical capabilities are a signal to our adversaries that we are innovative and agile in response to new challenges.

Today, innovation and technical leadership in the core technical fields associated with strategic deterrence are even more essential than at the dawn of the SSP. For a few select areas, nothing short of preeminence is LLNL's goal. In HPC and HED we remain not only leaders but pioneers, shaping the international landscape with our work. In the next generation of experimental technologies and energetic materials, our legacy of excellence will be harnessed to shape those future capabilities and expertise. Finally, in keeping with our founder's vision of a "Big Ideas" laboratory, we will continuously explore emerging technologies, such as additive and advanced manufacturing, to drive game changing advances for our mission.



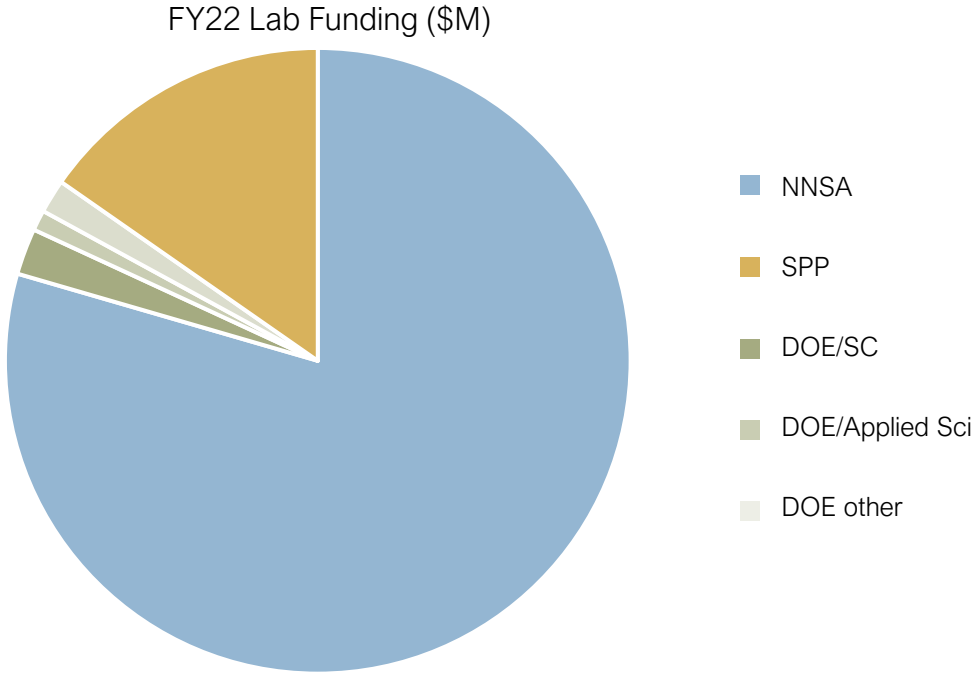
Section 4.2: Sponsored Science

DOE/Office of Science and other parts of DOE:

The DOE Office of Science (SC) is a major external source of funding for fundamental scientific research at LLNL. LLNL's SC program is formulated around a diverse portfolio of research that seeks to address major scientific challenges while contributing to the vitality of the Laboratory's Core Competencies and Mission Focus Areas. LLNL's current SC portfolio includes funding from: Advanced Scientific Computing Research (ASCR), Basic Energy Sciences (BES), Biological and Environmental Research (BER), Fusion Energy Sciences (FES), High Energy Physics (HEP), Nuclear Physics (NP). LLNL also performs research for several DOE applied energy programs that leverage Core Competencies and provide opportunities for LLNL staff to make important contributions for other national priorities. This portfolio includes funding from: Accelerator R&D and Production (ARDAP), Isotope R&D and Production (DOE IP), the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Environmental Management (EM), the Office of Fossil Energy (FE), and the Office of Nuclear Energy (NE).

Strategic Partnership Projects (SPP):

Developing and sustaining interagency and industrial national security work enhances our capabilities. These efforts feed new technology into our core mission while solving challenging national security problems for a variety of sponsors. The optimal SPP portfolio for LLNL is one that leverages and builds upon the Laboratory's Core Competencies, unique scientific and technical infrastructure, and integrated problem-solving skills. Approximately 80% of the SPP funding comes from a wide variety of organizations that reside within the Department of Defense (DOD). Other government agencies such as NIH and NASA also provides funding for fundamental research on a wide range of topics. This entire portfolio of diverse research includes developing and implementing cutting-edge solutions and is a major factor in recruiting and retaining the workforce.



Section 4.3: Internal Investments

Our internal institutional investments—in particular, our **Laboratory Directed Research and Development (LDRD) Program**—support the exploration of new ideas that anticipate future needs within our national security missions. The Laboratory uses funding from LDRD, ISS, ISCP, and L&R to achieve a specific set of goals—the most important areas of attention of the Lab: infrastructure, research capabilities, and people.

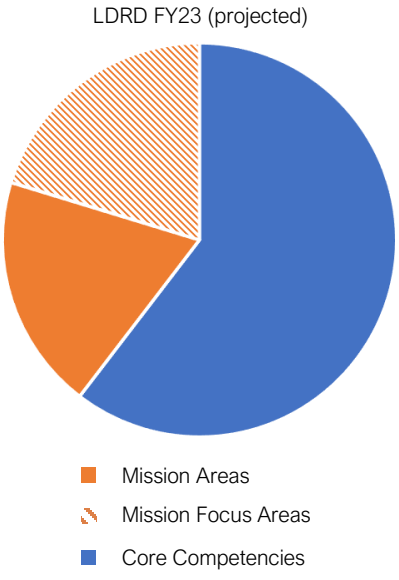
Laboratory Directed Research & Development (LDRD)

Internally funded high-risk, potentially high-value research and development

The LDRD program is a congressionally authorized component in the NNSA's S&T investment strategy that provides investments in cutting edge science and technology that allow the Laboratory to attract and retain the world's most talented scientists and engineers and enables them to expand the frontiers of knowledge and anticipate emerging national security challenges. Funded with approximately six percent of the Laboratory's budget, LDRD is awarded through a rigorous and highly competitive peer-review process.

The LDRD program is also a powerful means to hire outstanding staff, post-docs, and students; foster collaborations with other prominent scientific and technological institutions; leverage some of the world's most technologically advanced assets; and publish innovative science and technology achievements in high-impact journals and meeting proceedings.

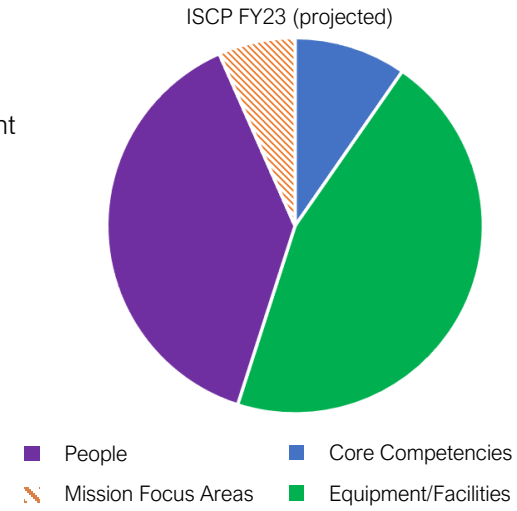
LDRD enables LLNL to invest in high-risk, potentially high-value research and development that creates innovative technical solutions for some of our nation's most difficult national security challenges. The graphic to the right displays how LDRD funding supports Laboratory research in three categories: Mission Areas, Mission Focus Areas (MFAs), and Core Competencies (CCs).



Institutional Scientific Capability Portfolio (ISCP)

Funding to maintain the Lab's core and mission competencies

ISCP is an important component of LLNL's overall strategic investment program that supports capability sustainment projects, workforce programs, and scientific infrastructure. ISCP projects are non-R&D activities that maintain or improve the Laboratory's core mission competencies and capabilities and must be applicable to current and future mission and S&T capabilities.

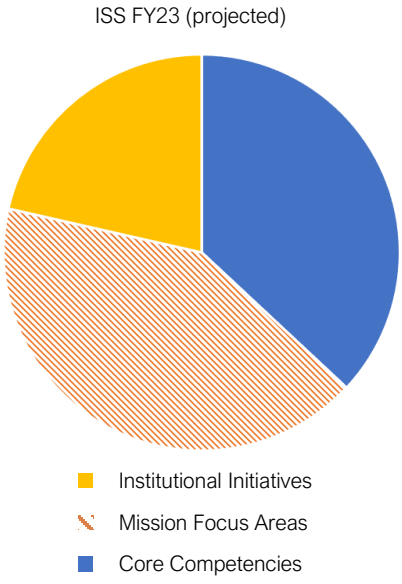


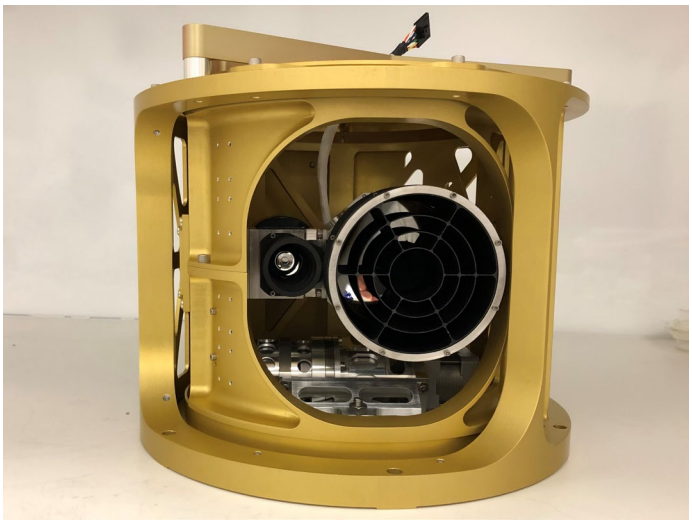
Section 4.3: Internal Investments

Institutional Strategic Support (ISS)

Funding for multi programmatic, mission related activities

Technical activities including sponsor engagement and program development associated with supporting LLNL initiatives and priorities that are multi programmatic and have cross directorate benefit; strategic studies and analyses related to LLNL missions or in support of decisions to be made by executive and national leadership; maintaining a knowledgeable workforce on emerging national security issues; liaison with NNSA, DOD, and other sponsors in the nuclear security arena; institutional investments that provide capability sustainment to develop and maintain the intellectual base that have Lab-wide benefit or cross-directorate benefit in LLNL's Core Competencies and Mission Areas that benefit multiple customers. Other activities include offsite institutional assignments and oversight.





Licensing and Royalties (L&R)

Funding scientific collaboration

L&R funds are generated by licensed Intellectual Property invented by Livermore researchers. Activities must meet the criteria defined by the Stevenson-Wydler Act (SWTIA). Recent uses of this funding include supporting LLNL's participation in The Accelerating Therapeutics for Opportunities in Medicine (ATOM) consortium, supporting the research of Early- and Mid-Career Award winners, and developing the Stellar Occultation Hyper-temporal Imaging Payload (*SOHIP),* an instrument that will be deployed on the International Space Station in 2023 (pictured at left).

Section 5: Review and Metrics

It's vital that we act as good stewards of all available resources.

How we allocate resources and how we evaluate programs affect how we fulfill our mission, make our research more impactful, and respond to future challenges and opportunities.

To keep our science and technology healthy and cutting-edge, we use a series of reviews and metrics to review our internal portfolio of investments. Regular portfolio review is governed by a uniform and consistent structure, so we can chart the health of our programs year-over-year without being beholden to changing variables. Following the guidance of Lawrence Livermore National Security's (LLNS) Parent Oversight Plan, portfolio review parameters include support of the Laboratory's mission, impact and recognition, research value, levels of collaboration, and program sustainability.

Metrics may take several forms—our S&T portfolio is widely varied, and the accompanying metrics also reflect that variance. Some metrics may be applied to each entry in the portfolio, while others will need to be tailored more specifically to each program. Currently utilized metrics include; the size and diversity of our postdoctoral cohort; the number and quality of our publications; the impact of our research, as measured by how well we transition innovations to industry and other partners; and the expertise of our staff, as recognized by awards, fellowship, and other external recognition from their peers. The Library is currently deploying SciVal to not only help our researchers better connect with their communities, but also expand the types and rigor of the metrics we generate.

The success of the Lab's S&T enterprise also depends on a vibrant, inclusive, and engaged workforce; state-of-the-art facilities; and meeting deliverables on time and within the budgets provided by sponsors. In the future, we will incorporate key performance indicators (KPIs) generated across the Laboratory and accessible via LabWatch, a new data and tracking dashboard under development that will begin beta testing in early 2023.

We will continue to incorporate the feedback and recommendations we gain from formal review processes like the Board Of Governors (BOG) meeting, Directorate Reviews or External Review Committees (ERCs). Portfolio review allows us to synthesize this information and arm each program, Core Competence, Mission Focus Area, or Institutional Initiative with the processes to manage and shape their S&T while making sure efforts are aligned with our enduring missions.

This maintains a distinction between what we stand for, which should never change...

...and how we do things, which should never stop changing.

Section 6: Science and Technology Strategic Objectives

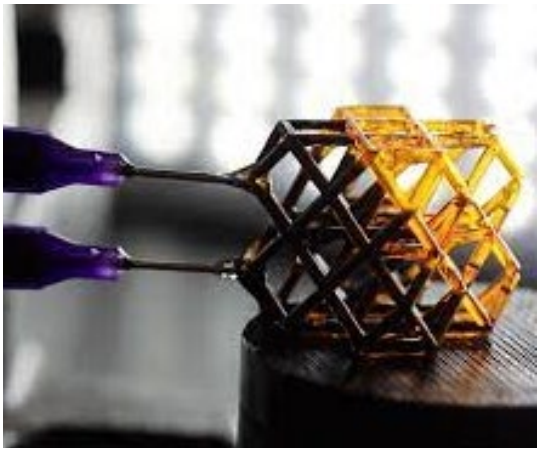
We are striving to make the nuclear security enterprise agile, resilient, sustainable, and responsive to emerging national needs.

As we look to the future, we continue to take on initiatives that focus on attracting, developing, and retaining talented new technical staff that enable the Laboratory to pursue its goal of "Science and Technology on a Mission." This section of the *Investment Strategy for Science and Technology* outlines how our strategic planning centers on interrelated urgent national priorities (Mission Focus Areas) and foundational S&T capabilities (S&T Mobilizers). Section 6.1 outlines areas of emerging science known as Institutional Initiatives, while 6.2 further illustrates how our S&T is applied to Mission Focus Areas. Sections 6.3 and 6.4 outline how our S&T Mobilizers and internal investments fulfill the Laboratory's mission-driven work in multiple ways.

Each element provides contrasting perspectives on investments—ensuring that the Laboratory is ready to support new mission requirements and sustain a vibrant S&T knowledge base to meet long-term mission needs and as-yet-unknown challenges. The Laboratory's many successes are the result of our dedicated staff's efforts to strengthen national security and global stability through world-class S&T.

Several examples of successful mission-driven work can be seen within the Laboratory's LDRD program:

The growth of LLNL's additive manufacturing (AM) team exemplifies how strategic internal investments can drive new areas of innovation. Launched as an LDRD project in 2008, AM was originally proposed as a potential replacement for conventional manufacturing of parts and components, with reductions in production facility footprint, costs, and/or part production time. Today, we see vastly increased use of AM for materials, parts and components within Mission Areas of the Laboratory; a growing list of publications and patents of new manufacturing technologies and new applications for AM techniques; strong staff growth and retention as a result of AM; and the 2019 opening of the Advanced Manufacturing Laboratory as a center of excellence enabling partnerships with industry and academia.



The ability to advance petawatt (PW) lasers from a few shots per day to high repetition rates and high average power is essential to practical applications in DOE and NNSA, including the production and use of secondary sources of x-rays and ions for R&D, next-generation particle accelerator technology, and medicine. A 2014 LDRD project developed a new diffraction grating and a new pulse compressor design to enable over a thousand-fold increase in average power for PW laser systems. With greatly reduced beam absorption, the grating can handle much higher laser power without the heat-induced mechanical distortion that would ruin the output laser beam. By enabling high-energy PW drivers that can create unique states of HED material and/or probe them with penetrating ion and photon diagnostics, this LDRD project has further advanced LLNL's world-class leadership in HED science.

Section 6.1: Emerging Science: Institutional Initiatives

Institutional Initiatives

Responding to shifting S&T landscapes

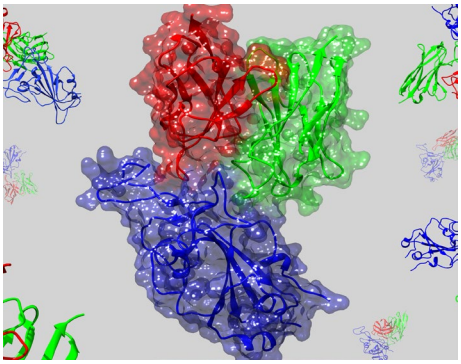
Mission relevance: Institutional Initiatives reflect the Laboratory's "team science" approach and support our single institutional mission by anticipating issues of national importance.

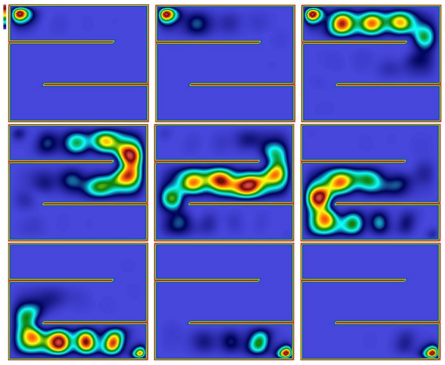
Institutional Initiatives were previously known as Director's Initiatives. The name change reflects the importance the Institution places on these incubators, another strategic application of our S&T Mobilizers. Institutional Initiatives are driven by visionary champions who have deep scientific expertise in a field relevant to the Lab's mission. Embracing the Lab's "team science" approach, Institutional Initiatives leverage internal resources, and have significant variation in their ideal outcomes—initiatives may build a program, develop a Core Competence, or help organize a national effort, among other examples. The defining feature of these initiatives is their flexibility—they emerge and evolve according to shifting S&T landscapes. The initiatives receive institutional investments in research, workforce development, and infrastructure.

This year, DDST performed a comprehensive review of the existing Institutional Initiative portfolio, assessing the objectives, key outcomes and how each is aligned with the Mission Focus Areas. Two initiatives have led to the establishment of enduring new elements at LLNL and have been sunset. The **Accelerated Materials and Manufacturing** Initiative has been essential for the establishment of the Accelerated Materials and Manufacturing Core Competence. Ongoing activities and lines of effort have already been subsumed into that Core Competence. **The Space Science and Security** Initiative has led to the establishment of a thriving Space Science and Security Program (SSSP) situated in Global Security and paved the way for the creation of the Space Science Institute.

Two Institutional Initiatives are well aligned with a Mission Focus Areas and will be transitioned into those efforts. The **Predictive Biology** Initiative has become a foundational part of the of the Bio Resilience MFA, and the work from the **Engineering the Carbon Economy** Initiative will become an important element of the Climate MFA.

The pioneering efforts of the **Cognitive Simulation** Initiative will continue. This year, we launched the **Computational Forecasting with Integrable Systems** Initiative to develop a class of dynamical systems with remarkable properties for modeling and prediction. This work builds on a key LLNL discovery—optimal control solutions are described by integrable systems. We also launched a new **Inertial Fusion Energy** (IFE) Initiative central to DOE's support of the reinvigorated national IFE program and the Laboratory's decadal vision for accelerating fusion energy as we look to fully leverage the new scientific frontiers enabled by ignition.





Section 6.1: Emerging Science: Institutional Initiatives

Cognitive Simulation

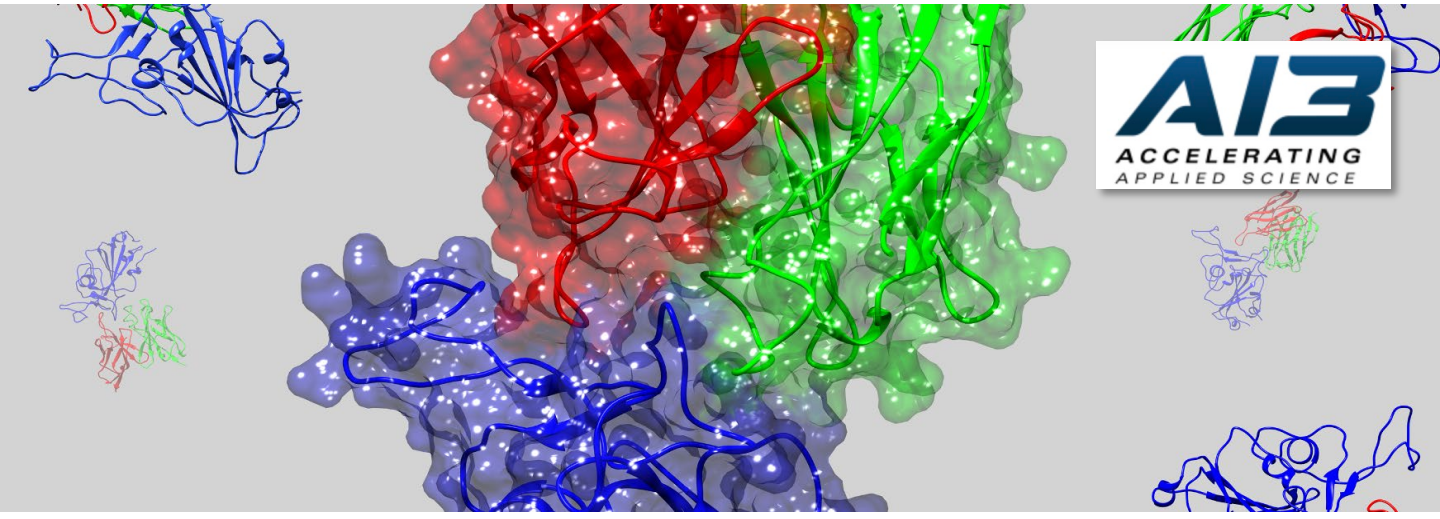
Accelerating applied science

Description:

The Cognitive Simulation Institutional Initiative steers the Laboratory's development of artificial intelligence (AI) tools to accelerate scientific discovery and mission impact across LLNL. Cognitive Simulation (CogSim) is a family of new techniques that bring together science-based simulation with data-driven AI to produce predictive models that are more accurate and efficient than the individual approaches. The Initiative works to identify critical program elements that can be transformed by these integrated methods. At the same time, it guides Lab S&T to develop state-of-the-art scientific tools that meet those mission needs. The Initiative also reaches outside the Lab, using its AI Innovation Incubator (AI3). AI3 works in partnership with private technology companies to develop CogSim solutions that emerge from cutting-edge partner technologies applied to demanding Laboratory science problems. These capabilities are specialized to advance our Laboratories most essential programs, but they also "spin out" through our private partners to provide benefit for the broader US economy. The expertise and thought leadership developed by CogSim initiative work informs the Lab's internal AI, simulation, and high-performance computing directions but also make Livermore a resource for AI and computing strategy, development, and policy with partners across the whole of government.

3–5-Year Vision:

The Cognitive Simulation Institutional Initiative will demonstrate transformational impact of bringing together AI and science-based simulation for key missions across the Laboratory. The CogSim Initiative team will work to accelerate stockpile modernization processes using the Discover, Design, Manufacture, Deploy (DDMD) framework. Solutions developed under DDMD will shorten the time to material discovery, accelerate design for performance and production, strengthen advanced manufacturing processes, and enhance the data-driven understanding of system aging. The Initiative will grow and steer the use of AI methods across the NNSA and the Tri-Lab while also multiplying the internal LLNL workforce and investment in AI. The Initiative will work with industrial partners to spin DDMD solutions into the broader economy. It will also use tools developed under DDMD advance Climate and IDTC efforts, with special emphasis on the Bio Resilience MFA where DDMD tools will be particularly suited to molecular discovery and manufacturing for response to biological threats.



Section 6.1: Emerging Science: Institutional Initiatives

Computational Forecasting with Integrable Systems

Building the applied science of complete integrability

Description:

Integrable dynamical systems provide the mechanism to propagate computer models built on limited information into the future, which is the core aspect of computational forecasting. Scientific advances in the 1960s began a series of breakthroughs that are continuing today in understanding completely integrable systems. By opening the door to easy solution of a wide class of nonlinear problems, the discoveries in integrable systems have led to a revolution in nonlinear applied science.

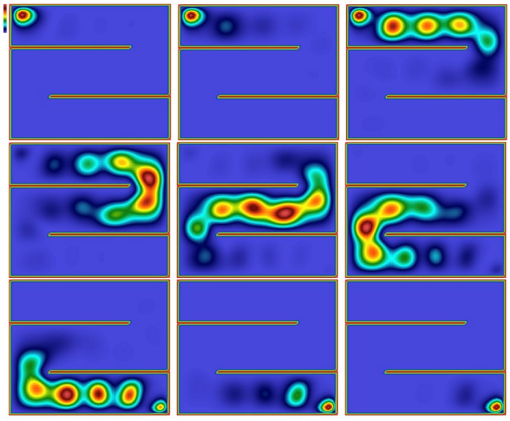
An open research frontier that LLNL is pursuing is in numerical solution of integrable systems applied to mission-driven models. With advances in numerical speed and accuracy, new problem domains might be solved including in combinatorial optimization, complex systems, and a variety of physical phenomena. Ultimately, novel and more performant computing architectures will likely be driven by research in integrable system computations.

Computational forecasting capabilities can also help meet the pressing national need for decision support tools to create advantage in both speed and surprise in international competition and warfighting. Coupling real-time data with simulation will enable playing out future scenarios and optimizing over action choices to achieve a desired long-term objective, all in near real-time. The newest Institutional Initiative, nicknamed “Guardrails” to evoke the way in which computer models will guard human decision making against catastrophic failures, has three main pillars:

Science: Computational Forecasting
Developing computational architectures and algorithms to address combinatorial complexity in model selection and prediction problems.

Mission: Decision Advantage
Managing the complexity of integration of domains and levels of conflict to better compete, deter, and win in national security spheres.

Capability: Best Solutions for LLNL Mission Focus Areas
Applying advances in forecasting and model selection to analytic wargaming, climate prediction, vaccine design, manufacturing enterprise optimization, and new design spaces.



The probability density of an optimally controlled agent navigating a simple maze can be predicted by solving an integrable system. Source: https://arxiv.org/abs/2212.00249

3–5-Year Vision:

The “Guardrails” initiative will provide dynamic insights for military commanders and civilian leaders to ensure success in competition, deterrence, and defeat. The initiative will support operationalizing real-time decision advantage capabilities for the Department of Defense and broader U.S. government while significantly advancing the scientific capabilities for solving combinatorial modeling problems at scale. On the three-year timeline, the Initiative will support demonstration of computational forecasting capabilities at scale on LLNL HPC, thus establishing a key part of the LLNL value proposition, and expansion of the scope of modeling into social science domains, which are now widely acknowledged as critical for managing future threats. Integrating the developing tools with humans, particularly in the military, will help to build trust in the system. Within five years, the Initiative will enable delivery of decision support products to users at military commands and across the U.S. government and will foster transfer of capabilities to LLNL’s broad mission.

Section 6.1: Emerging Science: Institutional Initiatives

Inertial Fusion Energy

Igniting a clean energy future with inertial fusion

Description:

Fusion, the process that powers the Sun, has the potential to provide a reliable, limitless, safe, and clean energy source. On Dec. 5, 2022, a team at LLNL's National Ignition Facility (NIF) conducted the first controlled fusion experiment in history to reach *ignition*, also known as scientific energy breakeven, meaning it produced more energy from fusion than the laser energy used to drive it. The experiment delivered 2.05 megajoules (MJ) of energy to the target, resulting in 3.15 MJ of fusion energy output, demonstrating for the first time the most fundamental science basis for inertial fusion energy (IFE). This milestone validates a critical first step of laboratory-scale laser driven IFE as a pathway to a fusion energy future.

By leveraging the decades of investment by NNSA in Inertial Confinement Fusion (ICF) and exploiting emerging technologies, this Initiative seeks to provide inclusive IFE leadership on the national and international stage, develop LLNL technical IFE efforts in areas highly synergistic with the Stockpile Stewardship mission, and work with the community to support the emerging public and private IFE landscape. IFE is a potential game-changing technology whose pursuit will bolster American competitiveness and energy and climate security.

3–5-Year Vision:

In partnership with the S&T leads across the Laboratory, the IFE Initiative will oversee and coordinate a foundational S&T portfolio at LLNL centered on focused areas important to both Stockpile Stewardship and IFE, resourced through LDRDs, public-private-partnership (PPP) funding, and DOE support, in order to help develop the foundational technologies the community needs for IFE while providing important capability for Stewardship. This includes efforts in areas such as high-gain target designs; higher throughput, more efficient target fabrication; advanced laser architectures; high-repetition-rate HED science; machine learning; and systems integration. In addition, the IFE Initiative will provide community leadership through continued development of national hub and center concepts for foundational S&T, including the IFE Virtual Collaboratory, an organization consisting of DOE national laboratories and funded institutions focused on facilitating PPPs and collaborations.

Section 6.2: Emerging Science: Mission Focus Areas

Stockpile and Enterprise Transformation

Producing crucial components faster

Description:

From a perspective of S&T, we envision national security as an aspect of mission fulfillment. The Laboratory's **Stockpile and Enterprise Transformation** Mission Focus Area seeks to advance the sophisticated enterprise of laboratories, facilities, and people ensuring confidence in the nation's nuclear deterrent. By improving key technologies, resources, and skills across the National Nuclear Security Administration (NNSA) complex, researchers are developing a better approach to stockpile sustainment, including laying the foundations for a more responsive and resilient enterprise.

Mission Relevance:

This MFA is directly aligned with the Laboratory's national security mission in that modernization of the stockpile production complex and advancement of S&T approaches and capabilities fundamental to qualifying and certifying the future deterrent will result in advanced experimental, design, and computational capabilities that will add significant resilience and responsiveness to our national security missions and enable "FPU in 5."

Scientific Underpinnings:

- A composition-aware HE detonation model has been able to explain the variability in a number of LX-17 and PBX-9502 experiments.
- In collaboration with the Kansas City National Security Campus, Livermore has opened the Polymer Production Enclave to deliver key components for nuclear warhead modernization programs.

3–5-Year Vision:

LLNL's goal of stewardship transformation aims to realize a more responsive and resilient enterprise through investments in processes and manufacturing, design, experimental and computational tools to accelerate the product realization process, from design, manufacturing, qualification, and certification. In every aspect of stockpile and enterprise transformation, an appropriate level of readiness and balance must be maintained throughout the production and design processes. Additional science expertise and solutions needed to achieve this goal include synthesis to manufacturing approaches that dramatically speed up production, computational (including AI, ML, and data sciences) and experimental tools that accelerate design to certification, improved predictive capabilities to deepen our understanding of the varied environments our systems will need to survive, and a technology maturation portfolio that demonstrates new capabilities in a system context.

Section 6.2: Emerging Science: Mission Focus Areas

Bio Resilience

Countering natural and man-made biological threats

Description:

The Bio Resilience Mission Focus Area (MFA) is a future-looking initiative to counter over-the-horizon biological threats by leveraging LLNL's unique competencies in high-performance computing, advanced bioscience and technology and bioengineering. Objectives include providing early biological threat detection and assessment; drastically accelerating design, development and testing of medical countermeasures; and developing integrated computational-experimental platforms for complex biosystem analysis and design.

Mission Relevance:

This MFA helps protect the nation by countering current and future biological and environmental threats. Biological expertise relevant to LLNL's national security mission includes genomic and molecular dynamics modeling, mechanisms of viral and bacterial threat agents, cognitive simulation models for biological system behaviors, and accelerated molecular design.

Scientific Underpinnings

- Accelerated design of antibodies and small molecules for infectious disease therapeutics on timescales of weeks to months rather than many years.
- Demonstration of synthetic biology-based design of microbial systems for efficient and clean extraction of critical rare earth elements from waste streams.
- Innovative "human on a chip" models the biology of the heart, nervous system, and blood–brain barrier on an engineering platform, potentially reducing the need for testing of drugs and chemicals on animals and humans.

3–5-Year Vision:

Researchers contributing to the Bio Resilience MFA aim to broaden global surveillance, detection, and response to infectious agents, pathogens, and other hazardous toxins. New solutions to counter emerging threats will be developed by integrating experimental and computational tools to understand, design, and optimize complex cellular systems and mechanisms for a variety of biodefense and bioeconomy applications. A growing area for new R&D will focus on development of integrated systems that use computing to steer automated experiments and the resulting data to drive the next generation of models. These active learning systems will enable a broad range of new understanding and capability to enhance our national security.

Section 6.2: Emerging Science: Mission Focus Areas

Climate Impacts and Resilience

Providing scientific tools to for mitigating, predicting, and adapting to climate change

Description:

The Mission Focus Area in **Climate Impacts and Resilience** couples capabilities in material science, carbon cycle and subsurface research and climate simulation to both mitigate the accumulation of greenhouse gases in the atmosphere and to predict the climate impacts at spatial scale required by decision makers. These results can be used to assess climate impacts on national security in a broad range of sectors including critical infrastructure and operations.

Mission Relevance:

Our changing climate poses an immense risk to national security, the economy, and public health. Livermore has been studying the climate and Earth system since the beginning of computer simulation. Over the past decades, codes originally developed to understand the complex dynamics of nuclear detonations and fallout patterns have evolved into Earth System models that couple the dynamics of atmosphere, ocean, land and sea-ice processes and provide predictive models of climate change.

Scientific Underpinnings

- This first-of-its-kind *Getting to Neutral: Options for Negative Carbon Emissions in California* report has served as an important resource guide for industry, academia, and policymakers.
- Livermore leads the Energy Exascale Earth System Model (E3SM) program, a single system that assesses how energy use impacts Earth's ecosystems, water availability, snowpack, sea levels, and other factors.

3–5-Year Vision:

This MFA will examine how changes to Earth's weather systems may pose security threats to the U.S. and its economy by developing and applying improved climate models. Researchers will advance the use of downscaling and bias corrections in the models necessary to address regional and local climate impacts. The updated models will be used to assess the resilience of the electrical power grid and national security infrastructure and operations, as well as to model predict localized threats such as flooding, drought, and extreme weather events.

Section 6.2: Emerging Science: Mission Focus Areas

Integrated Deterrence and Technology Competition

Focusing on transregional defense strategies

Description:

The Integrated Deterrence and Technology Competition (IDTC) Mission Focus Area (MFA) addresses the national need to deter aggression against the U.S., allies, and partners, while enabling the ability to fight and win should deterrence fail. Integrated deterrence (ID) requires working across domains, the spectrum of conflict, and all instruments of U.S. national power, to reduce competitors' perceptions of the net benefit of aggression relative to restraint. Technology competition is key to securing strategic advantage that enables ID. Our goal is to develop capabilities and partnerships to provide meaningful integrated options that advance deterrence.

Mission Relevance:

The 2022 National Security Strategy prioritizes ID, deeply aligning this MFA with LLNL's national security and global stability mission. Great power competition now involves basic research in fundamental science and emerging fields like quantum computing, artificial intelligence and machine learning and next-generation micro-electronics. New analysis methods, advanced statistical technologies and at-scale modeling of complex dynamical systems allows researchers to understand which type of new technologies will impact decision calculus.

Scientific Underpinnings

- Two intelligence informed technical exercises demonstrating LLNL's ability to integrate cross-domain analysis and technology solutions, leveraging expertise from across LLNL, have led to new programmatic efforts and multiple sponsor engagements.
- Newly funded LDRD programs will understand how enhance existing modeling and simulation tools and develop new algorithms for space domain awareness.

3–5-Year Vision:

The IDTC MFA aims to leverage LLNL's Core Competencies, all source intelligence abilities, existing security programs and lead-edge research to address ID. Efforts including parallelizing the JCATS/JLOD simulation capability, integrating artificial intelligence/machine learning, and federating with established community codes, as well as developing strategic game theoretic and wargaming capabilities with quantitative ID metrics. Our continued development of capabilities in demonstrated areas of expertise, including directed energy, advanced fires, spectrum dominance and cyber and space capabilities, as well as growing research in quantum information science and machine learning techniques, will become the basis of new U.S. capabilities and help policy makers understand their impact.

Section 6.3: Future State of S&T Mobilizers

The future of innovative S&T at LLNL depends on the S&T Mobilizers: our people, infrastructure, and Core Competencies. Our workforce is at the heart of everything we do, from training postdocs to be principal investigators through our LDRD program, to developing thought leaders by having them run a Center or Institute and form academic partnerships. Through thriving Core Competencies, we let technologists conduct impactful R&D that leads to them becoming world experts. The Laboratory will continue to invest in these S&T-focused elements that enable our workforce to be productive, innovative, and successful.

People

Across the Lab, effective team science is enabled through a healthy research culture of respect, openness, interdisciplinary teaming, workforce diversity, and collaborative approaches. Each year, we participate in hundreds of recruiting and conference events as we continue to develop talent pipelines for succession planning to meet the Laboratory's future needs. Our Faculty Mini-Sabbatical Program brings top academic talent from colleges and universities across the U.S. to exchange knowledge and build partner-ships. Faculty experience Laboratory resources and capabilities, exchange knowledge and advance their skills. Whether it's sparking scientific interest in K-12 students or recruiting the next generation of nuclear physicists, developing our workforce pipeline continues to be a strategic priority.

Facilities, Centers, and Institutes (3–5-Year Vision)

In the upcoming year, we will begin a systematic review of internally-funded Centers and Institutes to ensure they are well-aligned with current Laboratory priorities, integrated with and support the MFAs and OKRs, and are resourced appropriately. This portfolio review will determine if any of the existing Centers and Institutes should be phased out, which will create the opportunity to start new ones. LLNL will continue to provide essential support to facilities and capabilities to enable impactful basic and applied research and development and to support mission- and sponsor-driven work. Portfolio review for these activities will include exploring new funding models to ensure long-term viability.

Core Competencies (3–5-Year Vision)

Advanced Materials and Manufacturing: LLNL materials scientists, chemists, physicists, and engineers look forward to advancing and rapidly delivering novel AMM solutions for new environments, including applications in biosecurity, water security, space science and security, decarbonization, and materials for environmental remediation.

Biosciences and Bioengineering: The team seeks to address pressing issues in disease detection, prevention and treatment, ecosystem sustainability, biomanufacturing and other critical mission challenges. This is enabled by advancing predictive understanding of complex biological systems and developing cutting-edge tools and technologies.

Earth and Atmospheric Science: Looking ahead, LLNL will drive collaborative, inter-agency efforts and recommend solutions for atmospheric releases and carbon management as well as assess/predict climate impacts. We will invest in efforts aimed at increasing access to modeling codes and data to expand broader use of these resources.

High Energy Density Science: Scientists and engineers are pushing on all fronts to increase NIF's capabilities to address challenges, including higher energy and power limits, next-generation optics, improved targets with tighter specifications, and diagnostics for high yield. Additionally, the team will develop and deploy new NIF experimental platforms to enable multi-MJ yield science and applications.

HPC, Simulation, and Data Science: As LLNL embraces exascale and beyond computing capability, we continue to build expertise in computing hardware, software, application codes, and the physical sciences to simulate phenomena with higher fidelity and more realism.

Lasers and Optical S&T: Principal focus of future research remains high-energy and high-average-power laser technology.

Nuclear, Chemical, and Isotopic S&T: Programs in nuclear science and technology will advance neutrino science, the search for dark matter, cosmochemistry, and properties of the heaviest elements.

Section 6.4: Future State of Strategic Investments

We are grateful for the ability to make strategic investments that sustain Lawrence Livermore National Laboratory as a national resource for innovative solutions to complex, important national security challenges. We are determined to use these investments to keep the Laboratory an exciting and meaningful place to work for our world-class scientists and engineers. During the next year, we will continue to collaborate with all internal stakeholders to refine the S&T Roadmap and ensure it supports the Lab's overarching strategic plans.

Future State of Funding

NNSA/Defense Programs will continue to provide significant funding and support for the people, facilities and Core Capabilities that are the foundation for our science and technology enterprise. Sponsored science from the DOE Office of Science and other government agencies like NASA and NIH will enhance our S&T mobilizers and help attract and retain the next generation of science leaders. There will continue to be strong demand for internal resources, and thoughtful prioritization will be critical as we consider recapitalization of important facilities, enhancing experimental facilities and supporting our talented staff.

Future State of Review and Metrics

Assessing the effectiveness and impact of internal investments. the quality of the research we conduct, and the engagement, expertise and contributions of our staff is essential for the Lab's continued success. Over the next years, we anticipate adding to our existing suite of metrics and performing more benchmarking from a pool of similar organizations including as many DOE Labs as possible, DOD FFRDCs and other government-funded R&D organizations.

External reviews performed by trusted and independent experts provide valuable insight into the health and direction of our foundational science and technology enterprise, how well it aligns to near- and long-term mission drivers and vibrancy of our workforce. We will examine how best to use the well-established review processes, including Directorate Reviews, External Review Committees and the Science and Technology Committee of the LLNS Board of Governors. Reviews work best when they are held at the right frequency and produce a mix of actionable recommendations and observations about how LLNL fits into the broader national security and basic science landscapes. In the future, we will adjust the cadence of the reviews and the types of charges given to the committees to best match what the nation asks us to do. In 2023, we will establish External Advisory Boards for each of the MFAs.

S&T is embedded in *everything* we do.

Section 6.4: Future State of Strategic Investments

Future State of Partnerships

Academic Engagement Office

The Laboratory's Academic Engagement Office has a long history of fostering collaborations and partnerships between Laboratory researchers and the academic community. The team provides students and faculty at K-12 schools, community colleges, vocational schools, universities and post-doctoral programs with collaborative LLNL research assignments, work study opportunities, and educational activities that support the Lab's mission. By continuing to connect with students at all stages of learning, the team develops the Lab's future workforce while enhancing our community's awareness and understanding of science.

Open Innovation

A more mobile, open Laboratory helps us respond rapidly to the security challenges of a deeply inter-connected world. The Laboratory practices Open Innovation by connecting with industry, government agencies, universities, and non-governmental organizations to cultivate entrepreneurship, help the nation grow, and meet national and global security challenges.

Livermore Valley Open Campus

The Livermore Valley Open Campus (LVOC) makes it easier for renowned laboratories to help solve the world's pressing problems. Engineered to foster collaboration among LLNL, Sandia National Laboratories, private industry, and academic institutions, LVOC's 110-acre campus houses crucial infrastructure in the form of hybrid meeting spaces, laboratory facilities, and drop-in workspaces to promote innovation during the evolving COVID-19 pandemic through discovery, knowledge sharing, and technology maturation.

Driven by premier science and technology,
LLNL's internal investments support a talented workforce,
world-class competencies, state-of-the-art facilities,
and our mission-driven work.

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