

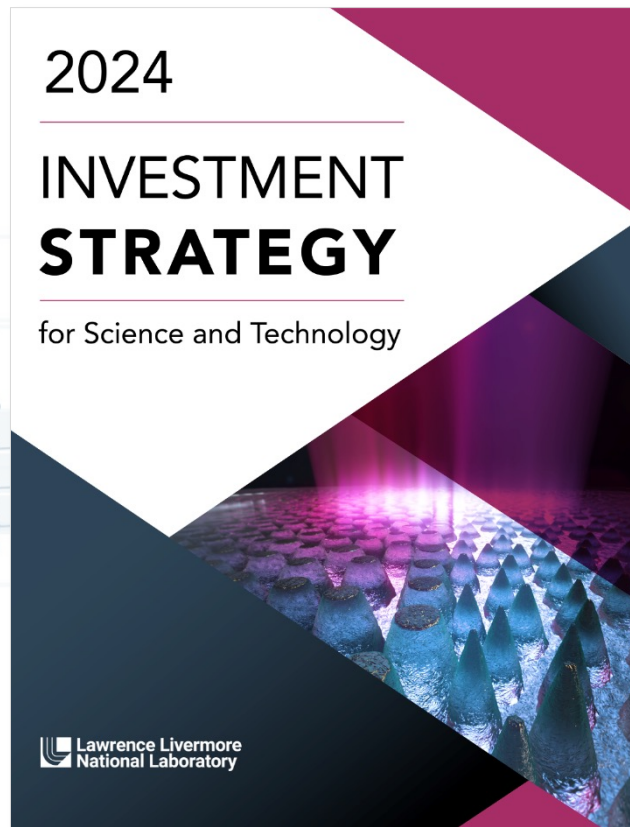
2024

INVESTMENT STRATEGY

for Science and Technology

Table of Contents

Introduction:	2
Science and Technology on a Mission: Note from Pat Falcone	3
Section 1 : LLNL Overview	4
1.1 Mission and Vision Statements	4
Section 2 : LLNL's Mission	5
2.1 Mission Areas	6
2.2 Mission Focus Areas	7
2.3 Mission Structure	8
2.4 Lab-Wide Objectives and Key Results	9
Section 3 : Science and Technology Enterprise at LLNL	10
3.1 Science and Technology Framework	11
3.2 Office of the Deputy Director for Science and Technology	12
3.3 S&T Mobilizers	14
3.4 S&T Mobilizers—People	15
3.5 S&T Mobilizers—Core Competencies	16
3.6 S&T Mobilizers—Facilities, Centers, and Institutes	31
Section 4 : Support of Science and Technology	32
4.1 Sponsored Science	33
4.2 NNSA Defense Program Science	34
4.3 NNSA Defense Nuclear Nonproliferation	34
4.4 Internal Investments	35
Section 5 : Review and Metrics	36
Section 6 : Emerging Opportunities	37
6.1 Institutional Initiatives	37
6.2 Mission Focus Areas	41
6.3 Future State of S&T Mobilizers	45
6.4 LDRD Highlights	46
6.5 Future State of Strategic Investments	47



Lawrence Livermore National Laboratory (LLNL) is chartered to develop, support, and employ world-leading scientific capabilities to enable national security mission responsibilities. These foundational capabilities include talented and multidisciplinary staff, premier facilities and equipment, and core scientific competencies to 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 ensuring 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 (DDST). 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 also serves as a resource for principal investigators as they consider and propose research projects aligned with internal investment priorities.

Science and Technology on a Mission



PATRICIA FALCONE
LLNL Deputy Director for
Science and Technology

Lawrence Livermore National Laboratory 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. Today we continue this tradition and live by our motto, “Science and Technology on a Mission,” 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 inside the Lab and with colleagues at other laboratories, universities, industrial firms, nonprofits, and government organizations. These factors have been essential to the many achievements and continue to be indispensable for the Laboratory’s vital mission responsibilities and the advancement of science and technology (S&T).

The 2024 *Investment Strategy for Science and Technology* is organized as was the 2023 version. This document includes Laboratory mission and vision descriptions, Mission Focus Areas (MFAs), and updated Lab-level 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 FY25.

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 describes 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 scientific portfolio and the evolving contributions of our S&T Mobilizers.

I hope you find this document informative and enlightening as it has been prepared to support transparency on how strategic science and technology investment decisions are made. We are grateful for the ability to make strategic investments that sustain LLNL 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.

A handwritten signature in black ink that reads "Pat Falcone". The signature is written in a cursive, flowing style.

Section 1: LLNL Overview

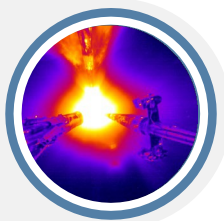
One Mission, Many Domains. Lawrence Livermore National Laboratory serves a wide variety of national security mission areas through the application of science and technology, and our enduring domain of nuclear deterrence. Established in 1952 at the height of the Cold War to advance nuclear science and 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.



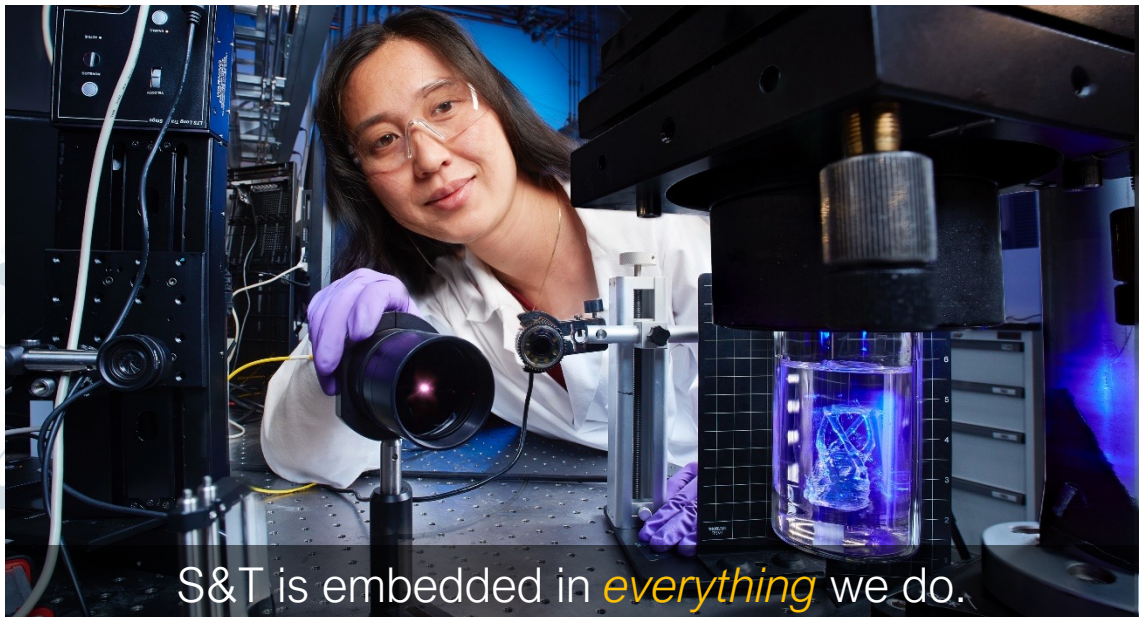
Who We Are: Our inclusive teams bring together exceptional scientific, technical, administrative, business, and operational experts to accomplish our important missions.

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. 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 advances, we apply cutting-edge science and technology to achieve breakthroughs in a variety of research areas.



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 working 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.

By splitting our broad and evolving mission into four areas relevant to the current and future stability of our world, we're better able to address issues of 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 foundational research through applied research to preliminary deployment of prototypes; each has a history of major mission and science contributions, and each enriches and draws from the Laboratory's Core Competencies.

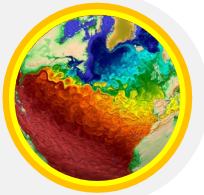
In all four Mission Areas, we count on our talented workforce to think bigger—to have bold ideas and fearlessly work at the edge of what is possible. Through their exceptional work in preeminent areas of science, LLNL's impact does not stop at our country's borders—our innovations make the world a better 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 National Nuclear Security Administration (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 to 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 technology competition.

Section 2.2: Mission Focus Areas

Mission Focus Areas

Focused cross-Laboratory efforts addressing targeted challenges

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. This 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 analyses. The four Mission Focus Areas receive special management attention, but they represent just a part of the 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 and targeted solutions for national security and global stability.

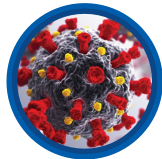
Stockpile and Enterprise Transformation accelerates the advancement of the sophisticated enterprise of laboratories, facilities, and people ensuring confidence in the nation's nuclear deterrent. **Bio Resilience** integrates LLNL's unique computing and experimental capabilities to identify, characterize, and counter natural and man-made biological threats at dramatically reduced timescales. **Climate Resilience** couples biogeochemistry, materials science, geology and climate simulation with infrastructure analysis to mitigate and adapt to greenhouse gas accumulation and predict climate impacts at scale. **Integrated Deterrence and Technology Competition** uses integrated science and technology to win the strategic competition, focusing on regional deterrence scenarios.

Stockpile and Enterprise Transformation



- Accelerate a resilient and responsive enterprise
- Enhance partnerships
- Produce next-gen ST&E for the current and future stockpile
- Leverage world-class workforce

Bio Resilience



- Analyze, assess, and predict threats
- Develop countermeasures and therapeutics
- Establish integrated computational-experimental platforms

Climate Resilience




- Reduce greenhouse gas accumulation via advanced technology
- Inform climate strategy through high-fidelity models
- Assess, adapt, 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: Mission Structure

The Laboratory counts more than 9,000 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 2.4: 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 us to fulfill mission deliverables. OKRs foster collaboration, connectivity, and help organizations reach aspirational goals. 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:** offers clear strategic direction
- **Objective:** defines what we seek to achieve
- **Key Result:** provides defined, measured progress



Mission and Program Delivery

North Star: Be a “game-changing” lab with timely delivery of innovation and transformational solutions to the biggest national security challenges.

Objective: (1) Work with partners to maintain first production unit dates for W80-4 (2027) and W87-1 (2030); (2) Mature and institutionalize the approach to MFAs.



Science and Technology

North Star: Engender innovation, technical excellence, and strategic impact through multidisciplinary foundational and applied Research and Development (R&D).

Objective: Enhance and communicate the S&T foundations of the Laboratory to drive mission opportunities.



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: Streamline operations, processes, and systems to accelerate work execution, prioritization, decision making and resource allocation.



Workforce

North Star: Transform the Lab's culture and reimagine workforce experiences to attract, and retain, world class talent to meet current needs and ensure future success.

Objective: Improve the employee experience to enhance engagement, productivity, and retention.

Section 3: Science and Technology Enterprise at LLNL

OKRs enable LLNL to more efficiently capture plans for continued growth. The guiding North Star for the Laboratory's science and technology OKR—**perform foundational and applied Research and Development (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 the following Objective:



Science and Technology

North Star: Engender innovation, technical excellence, and strategic impact through multidisciplinary foundational and applied Research and Development (R&D).

Objective: Enhance and communicate the S&T foundations of the Laboratory to drive mission opportunities.

This vital Objective comes with two Key Results:

- **Key Result 1:** Initiate an ongoing process for systematic review of our LLNL Centers and Institutes.
- **Key Result 2:** Define flagship LLNL S&T facilities and capabilities needed over the next two decades.

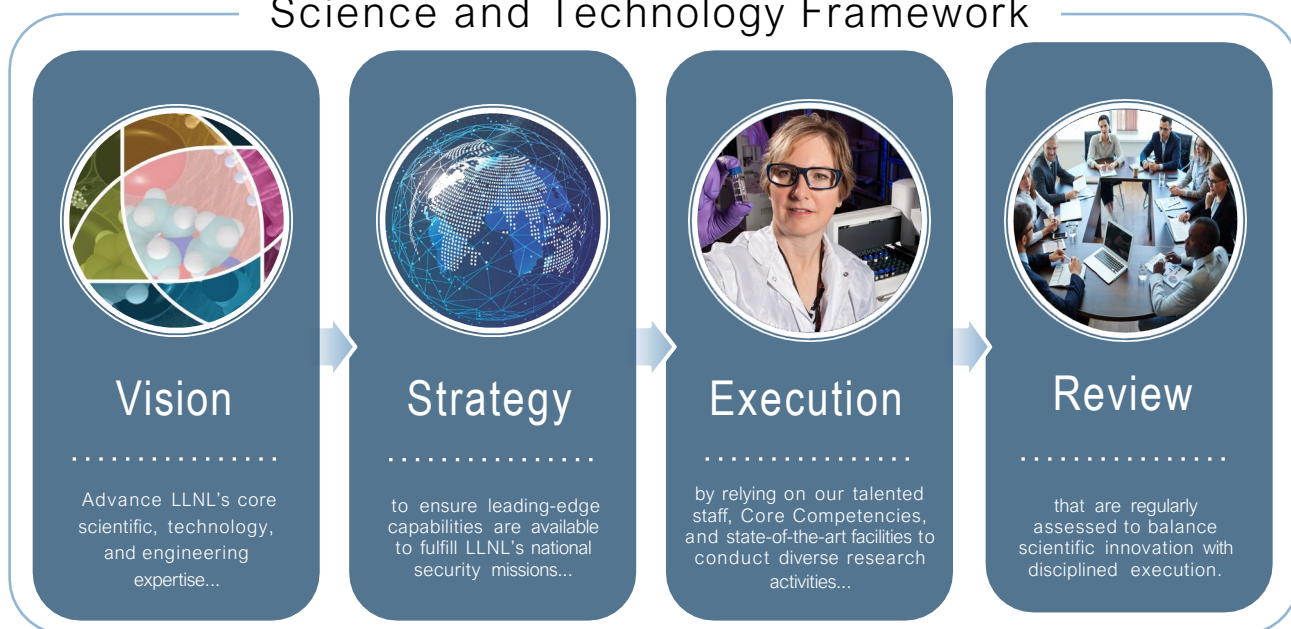
Fulfillment of Key Result 1: An ongoing review process has been implemented for our Centers and Institutes, emphasizing the identification of opportunities for sharing best practices and ensuring continuous improvement and accountability. These reviews assess performance, identify strengths and areas for enhancement, and align efforts with the Laboratory's strategic objectives. Ultimately, they empower us to maximize impact, secure resources, and maintain a reputation for excellence in research and innovation.

Fulfillment of Key Result 2: Multidisciplinary teams considered a combination of futuristic capabilities and facilities that could amplify LLNL's impact in addressing today's challenges. Locating LLNL's flagship facilities in the Livermore Valley Open Campus (LVOC) gives Laboratory researchers and external collaborators space to form dynamic partnerships and strengthen shared research. The Integrated Bio Resilience Laboratory will catalyze the formation of trans-disciplinary experimental work clusters focused on nationally important biological problems to advance innovation, convergent thinking, and continuous learning. The Prototyping Enclave will accelerate the development and application of climate solutions by leveraging the science and engineering capacities of the Laboratory in a facility where technology prototypes can be designed and tested. In addition, upgrades and new scientific facilities for the LLNL site are being explored in partnership with NNSA, including sustainment and revitalization of the National Ignition Facility.

Section 3.1: Science and Technology Framework

The Framework below is a broad look at the Lab's scientific strategic approach: 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 investment decisions.

Science and Technology Framework



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.

Section 3.2: 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) leads the process of investing in the Lab's science and technology enterprise. This approach ensures Livermore's world-renowned research excellence balances innovation with disciplined execution, and multidisciplinary teamwork with individual initiative. The combination of mission focus and scientific expertise 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)**
Serving as the primary resource to drive excellent science and technology for today's needs and tomorrow's challenges.
- **Institutional Science Capability Portfolio (ISCP)**
Supporting multi-programmatic and cross-directorate efforts including capability sustainment and sponsor engagement.
- **Licensing and Royalties (L&R)**
The Lab invests royalties generated from successful property in the next generation of S&T.
- **Development and Training Opportunities**
Assisting principal investigators to gain knowledge for planning and developing high quality, competitive proposals. Guiding staff on how best to engage with sponsors and partner with focus.

Partner: Growing relationships in service to scientific excellence and mission delivery

- **Academic Engagement Office (AEO)**
Fostering collaborations and sustainment of long-term academic partnerships among Laboratory researchers and the academic community. The program engages students and faculty in collaborative research, work study opportunities, and educational activities.
- **Innovation and Partnerships Office (IPO)**
Serving as an engine to create impact and drive engagement with industry and other entities enabling deployment. Innovation matters most when adopted at scale.
- **Science Education**
Providing professional development instruction to teachers, as well as student enrichment opportunities ranging from field trips to virtual tours to online videos and science experiments students can try at home.
- **Engagement with the Broader Science Policy Community**
Offering perspectives to policy makers and U.S. government officials while providing awareness and training to LLNL staff.
- **Commitment to International Partners**
Creating and nurturing purposeful strategic science and technology partnerships with allies to bolster deterrence and build resiliency through fundamental and applied research.



More information about many of these functions can be found in Section 3.4

Section 3.2: Office of the Deputy Director for Science and Technology (cont.)

Additional key functions of the DDST Office are to:

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

- **Investment Strategy for Science and Technology**
Outlining our strategic support of the quality, health, and sufficiency of the Laboratory's scientific and technical foundations in an annually updated document.
- [Performance Evaluation and Management Plan \(PEMP\)](#)
Featuring innovative science, technology, and engineering, transformative research and development, effective partnerships, and technology transfer in the Laboratory's annual evaluation report.
- [Science & Technology Review \(S&TR\)](#)
Highlighting LLNL's significant technical accomplishments, Science & Technology Review magazine provides in-depth scientific news to general audiences.

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

- [Awards and Recognitions](#)
Providing awareness and support to those looking to nominate individuals and teams for our prestigious internal and external awards, and professional societies.
- **Science and Technology Institutional Assessments**
Stewarding our External Review Committees and Board of Governors meetings to assess and provide feedback on the quality of our Core Competencies and strategic plans.
- [Postdoctoral Program Support](#)
Developing the ST&E workforce pipeline of the laboratory by furthering the career development of the postdoc through connections with the scientific community.
- **Postdoc and Mentor Career Development**
Equipping postdocs and their advisors and mentors with the essential skills and knowledge for impactful careers in science and technology.
- [Proposal Development Support](#)
Working with investigators to analyze calls for proposals, generate a compelling research plan that responds to all requirements and facilitates internal reviews that refine the project objectives.
- [Library Resources](#)
Enhancing discovery, delivery, and access to scientific content by effectively organizing, describing, and preserving our scientific and cultural heritage.
- **Archive**
Preserving LLNL's records of people, events, programs, and accomplishments for use by Laboratory staff and historians.

Section 3.3: S&T Mobilizers

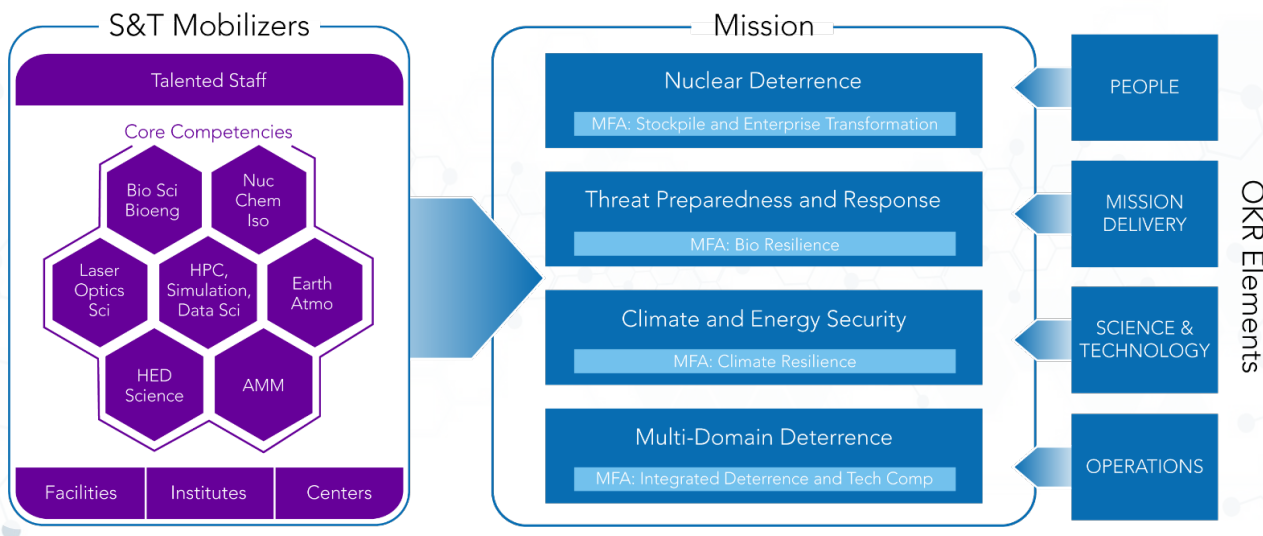
LLNL's Science and Technology enterprise has three constituent parts referred to as S&T Mobilizers: **talented staff**, **Core Competencies**, and **state-of-the-art facilities**. Each part of the enterprise is addressed in the Science and Technology Framework, and the importance of our S&T Mobilizers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

Our workforce is at the heart of everything we do, from leveraging the experience gained from serving as an LDRD principal investigator to leading a high-consequence program to developing thought leaders by having them run a Center or Institute and form academic partnerships through collaborations based around LLNL facilities. 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 in key areas that positions them among the world's experts in their chosen field.

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 science and engineering.

Discipline organizations at LLNL foster excellence and innovation in the key research disciplines needed for the Lab's Core Competencies. The Computing directorate advances scientific discovery through foundational and innovative research in mathematical methods; modeling and simulation; high performance computers; operational algorithms and workflows; mission-driven data science; and software solutions. The Engineering directorate invents, designs, simulates, prototypes, builds, and deploys creative technologies including new materials, components, and systems. The Physical and Life Sciences directorate delivers multidisciplinary scientific theoretical, experimental, and computational expertise to advance knowledge and to support mission-critical research with novel insights, data, and phenomenological understanding.

As illustrated below, the OKR process and S&T Mobilizers contribute to mission success to advance scientific discovery. Note that the Lab's institutional Mission comprises four Mission Areas (dark blue), with a Mission Focus Area (light blue) embedded within each.



Section 3.4: 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 mission-critical 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.

Research Integrity: The Academic Engagement Office's Research Integrity course was relaunched on January 17, 2023, as an in-person class and has since been offered numerous times. Over 250 Laboratory employees have taken the class thus far, and attendee feedback has been very positive. Research Integrity Officers from SNL and LANL attended the class remotely and are developing similar coursework based on LLNL's efforts.

Postdoctoral Program: LLNL employs more than 300 postdoctoral scholars, also called postdocs, as 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 professional development with resources, targeted training, and events such as the annual Research SLAM! competition.

Library: 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. Centrally located on LLNL's campus, the library offers collaborative working space in addition to physical and digital reference collections.

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 postdoctoral 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 potential industry partners. Through technology commercialization, encouraging entrepreneurship, and Laboratory business development activities, the IPO office advances the development and commercialization of scientific discoveries. With input from through the Lab, 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 workforce pipeline continues to be an important focus, from recruiting new talent and mentoring career development to recognition of career achievements.

Science & Technology Review: [S&TR](#) is published eight times a year to communicate our scientific 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 3.5: 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 seeks to contribute 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 laboratories, government organizations, industry, and academia.

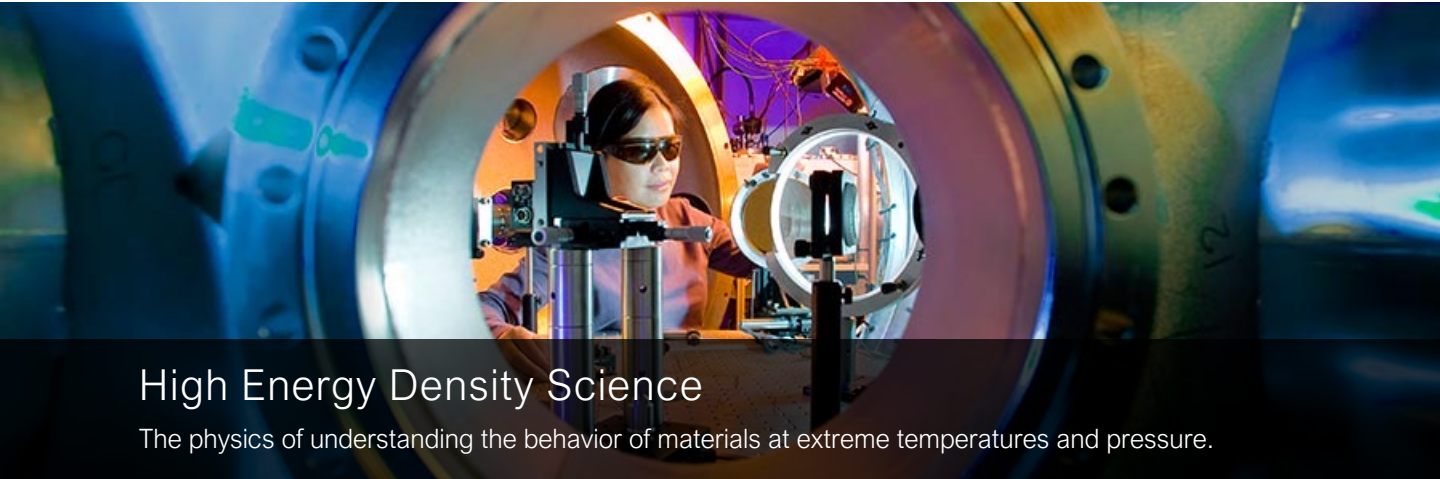
Mission Applications:

Core Competencies drive the scientific and technological research—from the experimental design process to application—underpinning our mission of national security and global stability. Internal investments and externally funded activities in these areas sustain Livermore as the nation's “Big Ideas” laboratory that provides innovative solutions to the most challenging national security problems and transformative scientific advances.



Each of the seven Core Competencies is described in the following pages.

Section 3.5: S&T Mobilizers—Core Competencies



High Energy Density Science

The physics of understanding the behavior of materials at extreme temperatures and pressure.

Description:

High Energy Density (HED) science explores matter under extreme conditions—achieving temperatures higher than 180 million degrees Fahrenheit, pressures of more than 1 billion Earth atmospheres across time scales spanning from equilibrium to nanoseconds. This research probes and discovers new scientific frontiers in the fundamental properties of matter, ranging from condensed phases to plasmas. This includes studying the pressure-volume-temperature relationship (commonly known as the equation of state [EOS]) and radiation transfer at unprecedented pressures and temperatures. LLNL researchers develop and use a variety of experimental platforms with exquisite diagnostics that are closely coordinated with advanced predictive theories, large-scale simulation and modelling conducted on world-leading high-performance computing systems. HED research yields essential data for understanding nuclear weapons' conditions, delivering extreme condition physical property data for weapon simulations, validating predictive theories used in weapon simulation codes, advancing inertial confinement fusion, and related areas of national security.

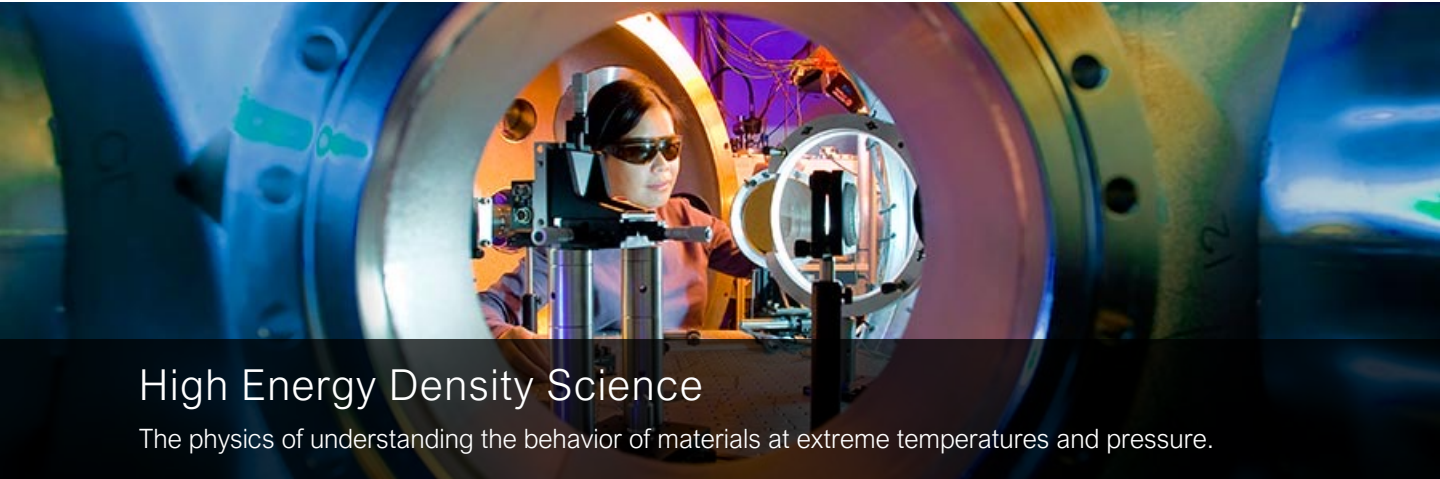
Mission Applications:

The Laboratory's innovative and collaborative staff advance mission-critical work in nuclear deterrence and energy security while strengthening inertial confinement fusion research. In support of the National Nuclear Security Administration stockpile stewardship mission, HED science research delivers critical experimental data and predictive models used to simulate and ensure the reliable operation of nuclear weapons as they age, are subjected to the extreme conditions of a thermonuclear explosion or are refurbished as part of life-time extension or modification programs. Advanced simulations of material dynamics and full systems on the Laboratory's world-leading high performance computers complement experiments to fully explore and deliver predictive models of the behavior of matter in these extreme conditions.

Accomplishments:

- For more than 60 years, LLNL researchers and colleagues worked to achieve fusion ignition, one of science's most challenging goals. An experiment on Dec. 5, 2022, has since been repeated at even higher levels, opening new vistas of HED science and enabling access to regimes even more relevant for future stockpile stewardship.
- Within HED science, LLNL has developed multiple diagnostics necessary for measuring material properties on short time scales and at high densities and temperatures. LLNL researchers developed high-speed cameras to create "movie frames" of experiments with time resolution better than 1/10th of a nano-second using x rays capable of probing ultra-dense materials.

Section 3.5: S&T Mobilizers—Core Competencies



High Energy Density Science

The physics of understanding the behavior of materials at extreme temperatures and pressure.

Accomplishments (cont.):

- LLNL scientists extended the range of static high pressure techniques, almost doubling the accessible pressure range to more than 6 million atmospheres
- Using HPC, LLNL scientists conducted large-scale simulations (10-100s million atoms) of metals under a variety of loading conditions to understand enhanced crystal plasticity models.

3–5-Year Vision:

Future improvements in experimental platforms, diagnostic measurement techniques, advanced theory and modelling will enable scientists to better understand, predict and control matter under increasingly extreme conditions—including stellar interiors, astrophysical events such as supernovae, conventional inertial confinement fusion (ICF) reactions, magnetic fusion reactions, conventional fission reactions, and nuclear device explosions. LLNL scientists are on a path to deliver enhancements to the range of experimental platforms and the accuracy of temperature diagnostics through techniques including pyrometry at the Nevada Test Site JASPER facility and EXAFS (Extended X-ray Absorption Fines Structure) at laser drive platforms. New capabilities over the next decade will include time-resolved “movies” capturing the structural and phase evolution of matter under dynamic loading conditions. In step with experimental advances, theory, simulations and modelling of HED experiments will also probe HED states of matter using HPC at unprecedented scales (>100 million atom) simulations to gain microscopic insights of the properties of matter at extreme conditions. Further models of radiation transport and opacity (absorption or radiation) will continue to be refined and more accurately predict energy deposition and flow under HED conditions. The repeated achievement of controlled fusion at NIF provides an intense source of neutrons, opening new fields of study on the effects of neutron energy deposition.

Section 3.5: S&T Mobilizers—Core Competencies



High Performance Computing, Simulation, and Data Science

Addressing national security challenges through innovative computational and predictive solutions.

Description:

High performance computing (HPC), simulation, and data science transforms theories that explain physical phenomena into models that can reliably predict outcomes. State-of-the-art simulations running efficiently on the world's most advanced computers are the integrating element of science-based stockpile stewardship and broadly underpin our ability to meet our national security needs across our missions and focus areas. For example, our scientists use HPC to simulate the behavior of matter under extreme conditions of temperature and pressure, which are characteristic of nuclear detonations, or other extreme conditions of radiation, corrosion chemistry, hypervelocities, and other realms that are challenging to study. The expanding scale and complexity of the Laboratory's mission require new data-driven and artificial intelligence/machine learning (AI/ML)–augmented approaches to scientific discovery and engineering design. These techniques applied to massive data sets can help Livermore researchers better understand and predict the behavior of complex systems and even design new materials and systems from the ground up. AI/ML also play vital roles in predicting results from both large and sparse data sets related to fundamental properties of materials and national security interests.

Mission Applications:

HPC at Livermore has a long history of success in close association with the Laboratory's nuclear deterrence mission. Computer scientists, data scientists, statisticians and mathematicians collaborate with domain scientists to develop and use simulation methodologies leveraging HPC to support nuclear deterrence, national security and basic scientific research. HPC capabilities remain critical to the Laboratory's science-based stockpile stewardship, ensuring the nation's existing nuclear weapons systems are safe and reliable. Leveraging that work rooted in deterrence, LLNL also uses HPC to continuously improve the scientific underpinnings of this deterrent, such as in studying the effects of material aging, and the broader range of today's missions including weather and earth-system modeling, quantum interactions, and more. Likewise, HPC facilitates stockpile modernization with newly designed and manufactured systems—like the W80-4 life extension and the W87-1 modernization programs.

Accomplishments:

- LLNL has become a premier destination for HPC researchers, whether their expertise is in artificial intelligence, simulation, or data science.
- LLNL scientists used a neural network approach to develop accurate and efficient interatomic potentials for molecular dynamics simulations.

Section 3.5: S&T Mobilizers—Core Competencies



High Performance Computing, Simulation, and Data Science

Addressing national security challenges through innovative computational and predictive solutions.

Accomplishments (cont.):

- Exascale supercomputer El Capitan will enter production use in 2024, with delivery of infrastructure components including racks, cooling, and networking by vendor partner HPE and installed with coordination by Livermore Computing staff.

3–5-Year Vision:

As LLNL's mission continues to expand in scale and complexity, so must our computational and predictive capabilities. A computational ecosystem capable of exascale—and beyond—performance will enable new data-driven and AI-augmented approaches to scientific discovery and engineering design. We will continue to build our expertise in computing hardware, software, codes, and the physical sciences to simulate these phenomena with higher fidelity and more realism.

Section 3.5: S&T Mobilizers—Core Competencies



Advanced Materials and Manufacturing

Designing unique materials and fostering innovation in advanced manufacturing to fabricate structures with the properties and performance needed to address national security missions.

Description:

LLNL brings a multidisciplinary approach to the rapid development of advanced materials and manufacturing (AMM) processes. Livermore continues to advance manufacturing technology, enabling the development of customized feedstocks and unique fabrication techniques. Novel diagnostic methods are developed and used to monitor and control both legacy and emerging manufacturing methods—accelerating the Laboratory’s ability to deliver timely solutions. AMM creates a more agile, responsive material development and manufacturing ecosystem to meet the needs of national security stakeholders. Scientists and engineers explore ways to reduce costs, material waste, and energy consumption while enhancing functionality and accelerating discovery, development, and scalability timelines. LLNL also uses multiscale/multiphysics predictive modeling and machine learning to reduce uncertainties on how a material will perform at scale, in relevant conditions, and over its service lifetime.

Mission Applications:

Current research builds on decades of experience studying a spectrum of materials, manufacturing technologies, and mission-relevant applications. Livermore’s expertise spans the entire design-development-deployment cycle, including materials that can meet emerging mission needs, capabilities to produce materials at scale, advanced manufacturing methods, and structures tailored to meet specific performance requirements. Scientists and engineers develop innovative materials with tailored properties that can be used for energy absorption, dissipation, generation or storage; bioinspired structures for use in drug delivery; advanced optics used in satellites and telescopes; quantum materials; and components that can function effectively in extreme environments.

Accomplishments:

- Design and qualification of customized alloys for extreme environments, with thermally stable microstructures that are lightweight and corrosion-resistant, leveraging both experiments and predictive models to identify aging-resistant materials.
- Synthesis of functionalized biomimetic membranes using carbon nanotubes to advance filtration, drug delivery, and energy technologies.
- Pushing the state-of-the-art in additive manufacturing, including invention of a Volumetric Additive Manufacturing technique, which can be used to fabricate 3D objects with complex architectures in a matter of seconds to minutes by projecting a combination of tomographic images into a photosensitive resin.

Section 3.5: S&T Mobilizers—Core Competencies



Advanced Materials and Manufacturing

Designing unique materials and fostering innovation in advanced manufacturing to fabricate structures with the properties and performance needed to address national security missions.

3–5-Year Vision:

The long-term vision for LLNL's Advanced Materials and Manufacturing Core Competency includes increased integration of automation, machine learning and artificial intelligence to further accelerate materials discovery, design, development, and deployment. Build-out of capabilities will include collaborative spaces for materials synthesis, characterization, and testing, including flagship enclaves for energetic materials, polymers, ceramics, alloys, and rapid prototyping.

Further emphasis on multi-material and graded-interface fabrications, including compatibility and aging analysis, will leverage current and future capabilities. Issues of feedstock development, availability, and recycling—in light of critical minerals and materials—will increasingly drive innovations. LLNL will continue to take a leadership role in DOE-sponsored research activities involving materials for a secure energy future.

Section 3.5: S&T Mobilizers—Core Competencies

Bioscience and Bioengineering

Protecting the nation by countering current and future biological and environmental threats.

Description:

Bioscience and bioengineering research at LLNL delivers transformative solutions to the nation's health and energy security needs. Fueled by deep understanding of complex biological systems, our laboratory staff integrate state-of-the-art analytical tools, systems biology techniques, human models, and high performance computing. This integrated approach allows us to explore underlying mechanisms of disease and engineer microbial communities, addressing biosecurity, health, and ecological threats.

Mission Applications:

Bioscience and bioengineering are powered by cutting-edge facilities such as the Select Agent Center with Biosafety Level 3 containment facilities and the Animal Care Facility for relevant animal models. The Center for Bioengineering employs advanced tools to tackle complex biological systems to counter biological threats and increase national resilience. Across the Laboratory, bioscience and bioengineering research is tightly coordinated to provide predictive, validated, and comprehensive solutions for national security challenges. The Laboratory's high performance computing resources are used to simulate biological systems across scales.

Accomplishments:


LLNL combines multidisciplinary biological expertise with world-class computing and experimental resources to address pressing national health and environmental challenges.

- Development of the LLNL therapeutic antibody design platform has led to the revitalization of an approved COVID-19 therapy that had waned in effectiveness.
- Development of sustainable biomining approaches for purifying rare-earth elements to safeguard the domestic supply of critical minerals for clean energy transition.
- Identification of microbial signatures that aid treatment of soldiers' combat-related injuries using a combination of microbial metagenomic DNA sequencing and advanced machine learning techniques.

3–5-Year Vision:

Looking ahead, Laboratory bioscientists will continue to be at the forefront of advanced diagnostics, therapeutics, and sustainable biomanufacturing through innovative, multidisciplinary research. Areas of emphasis include: 1) employing a comprehensive strategy for early biological threat assessment and developing broad-spectrum antibodies,

Section 3.5: S&T Mobilizers—Core Competencies



Bioscience and Bioengineering

Protecting the nation by countering current and future biological and environmental threats.

3–5-Year Vision (cont.):

novel therapeutics or vaccines to counter those threats, 2) integrating big-data analytics and computational modeling to enhance genotype-to-phenotype predictions, which will improve our understanding of pathogens, host- pathogen interactions, and disease outcomes, 3) engineering microbial systems and biomolecules, to solve pressing healthcare, energy, and climate problems, and 4) developing advanced experimental systems that provide mechanistic understanding and quantitative measurements for predictive models.

Section 3.5: S&T Mobilizers—Core Competencies

Earth and Atmospheric Science

Understanding the critical role Earth processes play in energy, environmental, and national security missions.

Description:

Researchers in the earth and atmospheric sciences continually innovate to make the world safer, the environment cleaner, and our energy resources more sustainable. Our key areas of research include seismology, geophysics, geomechanics, geochemistry, hydrology, atmospheric turbulence and dispersion, climate modeling and model intercomparison, climate change detection and attribution, energy systems, and carbon cycles.

Mission Applications:

Earth and atmospheric sciences play a central role in LLNL's mission-driven work. LLNL advances global-scale monitoring techniques for identifying clandestine nuclear testing. The Laboratory's legacy of innovation strengthens response efforts for nuclear emergencies and hazardous material releases, in addition to leveraging geoscience expertise to design and deploy next-generation weapons and intelligence gathering systems. For climate resilience, LLNL expertise in the earth sciences, climate modeling, and energy systems provides actionable data for resilient infrastructure and to mitigate against greenhouse gas accumulation. From refining space-based observations to analyzing seismic signals under the Earth's crust, LLNL's research teams apply their expertise to making our planet safer and more resilient.

Accomplishments:

- Since 1979, the National Atmospheric Release Advisory Center (NARAC) at LLNL has been on call 24/7 to respond to hazardous release emergencies around the world. NARAC monitored data from radiation detection sensors in Ukraine (2022), responded to nuclear power plant failures at Chernobyl (1986) and Fukushima (2011), airborne hazards in the wake of Hurricane Katrina (2005), the Deep Water Horizon oil spill fire (2010), and the spread of ruthenium across central Europe (2017).
- LLNL scientists participate in assessments conducted by the Intergovernmental Panel on Climate Change, a Nobel Prize-winning institution established in 1988, to provide the scientific basis for understanding climate change.
- The Stellar Occultation Hypertemporal Imaging Payload (SOHIP) prototype telescope, recently installed on the International Space Station, uses LLNL-patented technology to detect and characterize atmospheric waves and high-altitude properties such as temperature, pressure, and density at altitudes up to 50 kilometers.
- The Geophysical Monitoring Program at LLNL generates global-scale tomographic images of the Earth's interior to improve seismic and nuclear event monitoring. This work has also led to identifying the previously unknown southeast Indian Ocean slab.

Section 3.5: S&T Mobilizers—Core Competencies



Earth and Atmospheric Science

Understanding the critical role Earth processes play in energy, environmental, and national security missions.

3–5-Year Vision:

Over the next few years, LLNL will prioritize several investment areas to prepare for future challenges. These include enhancing regional-to-local seismic and nuclear event characterization through investments in machine learning methods, data fusion, big-data analysis, and exascale computing; expanding research on emerging technologies like hydrogen storage and direct air capture of carbon dioxide; and providing decision makers, including U.S. agencies tasked with ensuring our national security, with actionable data to foster climate resilience.

Section 3.5: S&T Mobilizers—Core Competencies



Lasers and Optical Science and Technology

Developing state-of-the-art optics and novel materials to meet the needs of advanced laser systems while designing, building, and operating next-generation laser technology.

Description:

The Laboratory's leadership in lasers and optical science and technology reflects longstanding expertise in systems engineering, laser construction and operation, and collaboration with commercial partners. LLNL scientists have a record of high-impact innovations advancing the state-of-the-art in optical system imaging and spectroscopic components. This is complemented by leadership in photonics, HED science, optical materials, the physics of laser-material interaction, and laser system modeling and simulations.

Mission Applications:

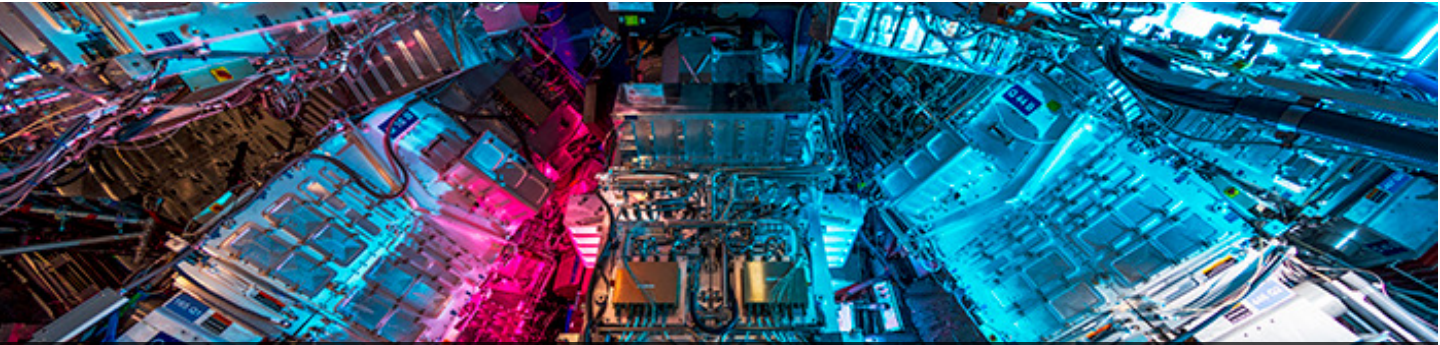
The National Ignition Facility (NIF) – home to fusion ignition – is a valuable tool in pursuing LLNL's core mission of safeguarding America's nuclear weapon stockpile while exploring high energy density (HED) regimes. NIF provides key insights and data for simulation codes used in weapon-performance assessments and certification. It is also an important resource for weapons effects studies and nuclear forensics analysis. The Laboratory's achievement of fusion ignition has the potential to accelerate the development of next-generation laser systems and optics science and technology. Such advances can help bring about a high-yield fusion facility for stockpile stewardship and modernization while laying the groundwork for inertial fusion energy (IFE).

Space Science and Security is a prominent area of interest for national security. LLNL research and development of adaptive optics systems has led to image quality improvements by compensating for blurring due to temporal atmospheric turbulence in large optical telescope systems. Thin film multi-layer and interference coating modelling and fabrication capabilities at LLNL have delivered unique optical components with tailored properties needed for satellite payload systems.

Accomplishments:

- On December 5, 2022, the NIF laser precisely delivered 2.05 megajoules (MJ) of energy and 440 TW of peak power to the target enabling the first demonstration of fusion ignition in a laboratory setting. This achievement, which generated 3.15 MJ of fusion energy, has since been repeated at even higher levels.
- Recent debris-induced laser damage mitigations on optics have enabled NIF to operate at 2.2 MJ (>20% above initial facility requirements) and 440 TW in FY24.

Section 3.5: S&T Mobilizers—Core Competencies



Lasers and Optical Science and Technology

Developing state-of-the-art optics and novel materials to meet the needs of advanced laser systems while designing, building, and operating next-generation laser technology.

Accomplishments (cont.):

- Collaborating with the University of California in pioneering adaptive optics to compensate for atmospheric turbulence for ground-based observatories and directed-energy applications. Images of auroras on Mars were transmitted back to earth by the United Arab Emirates Mars Mission Hope Probe in 2021 using a silicon carbide-coated mirror and diffraction grating developed and delivered by LLNL scientists and collaborators at the Laboratory for Atmospheric and Space Physics at the University of Colorado.

3–5-Year Vision:

The next generation of laser systems will continue to expand the envelope of capability in energy, pulse width, and repetition rate. Optics mitigations will continue to increase functionality, lifetime, and yield to enable improved performance of high energy lasers. Improving precision and control over all laser properties, including time-dependent waveforms and spectra, beam intensity and wavefront profiles, while tailoring polarization states will enable novel modalities for optimizing laser interactions with matter and mitigating instabilities. Development of high-dynamic range metrologies will enable improved detection and mitigation of defects and damage in optics exposed to ultra-high laser powers. The Laboratory will continue to advance the design, development, construction, and optimization of high laser systems for IFE and high-yield stockpile stewardship applications, including using advanced additive manufacturing techniques of transparent ceramic and glass to create custom passive and gain components for laser systems.

LLNL will continue to develop leading-edge optical components and systems for imaging and space science applications. Adaptive optics systems to improve image will be implemented with increasingly effective computational algorithms and predictive control techniques. Novel multi-layer coatings with properties tailored for optimal performance over specific ranges of the light spectrum will be developed to support and enable new optical systems, including space missions and payloads.

Section 3.5: S&T Mobilizers—Core Competencies



Nuclear, Chemical, and Isotopic S&T

Studying reaction pathways of chemical and nuclear systems.

Description:

Nuclear, chemical, and isotopic research will advance our scientific understanding, capabilities, and technologies in nuclear and particle physics, radiochemistry, cosmochemistry, forensic science, and isotope systems to support LLNL's national security mission. Leveraging unique experimental and computational tools, we study nuclear reactions, the limits of nuclear stability, actinide behavior, heavy-element chemistry, isotope geochemistry, and environmental science. Our leading-edge scientific research efforts provide the foundation for addressing these challenges. Our overarching strategy is to position LLNL at the nexus between fundamental nuclear and chemical science research and nuclear security applications. This approach will support efforts to recruit, train, and retain top-flight scientists and engineers who will play a key role in executing the Laboratory's core nuclear security missions, while enhancing LLNL's reputation as a center for innovative scientific research.

Mission Applications:

Chemical, nuclear, and isotopic science research directly benefits our national security mission by improving the safety and reliability of our strategic deterrence and enhancing our detection and attribution capabilities for special nuclear materials and nuclear detonations. Our unique isotopic analysis capabilities support LLNL's efforts to develop innovative climate change mitigation approaches.

Accomplishments:

- Analyzed asteroid and lunar samples to understand the evolution of the solar system and support future exploration of the Moon.
- Developed a novel microfluidic platform for rapid radiochemical separations and measurements in a lab or in the field.
- Lead an international effort to develop a modern toolkit for storing and using evaluated nuclear reaction data, enabling higher-fidelity nuclear physics simulations and faster adoption of new data and techniques into nuclear science applications.
- Performed precision measurements of nuclear fission cross-sections for uranium and plutonium using a time projection chamber in the Neutron Induced Fission Fragment Tracking Experiment (NIFFTE).

Section 3.5: S&T Mobilizers—Core Competencies



Nuclear, Chemical, and Isotopic S&T

Studying reaction pathways of chemical and nuclear systems.

3–5-Year Vision:

Prioritized research areas in nuclear, chemical, and isotopic science and technology include development of novel neutron sources and targets for future nuclear data measurements for national security programs, preparation for NASA sample return missions that will use state-of-the-art new instrumentation for isotopic and spatial analysis, and investigations into the use of quantum systems for detectors and sensors as well as quantum computing for nuclear theory and data applications. LLNL scientists will also respond to long-range planning needs recently released by the Office of Science in Nuclear Physics and High Energy Physics including the searches for neutrinoless double beta decay, sterile neutrinos, and dark matter, experimental and theoretical research on nucleosynthesis, and probing the quark and gluonic structure of nuclear matter.

Section 3.6: S&T Mobilizers—Facilities, Centers, & 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 Applications:

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 Laboratory
- Center for Micro- and Nanotechnology
- Contained Firing Facility
- Electron Beam Ion Trap
- Forensic Science Center (FSC)
- High Explosives Applications Facility (HEAF)
- Jupiter Laser Facility (JLF)
- Livermore Computing Complex
- Manufacturing Complex
- National Atmospheric Release Advisory Center (NARAC)
- National Ignition Facility (NIF)
- Optical Fabrication and Processing
- Polymer Enclave
- Select Agent Center
- Site 300
- SKYFALL

Discipline-Oriented Institutes and Centers

- Center for Accelerator Mass Spectrometry
- Center for Advanced Signal and Images Sciences
- Center for Applied Scientific Computing
- Center for Bioengineering
- Center for Computational Engineering
- Center for Design 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
- Livermore Center for Quantum Science
- Nondestructive Characterization Institute
- Space Science Institute

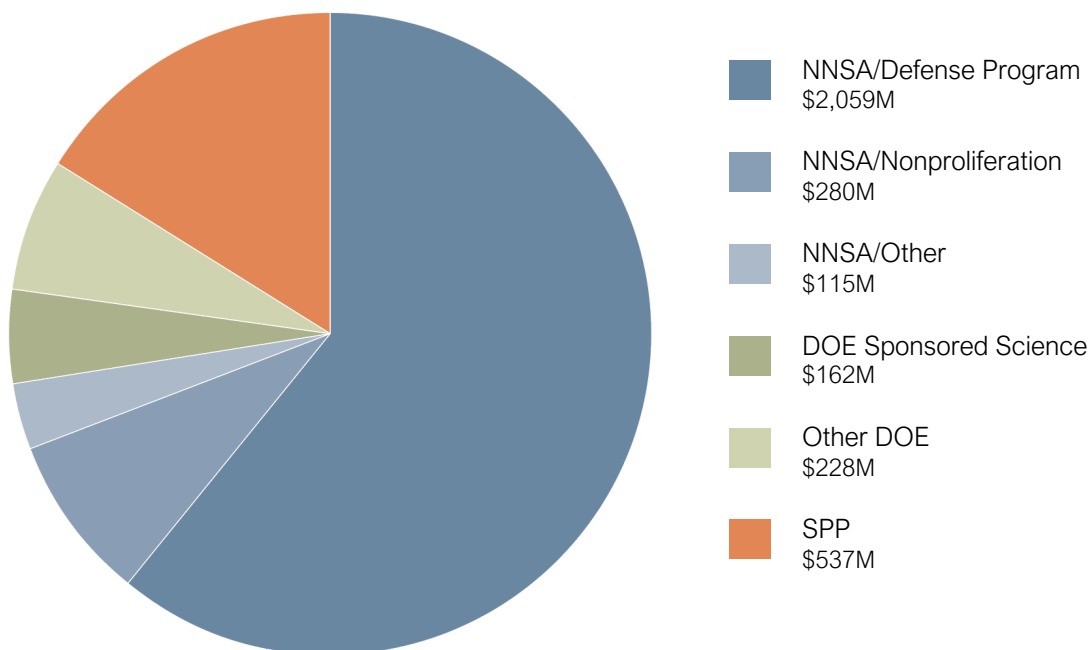
Section 4: Support of Science and Technology

Financial support of LLNL's science and technology enterprise relies on a variety of funding sources. The largest and most important sponsor is NNSA/Defense Programs, which provides the majority of support for and enables synergy among our S&T Mobilizers. LLNL also conducts significant research and development for NNSA/Defense Nuclear Nonproliferation, DOE/ Office of Science and other DOE offices. This broad and diverse portfolio allows LLNL to apply its technical competencies to the full suite of DOE missions and Departmental priorities, while providing synergy to our core NNSA mission.

Many non-NNSA mission areas benefit from the Laboratory's expertise, unique capabilities, and facilities. These Strategic Partnership Projects (SPPs), often conducted in collaboration with other organizations, 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 support outstanding researchers that contribute to a healthy, vibrant Laboratory. In addition to externally funded work guided by sponsors, LLNL 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 outlines sources of funding and their internal investment as detailed in the chart below:

Total FY23 Lab Funding (\$M)



Section 4.1: Sponsored Science

DOE Office of Science

The DOE Office of Science (SC) is an enduring partner and a major 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 all eight program offices: Accelerator R&D and Production (ARDAP), Advanced Scientific Computing Research (ASCR), Basic Energy Sciences (BES), Biological and Environmental Research (BER), Fusion Energy Sciences (FES), High Energy Physics (HEP), Isotope R&D and Production (DOE IP) and Nuclear Physics (NP).

Applied Energy and Environmental Management Offices

LLNL also conducts a broad range of research activities for additional DOE Program Offices that leverage Core Competencies and provide opportunities for LLNL staff to make important contributions to national priorities. This portfolio includes funding from: Advanced Research Projects Agency-Energy (ARPA-E), the Office of Clean Energy Demonstrations (OCED), the Office of Electricity (OE), the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Environmental Management (EM), the Office of Fossil Energy and Carbon Management (FECM), the Office of Nuclear Energy (NE), and the Office of Cybersecurity, Energy Security, and Emergency Response (CESER).

Strategic Partnership Projects (SPP)

Advancing Laboratory Technology in Work Beyond DOE

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 both leverages and augments the Laboratory's Core Competencies, unique scientific and technical infrastructure, and integrated problem-solving skills.

Approximately 75% of the SPP funding results from successful proposals to a wide variety of organizations that reside within the Department of Defense (DOD), including the Defense Advanced Research Projects Agency (DARPA) and each of the six branches of the U.S. Armed Forces. Other government agencies such as National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), and Department of Homeland Security (DHS) also provide funding for research ideas on a 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 Laboratory's talented workforce.

One illustrative example of the synergistic benefits that accrues to LLNL and the SPP sponsor is the Laboratory's contribution of a high-purity germanium (HPGe) sensor on the recently launched NASA satellite to rendezvous with the asteroid 16 Psyche.

LLNL's HPGe instrument will collect data that will advance our understanding of the formation of Solar System, a key objective of NASA. In turn, the advances in HPGe technology will allow LLNL to strengthen support of NNSA's nuclear non-proliferation mission.



The LLNL team designed and built the gamma-ray spectrometer for the NASA mission to Psyche over five years from 2018 to the spring of 2023.

Section 4.2: 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 deliver tangible impacts on developing programs and are a signal to our adversaries that we are innovative and agile in response to new challenges.

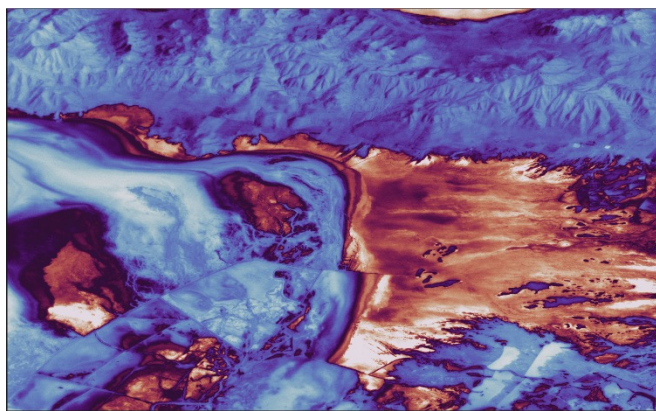
Today, innovation and technical leadership in the core technical fields associated with strategic deterrence are even more essential than at the dawn of the SSP. For a few select areas, nothing short of preeminence is LLNL's goal. In HPC and HED we remain not only leaders but pioneers, shaping the international 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 founders' 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 4.3: NNSA Defense Nuclear Nonproliferation

The mission of NNSA's Office of Defense Nuclear Nonproliferation (DNN) is to prevent the proliferation of nuclear weapons and reduce the threat of nuclear and radiological terrorism. Innovation in science and technology is required to forestall nations and non-state actors from making nuclear weapons or obtaining weapons-enabling materials, knowledge, and equipment.

LLNL's longstanding support of this important national priority draws upon the strength of our Core Competencies, while an ever-evolving security environment spurs innovation and creates new technologies. LLNL currently leads multiple national efforts to advance capabilities for the nonproliferation mission, including new methods for arms control treaty verification and the use of machine learning to discover evidence of potential nuclear proliferation on a global scale. DNN funding also allows LLNL staff to develop hierarchical, multi-modal detection approaches to characterize threats and create sophisticated physics-based modeling capabilities to optimize mitigation strategies.

Section 4.4: Internal Investments



SOHIP provides imagery (a false color image of Utah is shown above) and data to detect and characterize gravity waves and high-altitude atmospheric properties.

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. Recent uses of this funding include supporting LLNL's participation in the Accelerating Therapeutics for Opportunities in Medicine consortium, supporting the research of Early- and Mid-Career Award winners, and developing the Stellar Occultation Hyper- temporal Imaging Payload (SOHIP), an instrument deployed on the International Space Station in 2023.

Section 4.4: Internal Investments (cont.)

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

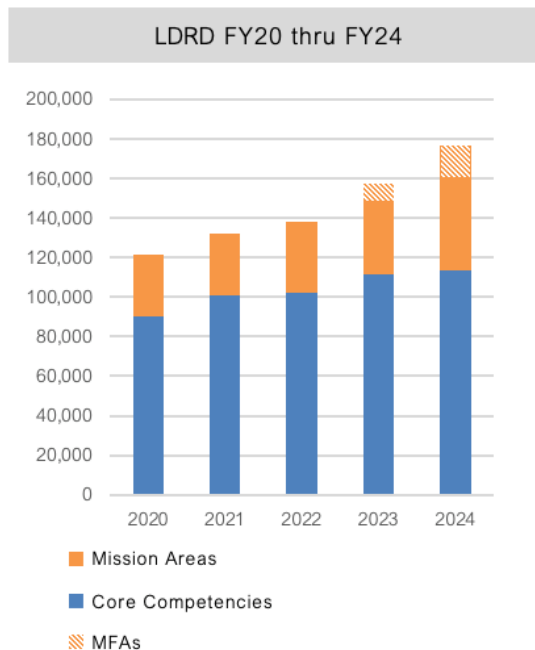
Laboratory Directed Research & Development

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 review and selection process.

The LDRD program is also a powerful means to hire outstanding staff, postdocs, 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.

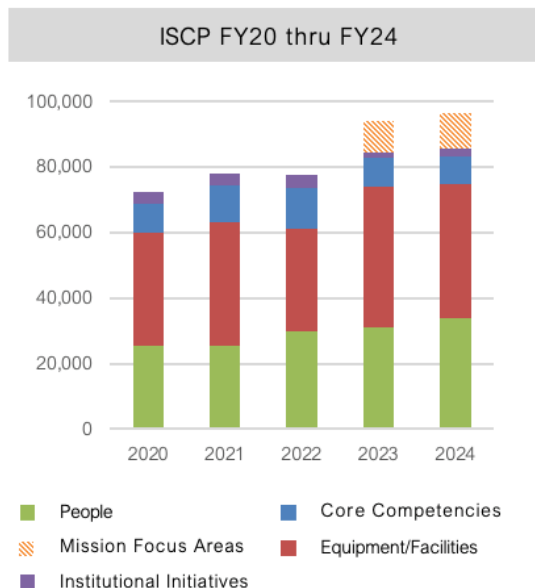
LDRD enables LLNL to invest in high-risk, potentially high-value research and development that creates innovative technical solutions for some of our nation’s most difficult national security challenges. The graphic to the right displays how LDRD funding supports Laboratory research in three categories: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



Institutional Scientific Capability Portfolio

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, sponsor engagement and program development associated with supporting LLNL initiatives and priorities that are multi programmatic and have cross directorate benefit, workforce programs, and scientific infrastructure. ISCP projects are non-R&D activities funded by indirect resources 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 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. 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 scientific 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 are tailored more specifically to each program. Current 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 of the metrics we consider.

The success of the Lab's scientific 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. We are working to incorporate key performance indicators (KPIs) generated across the Laboratory and accessible via LabWatch, a data and tracking dashboard providing a source of truth for performance metrics. The underlying ethos of LabWatch is simple: "Measure to an outcome, not a number. This approach will keep us focused on metrics—and results—that matter."

We will continue to incorporate the feedback and recommendations we gain from formal review processes like the Board Of Governors (BOG), Directorate Reviews, or External Review Committees (ERCs). Portfolio review allows us to synthesize this information for our continued, collective benefit.

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: Emerging Opportunities

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

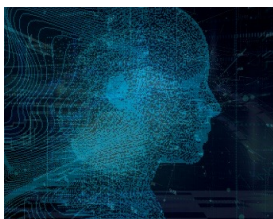
This section of the *Investment Strategy for Science and Technology* outlines interrelated urgent national priorities and foundational scientific capabilities. Section 6.1 outlines areas of emerging science known as Institutional Initiatives, while 6.2 further illustrates how scientific expertise is 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, including through successful LDRD projects.

Each element ensures the Laboratory can support new mission requirements, meet long-term mission needs, and rise to 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 science, technology, and engineering.

Section 6.1: Institutional Initiatives

LLNL was established as a “Big Ideas” laboratory and generations of employees have carried forward that tradition with multidisciplinary teams and a history of taking bold—but well considered—technical risks. The complexities of future challenges to national security demand that we build upon the Laboratory’s culture of innovative thinking to achieve high-payoff advances. Innovation is part of LLNL’s approach to program delivery but, more importantly, it is strongly embodied in our Institutional Initiatives.

Driven by visionary champions with scientific expertise in mission-critical fields, Institutional Initiatives reflect the LLNL’s “team science” approach by gathering multidisciplinary teams to address issues of national importance. By anticipating areas of increased global attention, Institutional Initiatives provide a chance to “lean forward” in emerging scientific realms. Three Institutional Initiatives are introduced below, with additional details on the following pages.



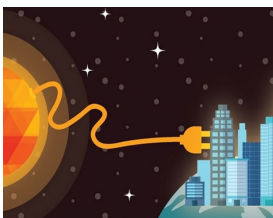
Cognitive Simulation

The Cognitive Simulation Institutional Initiative aims to accelerate the integration of AI, high performance computing, and empirical data for a range of scientific applications. Researchers focus on inertial confinement fusion and high-energy-density projects crucial to stewardship of the nation’s nuclear stockpile, but additional mission-relevant applications include climate studies, AI-driven manufacturing, and biosecurity projects.



Decision Superiority

This Institutional Initiative was created to build on mathematical advances in complex systems to foster scalable, stable, and robust modeling and forecasting capabilities that can resolve decisions with limited information. Simply put, the Decision Superiority Initiative helps meet the pressing national need for decision support tools.



Inertial Fusion Energy

The achievement of fusion ignition at the National Ignition Facility (NIF) demonstrates the fundamental basis of Inertial Fusion Energy (IFE) and is a pivotal first step towards a fusion energy future. The IFE Institutional Initiative is enabling the U.S. national, technical, and community leadership needed to build the foundational science and technology for IFE and support the Department of Energy (DOE’s) vision for accelerating the commercialization of fusion energy.

Section 6.1: Institutional Initiatives (cont.)

Cognitive Simulation

Accelerating applied science

Description:

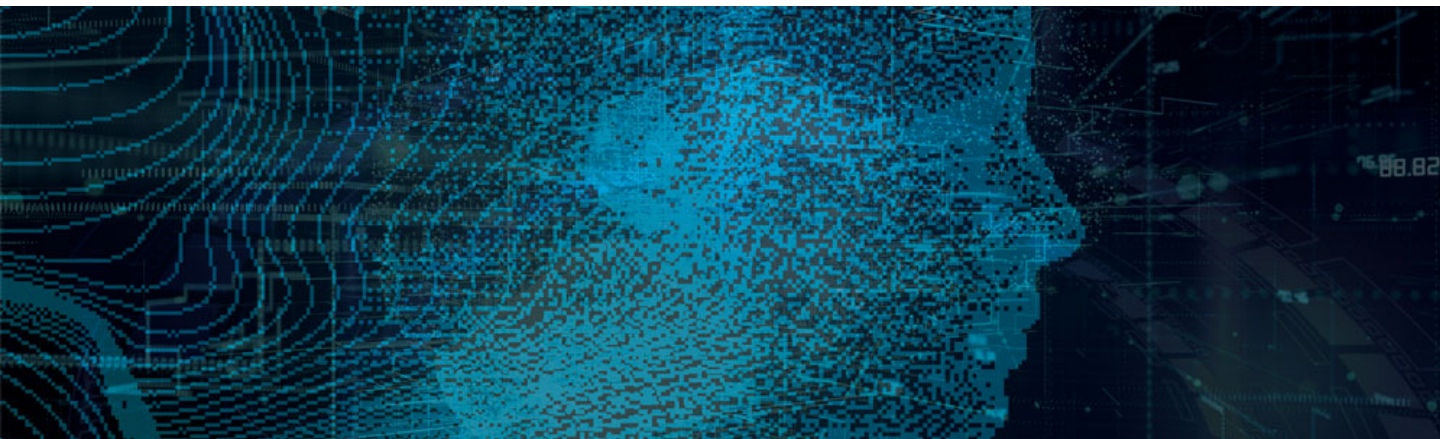
The Cognitive Simulation Institutional Initiative harnesses artificial intelligence (AI) to combine LLNL's simulation capabilities with high-quality experimental datasets. These new models improve scientific predictions by coupling large ensembles of simulations with limited quantities of experimental data—a process that enables AI to incorporate, adapt to, and guide experimental observations. The improved models deliver highly detailed uncertainty quantification and quantitative measures of the value of past and future experiments.

CogSim provides solutions to key problems across LLNL's national security missions. While many techniques are pioneered entirely inside the Laboratory, several CogSim methods are expanded through public/private partnerships steered by the [AI Innovation Incubator \(AI3\)](#). This enables LLNL to share compelling interdisciplinary science challenges with AI and computing industry leaders. Demand is high for engagement with LLNL's unique CogSim research ecosystem; and new techniques and approaches that benefit both national security and national economic competitiveness can be accomplished.

3–5-Year Vision:

AI already plays an important role in how scientific experiments are conducted, how supercomputers run simulations, and how large datasets are analyzed to make predictions. As computing systems evolve past exascale capabilities toward zettascale and beyond, so too will AI technologies. Large language models will influence scientific discovery processes, including hypothesis investigation. AI-driven automation will become more routine in laboratories and experimental facilities, producing data at unprecedented rates. Advanced manufacturing techniques augmented with AI will enable adaptive design processes and smarter production operations.

The Cognitive Simulation Institutional Initiative will ensure LLNL upholds a deliberate, focused vision for AI development and execution in addressing national security priorities. As part of this effort, AI3 will continue to coordinate multi-partner expertise focused on applications while nurturing the Laboratory's visibility and influence with sponsors and government partners.



Section 6.1: Institutional Initiatives (cont.)

Decision Superiority

Building the applied science of complete integrability

Description:

Decision superiority capabilities help meet the pressing national need for computational tools to create advantages in both speed and insight in international competition and warfighting. LLNL is pursuing an open research frontier in the numerical solution of integrable systems applied to mission-driven models. With advances in numerical speed and accuracy, new problem domains can be solved, including combinatorial optimization, complex systems, and a variety of physical phenomena.

Meeting the dynamic planning challenges for decision superiority requires new approaches beyond current simulation and machine learning methods, which aren't always available to make timely recommendations for rapidly changing environments.

A recent breakthrough identified new ways to solve optimal control and reinforcement learning problems by casting them as components of completely integrable systems in time and space, which enables efficient solutions via parallel computations. Additional advances in probabilistic machine learning and high-throughput computing methods enable solutions of decision support problems under unique national security mission constraints. Decision superiority researchers are applying these innovations by partnering with experts at LLNL and other national laboratories in defense systems modeling and simulation.

Coupling streaming data with simulations enables playing out future scenarios and optimizing action choices to achieve a desired long-term objective, all in near-real-time. To help build these capabilities, LLNL investments in decision superiority are focused on three technical pillars:

- Data brokering to provide necessary information for decision-making.
- Algorithmic innovations to meet speed, scale, and computing platform requirements for decision modeling.
- Verification and validation approaches to help identify capability gaps and build trust with users.



Improving decision support has global applications across multiple domains.

3–5-Year Vision:

Based on mathematical advances in complex systems, LLNL is creating scalable, stable, and robust modeling and forecasting capabilities that can resolve complex decisions with limited information. LLNL advances could include learning how operational data can solve combinatorially hard planning problems. Efficiently representing how operational data is embedded on conventional computing architectures is a solution that will drive evolution in computing architecture designs.

On a three-year timeline, LLNL decision superiority teams expect to demonstrate real-time planning capabilities at scale on LLNL high performance computing systems. This will help expand modeling into social science domains, widely acknowledged as critical for managing future threats. Integrating the developing tools with humans will help build trust in the system. Within five years, evolving LLNL capabilities will enable delivery of decision support products to users across the U.S. government and will foster transfer of capabilities to a broader LLNL mission set.

Section 6.1: Institutional Initiatives (cont.)

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.

LLNL is enabling the national, technical, and community growth of a robust U.S. IFE program. Livermore's IFE Institutional Initiative provides inclusive leadership on the national and international stage, builds up IFE efforts within LLNL in areas synergistic with stockpile stewardship, and supports the emerging public and private IFE landscape.

3–5-Year Vision:

In achieving ignition, the U.S. has taken the first pivotal step to inertial fusion energy. Achieving fusion energy will require sustained, long-term investments and innovations in multiple fields to enable a viable energy source.

LLNL, in partnership with the community, will continue to grow a robust and coordinated U.S. IFE program spanning the public and private sectors to build the first pilot plants, with key components including integrated plant design to drive science, technology, and engineering to close existing gaps and set requirements for fusion pilot plant concepts; national hubs with the necessary new facilities to advance component technologies and foundational science; access to unique, world-leading NNSA and DOE facilities to provide near-term data and reduce risk; a proactive workforce development effort spanning all levels, and inclusive public engagement about fusion.

U.S. leadership in IFE could profoundly transform long-standing energy geopolitics, strengthen energy and climate security, and bolster national security for the U.S. and allied partners. It is a worthy scientific and engineering grand challenge building on the historic achievement of fusion ignition.



Section 6.2: Mission Focus Areas

Stockpile and Enterprise Transformation

Increasing the responsiveness and resilience of the Nuclear Security Enterprise

Description:

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 and modernization, including laying the foundations for a more responsive and resilient enterprise.

Mission Applications:

This MFA is directly aligned with the Laboratory's national security mission to work with the NSE to modernize the stockpile and the production complex while advancing the S&T approaches and capabilities fundamental to qualifying and certifying the existing and future deterrent. Advancing the experimental, design, and computational capabilities that underpin the Enterprise will add significant resilience and responsiveness to our national security missions and enable "First Production Unit (FPU) in 5."

Accomplishments:

- LLNL and Kansas City National Security Campus staff were able to demonstrate significant increased yield on a critical part through collaboration enabled by the Polymer Enclave.
- LLNL and Y12 scientists and engineers, in partnership with industry achieved TRL 5 for the Electron Beam Cold Hearth Melter for a critical alloy within 2 years.

3–5-Year Vision:

LLNL's goal of stewardship transformation aims to realize a more responsive and resilient enterprise through several avenues: anticipation (of future needs and solutions to meet those needs); modernization (manufacturing methods, processes and practices); and integration (including our NSE design and production partners, our DOD stakeholders, and strategic academic, industrial, and international partners).

Enablers for the needed transformation include advanced manufacturing tools—including exploring the use of automation to improve reproducibility of processes; novel non-destructive, in-situ characterization modalities to reduce inspection times; and experimental and computational tools (including AI, ML, and data sciences) to accelerate the design-produce-certify product realization process. Successfully achieving the goals of Stockpile Enterprise Transformation relies not only on existing partnerships but investment in new strategic collaborations.

Section 6.2: Mission Focus Areas



Bio Resilience

Integrating computing and experiments to transform national biodefense

Description:

The Bio Resilience 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 Applications:

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.

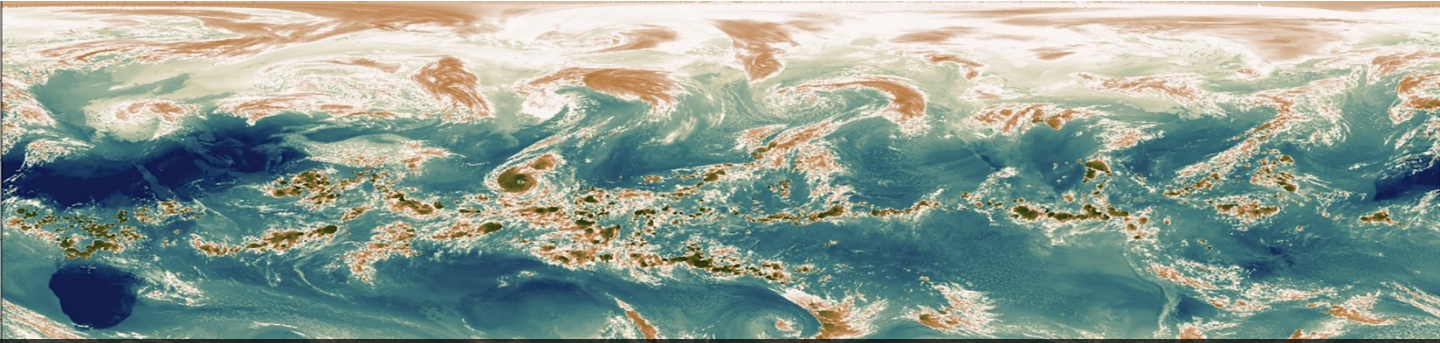
Accomplishments:

- Predictive models of molecular binding and properties integrating physics-based mechanistic simulations with data-driven machine learning.
- 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 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 R&D area will focus on development of integrated systems that use computing to steer automated experiments and the resulting data to inform new models. These active learning systems will enable a broad range of new understanding and capability to enhance our national security.

Section 6.2: Mission Focus Areas



Climate Resilience

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

Description:

The primary goal of the Climate Resilience MFA is to minimize and predict the impacts of climate change on national security. Our mitigation efforts focus on carbon removal methods involving carbon storage in soils, enhanced mineralization, direct air capture, etc. coupled with techno-economic analysis of removal and storage systems. Our adaptation effort links climate simulations at the necessary spatial and temporal scales with infrastructure models to predict impacts of climate change.

Mission Applications:

Climate change poses an immense risk to national security, the economy, and public health with consequences that cascade across sector boundaries. Earth System models (ESM) combine atmosphere, ocean, land, and sea-ice processes to predictive models of climate change for impact analysis. ESM models also predict the results of various atmospheric carbon concentration pathways dependent on economic conditions and the success of global greenhouse gas abatement efforts.


Accomplishments:

- This first-of-its-kind [Getting to Neutral: Options for Negative Carbon Emissions in California](#) report was an important resource for industry, academia, and policymakers and was followed by a nationwide assessment, [Roads to Removal](#).
- As part of a multi-lab cohort, LLNL is developing the Energy Exascale Earth System Model ([E3SM](#)) that can be used to assess how energy use impacts Earth's ecosystems, water availability, snowpack, sea levels, and other factors.

3–5-Year Vision:

This MFA will examine how carbon removal can help minimize changes in the Earth's climate and how unpreventable changes threaten the U.S., its economy, allies, and adversaries. We will advance carbon removal by contributing to the development of removal, capture, transport and storage systems tuned to the regional differences, opportunities and environmental justice concerns. Researchers will advance the use of Earth system models to address regional and local climate impacts, such as flooding, drought, and extreme weather events, and assess how these events influence the resilience of the electrical power grid, national security infrastructure and critical operations.

Section 6.2: Mission Focus Areas



Integrated Deterrence and Technology Competition (IDTC)

Integrating LLNL capabilities to impact regional deterrence

Description:

The IDTC MFA addresses the national need to deter aggression against the U.S., allies, and partners, while enabling the ability to fight and win across the full spectrum of conflict to maintain and restore deterrence. Integrated deterrence 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 integrated deterrence. The MFA aims to integrate across LLNL to develop capabilities and partnerships to provide integrated options that advance deterrence. This is facilitated through a combination of scenario-based exercises, multi-domain modeling and simulation, demonstrations, and deterrence analysis.

Mission Applications:

The 2022 National Security Strategy prioritizes integrated deterrence, 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 advanced weapon capabilities, conventional nuclear integration, critical infrastructure, cyber and space resilience, as well as artificial intelligence and machine learning. New analysis methods and at-scale modeling of complex systems allows researchers to understand which new technologies will impact decision calculus and create national strategic advantages.

Accomplishments:

- Networks of systems ranging from critical infrastructure to general logistics are central to ID. Recent LLNL efforts in this area have led to multiple sponsored efforts.
- Development of LLNL modeling and simulation capabilities across the hierarchy from physics to conflict simulation, to enterprise and infrastructure modeling, to high-level strategic competition, incorporating AI/ML to inform strategic decisions.
- Development of technological capabilities to provide early conflict effects and domain awareness.

3–5-Year Vision:

The IDTC MFA aims to leverage and integrate LLNL's Core Competencies, all-source intelligence abilities, existing security programs and leading-edge research to address integrated deterrence and strategically outcompete our adversaries. Central to this vision is integration of nuclear, conventional, and non-kinetic capabilities to support deterrence missions.

Section 6.3: Future State of S&T Mobilizers

The future of innovative science 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 advance Core Competencies. It's vital that the Laboratory continues investing in what allows our workforce—no matter their role—to be productive, innovative, and successful.

People

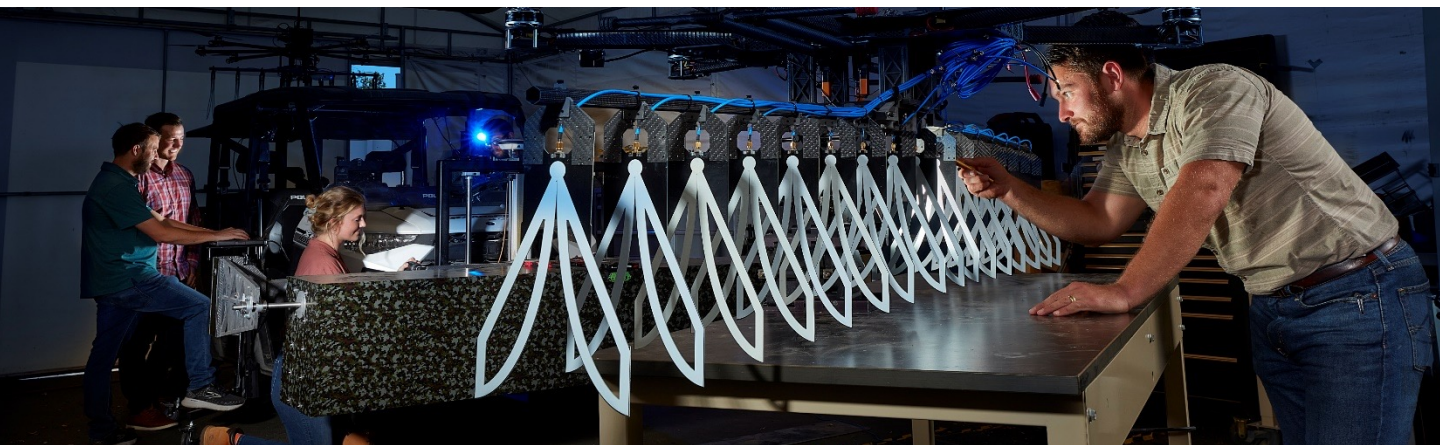
Across the Lab, effective team science is enabled through a healthy research culture of respect, openness, interdisciplinary teaming, workforce diversity, and collaborative approaches. Each year, we participate in hundreds of recruiting and conference events as we continue to develop talent pipelines 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 partnerships. Faculty experience Laboratory resources and capabilities, share best practices, 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

2023 included a systematic review of internally-funded Centers and Institutes to ensure they are aligned with Laboratory priorities, support MFAs and OKRs, and are resourced appropriately. This portfolio review strengthened the community of such entities and offered an opportunity to share best practices. 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.

Core Competencies

The Laboratory continually works to enhance the quality, relevance, and vitality of all seven Core Competencies. We will actively pursue efforts to assess these competencies, including the support provided by our LDRD Program and our institutional funding, and validate quality via external reviews, honors awarded to LLNL staff, and the success of external partnerships. Our visibility in the external research community, and our ability to shape and respond to our sponsors' vision and strategic plans, will also serve to demonstrate our expertise.

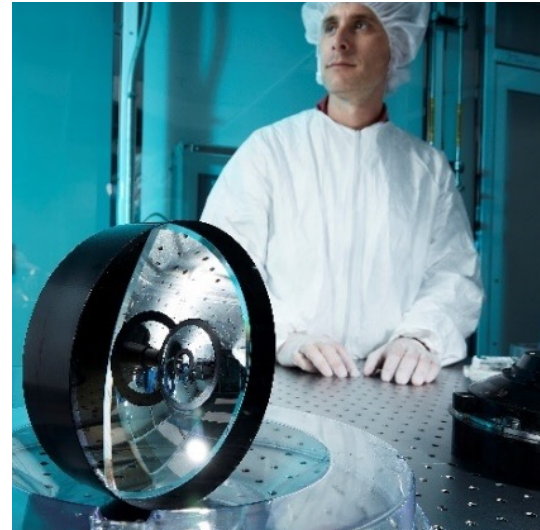


Section 6.4: LDRD Highlights

Several examples of successful mission-driven work dependent on the S&T Mobilizers can be seen within the LDRD program:

Optical Science Space and Security

LLNL's Optical Science teams exemplify how LDRD's strategic internal investments can drive innovation with significant results over time. For over 25 years, Lawrence Livermore researchers and collaborators have developed and applied innovative optical science technologies used for ground-breaking science. The MACHO survey, launched in 1989, examined dark matter using microlensing, a technique that will be used in the new DOE-supported Vera Rubin Observatory; LDRD research played important roles in developing data analysis techniques for MACHO and subsequent large data surveys. In the mid-1990s, LDRD funded the LLNL Laser Guide Star Project. Deployed at Lick Observatory, this was the first Laser Guide Star Adaptive Optics (AO) system at a major astronomical telescope. In 2008, an LDRD project used advanced AO and imaging techniques to take the first image of a system of extrasolar planets. Today, LDRD optical science research provides support for the Lab's Space Science and Security program including the design and development of monolithic telescopes as well as research to identify asteroids and better understand black holes.



LLNL's Space Program has built and flown these telescopes on satellite missions for U.S. government sponsors.

High Performance Computing, Simulation, and Data Science

The Laboratory is a world leader in applying high performance computing (HPC) to complex science, technology, and engineering challenges. LDRD investments have been a critical factor behind our preeminence in HPC. These LDRD investments in extreme-scale computing have resulted in more efficient use of HPC systems and faster times to scientific insight for the users of HPC systems.

Today, LDRD projects in HPC, Simulation, Machine Learning / Artificial Intelligence, and Data Science have advanced scientific innovation, most notably with recent successful inertial confinement fusion experiments.

Simulation and modeling capabilities predict with confidence the behavior of nuclear weapons through comprehensive, science-based simulations as well as bring predictive capabilities to a broad range of scientific areas, including advanced manufacturing, climate science, and nuclear chemistry. HPC is used to design, develop, and deploy capabilities not only in support of Livermore's mission and program goals, but also to improve national security and embolden U.S. economic competitiveness.



LLNL researchers are integrating technologies such as the Sierra supercomputer (left) and NIF (right) to understand complex problems like fusion in energy and the aging effects in nuclear weapons.

Section 6.5: 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.

Future State of Funding

NNSA—principally Defense Programs, and other offices—will continue providing 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, NIH, and DARPA 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. A long-term objective will be using LabWatch as the permanent repository for all science-related metrics and associated data. LabWatch ensures that all users are relying on the same verified data to understand our successes and opportunities for improvement.

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. We will continue to adjust the charges given to the committees to best match what the nation asks us to do while responding to internal priorities. Over the next few years, we anticipate creating new tools to integrate publications, honors and awards and intellectual property successes to assess the achievements of our people, Core Competencies, and MFAs.

Future State of Laboratory Strategy

The Laboratory's strategic vision was launched in 2023 and is built upon four pillars: expediting mission and program delivery; driving S&T innovation; delivering operational excellence; and nurturing our workforce and culture. As the 2024 LLNL Strategic Objectives are finalized and implemented, future iterations of the *Investment Strategy for Science and Technology* will amplify that central document. Strategic objectives for each pillar are outlined below:

Mission and Program Delivery

- Meet Evolving Nuclear Deterrence Requirements with Timely Delivery
- Enhance Resiliency and Timely Response to Future National Security Threats
- Serve as a Trusted Partner to Accelerate National Efforts

Science and Technology

- Devise Innovative Solutions through Multidisciplinary Teamwork
- Enhance Technical Leadership in S&T Core Competencies
- Accelerate S&T Discovery with Unique Flagship Facilities
- Nurture Mutually Beneficial National and International Partnerships

Operations

- Enable Faster Decision Making and Execution
- Evolve to a Risk-Managed, Agile Operations and Oversight Model
- Streamline Lab-wide Operations with Improved Productivity
- Accelerate Progress to a Sustainable Site that Embraces Hybrid Work

Workforce

- Engage in Impactful, Challenging Work
- Create Greater Personal Growth Opportunities
- Provide a Collaborative, Inclusive Environment
- Offer Wide-Ranging Career Opportunities

Section 6.5: Future State of Strategic Investments (cont.)

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. Moving forward, an effort will be made to define and nurture a set of strategic academic relationships to enhance engagement with particular student cohorts. 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 connected world. The Laboratory's partnership and open innovation initiatives are purposefully oriented to ensure excellence and to understand the use and implications of critical and emerging technologies. These connections with industry, government agencies, universities, and international counterparts cultivate entrepreneurship, help the nation grow, and meet national and global security challenges.

Livermore Valley Open Campus

The Livermore Valley Open Campus (LVOC) was created to foster collaboration among LLNL, Sandia National Laboratories, private industry, and academic institutions. Earlier investments in LVOC collaboration spaces, such as the Advanced Manufacturing Laboratory and the adjacent office building space have resulted in productive collaborations. Celebrating its first full year of operations at LVOC in FY23, the University of California Livermore Collaboration Center (UCLCC) reflects a growing dimension of parent company support and expertise and manifests a vision of enhanced university / laboratory collaboration. UCLCC serves as a multi-campus hub to expand collaborations and partnerships through outreach and education. New facilities at LVOC—the Integrated Bio Resilience Laboratory and the Prototyping Enclave—are being planned. These two experimental facilities are critical facility needs for the future.

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.

Acronym List

AEO: Academic Engagement Office	ISCP: Institutional Scientific Capability Portfolio
AI: artificial intelligence	JLF: Jupiter Laser Facility
AI3: AI Innovation Incubator	KPI: key performance indicator
AMM: Advanced Materials and Manufacturing	LDRD: Laboratory Directed Research and Development
BOG: Board of Governors	LLNL: Lawrence Livermore National Laboratory
DARPA: Defense Advanced Research Projects Agency	LLNS: Lawrence Livermore National Security
DDST: Deputy Director for Science and Technology	L&R: Licensing and royalties
DHS: Department of Homeland Security	LVOC: Livermore Valley Open Campus
DOD: Department of Defense	OKR: Objectives and Key Result
DOE: Department of Energy	NASA: National Aeronautics and Space Administration
DNN: Office of Defense Nuclear Nonproliferation	NARAC: National Atmospheric Release Advisory Center
EOS: equation of state	NIF: National Ignition Facility
ERC: external review committee	NIH: National Institutes of Health
FFRDC: Federally Funded Research and Development Center	NNSA: National Nuclear Security Administration
FY: fiscal year	MFA: Mission Focus Area
FSC: Forensic Science Center	MJ: megajoule
HEAF: High Explosives Applications Facility	ML: machine learning
HED: high energy density	R&D: research and development
HPC: high performance computing	SC: Office of Science
HPGe: high-purity germanium	SOHIP: Stellar Occultation Hyper-temporal Imaging Payload
ICF: inertial confinement fusion	SPP: Strategic Partnership Project
IDTC: integrated Deterrence and Technology Competition	SSP: Stockpile Stewardship Program
IFE: inertial fusion energy	S&T: science and technology
IPO: Innovation and Partnerships Office	ST&E: science, technology, and engineering

LLNL-MI-1087002

V2_01/02/2024

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

