Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) is preeminent in its ability to harness the power of science and technology to address critical national security challenges.

Compelling Mission

Since its inception in 1952, LLNL has embraced its role as a "new ideas" laboratory, focusing on novel concepts and innovative approaches to national security science and engineering.

Its defining responsibility is stockpile stewardship—ensuring the safety, security, and reliability of the nation's nuclear stockpile. Yet LLNL's mission is broader than stockpile stewardship, as dangers ranging from nuclear proliferation and terrorism to cyber attacks and climate change threaten national security and global stability. The Laboratory's science and technology are being applied to achieve breakthroughs for counterterrorism and nonproliferation, defense and intelligence, energy and environmental security.

Strategic Partnerships

LLNL engages in partnerships with other laboratories, research universities, and high-technology industries to solve pressing national and global problems. Livermore has particularly strong partnerships with Sandia National Laboratories and Los Alamos National Laboratory, with shared stockpile stewardship and other national security initiatives, and with the University of California. Closer to home, the Laboratory is partnering with California's energy providers to improve the efficiency, security and safety of the state's utility systems.

Exceptional Science and Technology

The Laboratory's mission requires outstanding capabilities in multiple scientific and engineering disciplines, including:

- **High-Energy-Density Science**: Provides international leadership in studying and controlling matter under extreme conditions of temperature and pressure.
- **High-Performance Computing, Simulation, and Data Science:** Leads in the development, integration and use of new computer architectures, predictive simulation capabilities, knowledge extraction tools, and analytical techniques.
- **Nuclear, Chemical, and Isotopic Science and Technology**: Advances the fundamental understanding, scientific capabilities, and technologies in nuclear and particle physics, radiochemistry, analytical chemistry, and isotopic signatures to support LLNL's multifaceted national security mission.
- **Advanced Materials and Manufacturing**: Meets NNSA and national needs for the responsive, cost-effective development of advanced materials and manufacturing processes and systems.
- **Lasers and Optical Science and Technology**: Designs, builds, and reliably operates complex laser systems that dramatically advance the state of the art to meet strategically important applications.
- **Bioscience and Bioengineering**: Works at the interface of biology, engineering, and the physical sciences to address national challenges in biosecurity, chemical security, bioenergy, and human health.
- **Earth and Atmospheric Science**: Advances the frontier in Earth and atmospheric sciences to develop innovative capabilities that drive LLNL's energy and national security missions.

Key Facilities

The Laboratory supports a number of unique facilities that are central to its ability to carry out its national security mission:

- **National Ignition Facility (NIF):** Largest, most-energetic laser facility in the world.
- **Livermore Computing (LC):** Home to some of the world's fastest computers, including Sierra (125 peak petaflops) and Sequoia (20 petaflops).
- **High-Explosives Applications Facility (HEAF):** State-of-the-art research facility for formulating, characterizing, processing, and testing energetic materials.

- **National Atmospheric Release Advisory Center (NARAC):** National resource for predicting the spread of airborne releases of hazardous materials.
- **Advanced Manufacturing Laboratory (AML):** Houses some of the most capable equipment in the field of advanced manufacturing. Additional resources include material evaluation and characterization equipment, HPC modeling and simulation systems, and manufacturing capabilities from several LLNL programs.
- **Forensic Science Center (FSC):** Nationally recognized forensic analysis capabilities in support of nuclear, chemical, explosives and biological counterterrorism.
- **Center for Accelerator Mass Spectrometry (CAMS):** World's most versatile and productive accelerator mass spectrometry facility.
- **Site 300:** Remote site for high explosives and environmental testing.
- **Livermore Valley Open Campus (LVOC):** An unclassified research and development space connecting industry and academia with Laboratory expertise to advance HPC, energy and environmental security, cyber security, economic security, and non-proliferation.

Operational Excellence

Effective management, business practices, and operations provide the essential foundation for LLNL's mission activities. Safety, security, and environmental sustainability are explicitly designed into all activities. Working within a framework of performance-based management, the Laboratory strives to continually improve the quality of its business and operational performance.

Outstanding Workforce

The challenges of our missions demand that we draw on the widest possible diversity of talents, thought, and experiences. LLNL's workforce includes roughly 4,831 scientists, engineers, and postdoctoral fellows, as well as visiting scientists and students. Below is a breakdown of our scientific workforce by highest degree discipline and highest degree level:

Engineering	35%	Ph. D.	1,914
Math/Comp Sci	15%	Masters	1,001
Physics	13%	Bachelors	1,503
Physical Sci	12%	Associates	413
Bio/Med	6%		
Other	19%		

LLNL-MI-675190
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November 30, 2021

Lab At A Glance

Location: Livermore, California

Type: National security laboratory

Contract Operator: Lawrence Livermore National Security, LLC

Principal Sponsor: National Nuclear Security Administration, DOE

Director: Kimberly S. Budil

Website: http://www.llnl.gov/

Physical Assets:

- 7,000 acres (owned)
- 521 building/trailers
- 6.5 million gross square feet in active buildings
- Replacement plant value: $22.9B

Human Capital:

- 8,172 LLNS employees, including:
  - 19 joint faculty
  - 300 postdoctoral researchers
  - 120 undergraduate interns
  - 153 graduate students

FY 2021 Funding: $2.8 billion

- Weapons activities: 66%
- Department of Defense: 12%
- Nonproliferation/Counterterrorism: 7%
- Department of Energy: 5%
- Safeguards and Security: 4%
- NNSA Construction: 2%
- Other: 2%
- DOE Integrated Contractor: 1%
- Homeland Security: 1%

Stockpile Stewardship at LLNL

Ensuring confidence in the safety, security, and effectiveness of the U.S. nuclear deterrent.

Maintaining the Stockpile

Since 1992, scientists have not confirmed the performance of America's nuclear arsenal by conducting explosive tests underground at the Nevada Test Site. Instead, researchers ensure the continuing safety, security, and effectiveness of America's nuclear stockpile through the National Nuclear Security Administration's (NNSA's) science-based Stockpile Stewardship Program.

Established in 1994, this program comprises surveillance, advanced simulations, scientific and engineering experiments, materials research, and refurbishment. As part of stockpile stewardship, LLNL scientists and engineers regularly assess the health of the stockpile to inform refurbishment decisions.

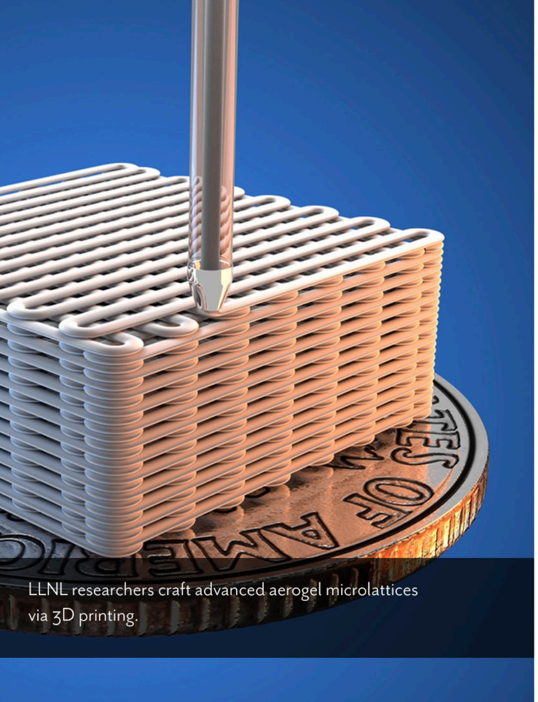
A critical part of stockpile stewardship is life extension programs (LEPs), which refurbish, replace, or redesign aging components of a warhead or bomb that require modernization. Experts design components and systems for the LEPs and certify the life-extended models when they enter the stockpile.

By ensuring confidence in the safety, security, and effectiveness of the U.S. nuclear deterrent, stockpile stewardship permits the nation to retain a small nuclear stockpile consistent with the need to deter adversaries and reassure allies.

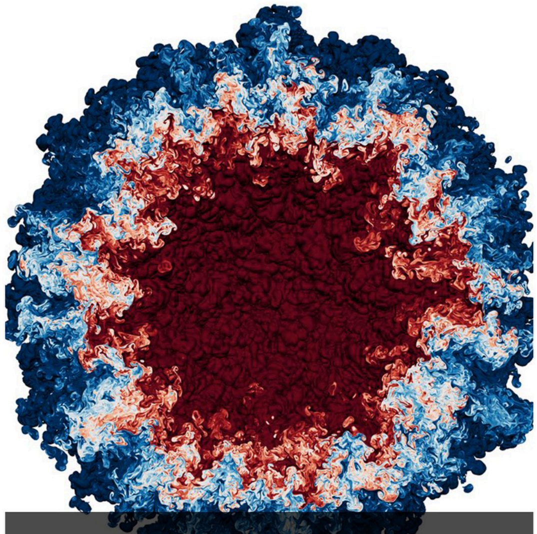
Accomplishments

In addressing technical challenges, stockpile stewardship has worked exceedingly well. An expert workforce; advances in nuclear theory, understanding how aging mechanisms can degrade performance and safety; investments in world-class experimental facilities such as the National Ignition Facility (NIF) and the Contained Firing Facility (CFF); improvements in materials and manufacturing; and the development of new supercomputing capabilities all contribute to advances and accomplishments across LLNL. These include:

- The W87-1 Modification Program restarted in FY19 and will field a warhead on the U.S. Air Force's new Ground-Based Strategic Deterrent by FY2030.
- LLNL is making excellent progress in the LEP for the W80-4 warhead for the U.S. Air Force Long-Range Standoff missile. Livermore experts work closely with Air Force and missile contractors and are transferring design details to NNSA production agencies.
- Recent upgrades to aging facilities and infrastructure at LLNL's main campus and remote Site 300 enhance support for stockpile stewardship.
- LLNL high-explosives experts have pioneered the use of insensitive high explosives (IHEs) to lessen the possibility of accidental detonation.
- Multi-physics simulations performed on cutting-edge computer platforms are powerful tools for design assessment and certification of nuclear weapon weapons and their components. The next-generation supercomputer, Sierra, plays an important role in modeling complex physical phenomena.
- Experiments conducted on NIF, the world's largest and most energetic laser, test materials in high-energy-density regimes formerly inaccessible to scientists.
- An LLNL team gathered 6,500 decomposing films of the nation's 210 atmospheric nuclear tests. The films were scanned to preserve content and reanalyzed to extract more precise data about nuclear weapons performance.



LLNL researchers craft advanced aerogel microlattices via 3D printing.



A 98-billion-cell inertial confinement fusion-inspired hydrodynamic instability simulation.

One of seven large fully contained firing tanks at the High Explosives Applications Facility (HEAF).

Scientific Underpinnings

Stockpile stewardship takes advantage of five LLNL core competencies: high-energy-density science; lasers and optical science and technology; advanced materials and manufacturing; high-performance computing (HPC), simulation, and data science; and nuclear, chemical, and isotopic science and technology. In an example of cross-disciplinary science, researchers studying the aging of weapons plutonium have combined advances in nuclear theory with new types of experiments and supercomputer simulations.

A critical element in stockpile stewardship is high-performance computing and simulation. LLNL's Sierra, with a peak speed of 125-petaflops, is a six-fold performance improvement over LLNL's previous supercomputer, Sequoia. Sierra performs complex multi-physics calculations needed for the demanding requirements of stockpile stewardship. Scientific achievements from across the enterprise are further detailed below.

- NIF supports stockpile stewardship through a wide range of experiments. High-energy-density science research explores crucial environments for stockpile stewardship and critical to understand nuclear weapons performance.
- LLNL uses revolutionary advanced manufacturing methods to make parts with optimized properties at lower costs and shorter production schedules.
- LLNL energetic materials scientists examine the physical, chemical, detonation, and mechanical properties of high explosives used in the nuclear stockpile. Researchers are exploring the use of new insensitive high explosives to further enhance safety.
- Scientists combine data from computer simulations, previous nuclear tests, non-nuclear experiments, and theoretical studies to quantify confidence factors (known as quantification of margins and uncertainties) for assessing nuclear weapon performance.
- In hydrodynamic testing at the CFF, components are subjected to extreme pressure and shock and start to behave like liquids. These experiments—combined with results from other experiments as well as theory and HPC—ensure confidence in the nation's nuclear deterrent by providing vital data about what happens during a nuclear detonation.
- Researchers have developed advanced diagnostic techniques that gather data to validate simulation models and enhance understanding of weapon physics.

The Future

During the next few years, researchers will continue meeting the goals of the W80-4 Life Extension Program (LEP) and the W87-1 modification. Livermore scientists and engineers will explore ways to take advantage of advanced manufacturing to improve quality while reducing costs.

LLNL scientists will refine the physics and engineering simulation codes that support annual assessments and LEPs by improving the predictability and quantification of uncertainties. Stockpile surveillance activities, weapon subsystem tests, and flight tests will supply critical data to simulations.

Meeting Stockpile Stewardship Program goals demands outstanding scientific and engineering talent. In response to an increasing number of retiring researchers, LLNL is training the next generation of stockpile stewards.

LLNL-MI-836040
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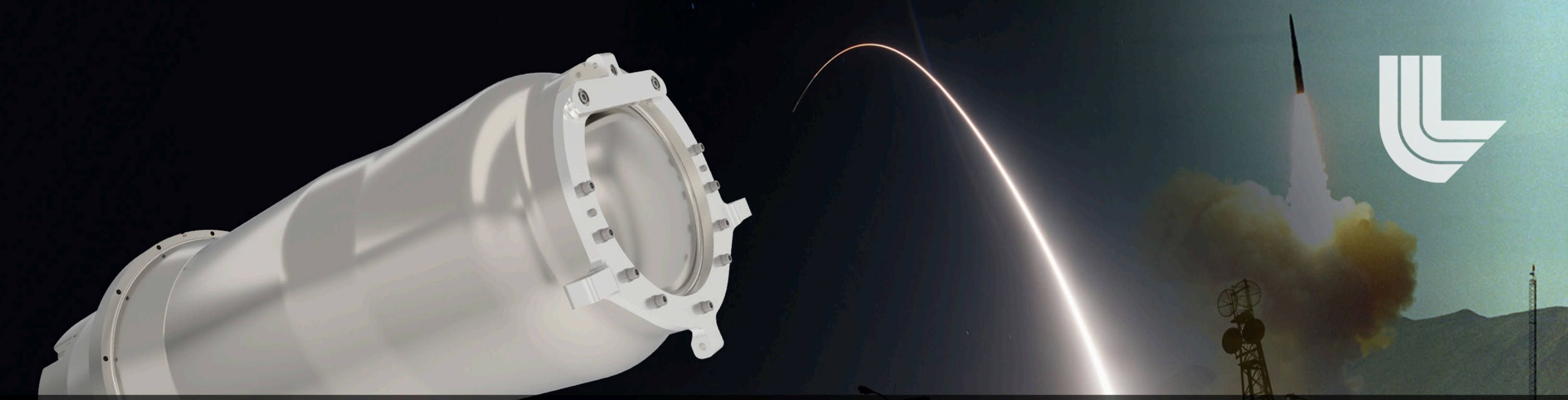
June 7, 2022



W80-4 and W87-1 Warheads

These warheads are being developed in cooperation with the Department of Defense (DOD) and will serve the nation into the second half of this century.

Modernizing the Stockpile

Lawrence Livermore National Laboratory (LLNL) is the lead design agency for the nuclear explosive package in two separate programs: the W80-4 Life Extension Program (LEP) and the W87-1 Modification Program.

The W80-4 replaces the W80-1 warhead, currently employed in the U. S. Air Force's Air-Launched Cruise Missile (ALCM). The Long-Range Standoff missile will replace the aging ALCM.

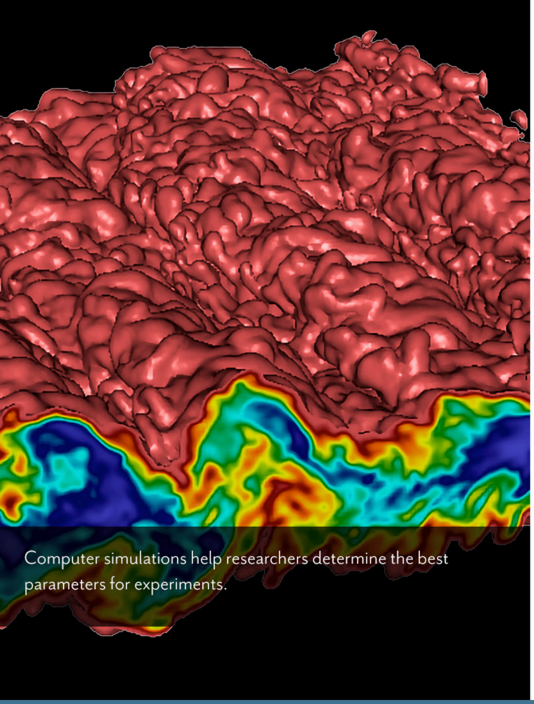
The W87-1 Modification Program will replace aging W78 warheads (more than 50 years old when due for replacement) in the stockpile and, together with the W87-0, underpin the nuclear triad. The W87-1 will be fielded in the Air Force's Ground-Based Strategic Deterrent missile, slated to replace the aging Minuteman III Intercontinental Ballistic Missile system.

The W80-4 will be the first warhead designed for use with a new missile since nuclear testing ended in 1992. The W87-1 is the first modern warheads to have all of its components manufactured in the modern National Nuclear Security Administration (NNSA) complex. These designs are based on well-tested nuclear components and will not require new underground nuclear tests to certify the warheads. Certification will rely on improved understanding and the highly capable tool set developed by the science-based Stockpile Stewardship Program (see Scientific Underpinnings on back).

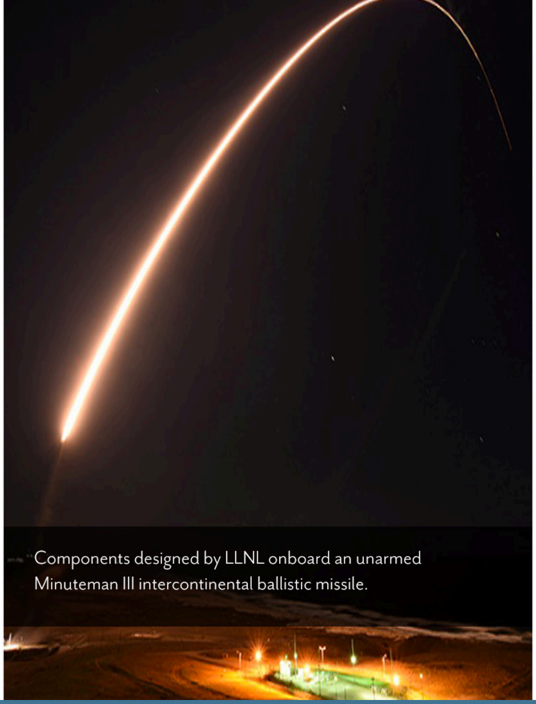
Accomplishments

The W80-4 LEP continues Phase 6.3 development engineering efforts, started in 2019, to perform design development and testing that enables design and specification release of the W80-4 warhead to the production agencies. The W87-1 Modification Program, restarted in January 2019, is in Phase 6.2: feasibility study and design options. LLNL is committed to completing the W80-4 LEP and W87-1 Modification Program in support of DOD's nuclear modernization programs. Both the W80-4 and W87-1 teams are making significant progress:

- Between the two programs, more than 200 team members work with production agencies, NNSA, and the U.S. Air Force to design hardware, transfer technology, address manufacturing issues, deliver hardware, and execute vital system assessments.
- For the W80-4 LEP, an extensive range of full-system tests and hundreds of small-scale tests provide confidence in the performance of design options that include advanced manufactured components.
- The W87-1 Modification Program is currently conducting Phase 6.2—feasibility study and down select—with the goal of entering Phase 6.2A—design definition and cost study—in the third quarter of FY2021.
- LLNL leads the Department of Energy's effort to develop and qualify the insensitive high explosives (IHEs) formulated using newly produced compounds. Manufacturing production-scale quantities of the new explosives is underway.
- Ongoing revitalization at LLNL's main site and experimental test site ensures the readiness of facilities and infrastructure to execute both programs.
- The next-generation supercomputer, Sierra, with a peak speed of 125-petaflops, is now sited at Livermore and plays a central role in assessing W80-4 and W87-1 performance and certification.
- Material characterization experiments conducted at the National Ignition Facility (NIF) strengthen the technical foundation and inform program options.



Computer simulations help researchers determine the best parameters for experiments.



Components designed by LLNL onboard an unarmed Minuteman III intercontinental ballistic missile.

LLNL staff pictured with a W80-4 nuclear explosives package engineering test.

Scientific Underpinnings

The science-based Stockpile Stewardship Program, established in 1994 as a response to the end of explosive nuclear testing, provides advanced tools for developing and certifying warheads. Prior to the program, the nation benefited from underground nuclear testing to calibrate and adjust computational models of warhead performance and safety. The program improves knowledge of the underlying physics and engineering through understanding validated by modern experiments. Certification of the warheads will be informed by extensive component testing, high-fidelity and predictive warhead simulations that model the integration of a warhead on a new delivery platform, and high-fidelity flight tests. A few key program facts:

- The program resolved the long-standing energy balance anomaly, removing a major source of disagreement between simulations and test data on past nuclear events.
- Understanding data on material equations of state—how materials behave at extreme pressures and temperatures—enables greater predictive modeling not available during the nuclear testing era.
- High-performance computing advances have fostered a shift from 2D to 3D modeling with a special focus on quantifying uncertainty, which alleviates the need to rely on approximations that were required during the nuclear test era.
- Modern hydrodynamic testing and diagnostics at the Contained Firing Facility and high-energy-density experiments on platforms such as NIF provide data important to informing confidence in weapon performance models.
- Predictive warhead lifetime models are being developed to ensure confidence in warhead lifetimes, as are nondestructive evaluation tools to assess component health and preserve assets.
- Significant advancements in manufacturing are improving the quality of replacement components.
- The warheads will be certified to meet requirements in both normal and abnormal environments. Computational engineering models, validated using data from missile flight tests and engineering tests, ensure warhead safety and reliability.

The Future

The W80-4 LEP's next stage will be Phase 6.4—production engineering. The follow-on phases are Phase 6.5—first production, and Phase 6.6—full-scale production. For the W87-1, the team will establish a baseline cost for the W87-1 during the next step, Phase 6.2A—design definition and cost study.

Program execution will focus on meeting NNSA's product realization requirements, including its deliverables and timeline. Improved manufacturing efficiencies, the use of insensitive high explosives, and new technologies such as advanced manufacturing will all play a role in meeting these requirements.

Addressing future scenarios of warhead survivability will require exascale-class computers such as LLNL's El Capitan, projected to be the world's most powerful supercomputer when it is fully deployed in 2023. El Capitan will provide routine 3D studies of critical warhead requirements, ensuring the NNSA laboratories can meet their primary mission of keeping the nation's nuclear stockpile safe, secure, and effective.

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High-Performance Computing, Modeling, and Simulation

Addressing national security challenges through innovative computational solutions on world-class computer resources.

Computing at Livermore

The goal of high-performance computing (HPC), modeling, and simulation is to transform theories that explain physical phenomenon into models that can reliably predict outcomes, thereby reducing the number of expensive experiments needed to verify predictions or design new products. HPC simulations predict complex physical behavior, while experiments verify the computer simulations with real outcomes.

HPC is a linchpin of LLNL's nuclear deterrence mission. Scientists at Livermore use HPC to simulate the behavior of matter under extreme conditions of temperature and pressure, which are characteristic of nuclear detonations.

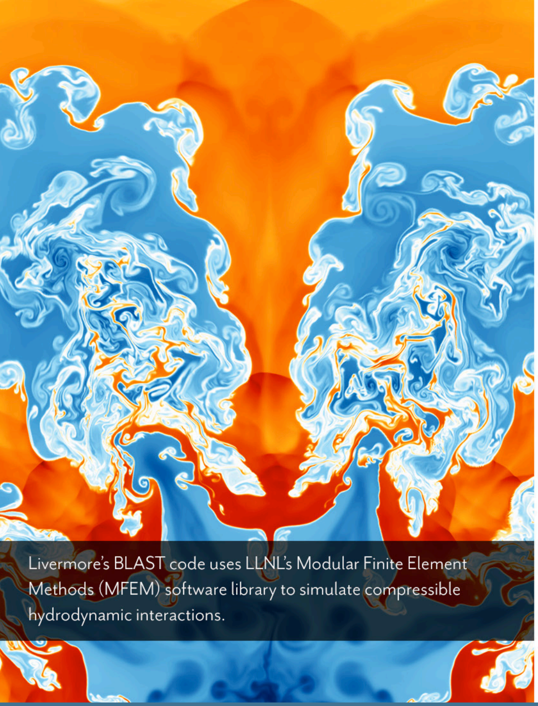
Livermore's advanced computing ecosystem also supports the broader mission needs of the Department of Energy and its National Nuclear Security Administration and other agencies such as Defense and Homeland Security.

In support of its research, the Laboratory operates a major computing center, Livermore Computing, which is one of the world's most prominent and consistently successful computer centers.

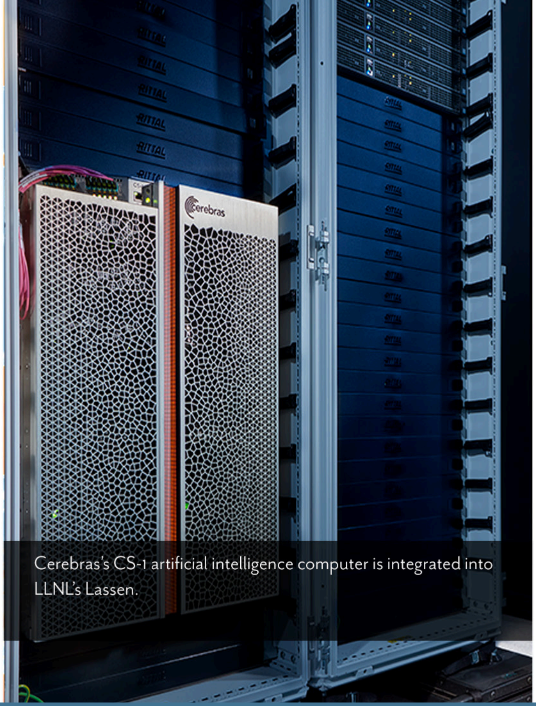
Accomplishments

Lawrence Livermore is a leader in developing and using HPC to perform its missions in nuclear deterrence, national security, and basic scientific research. Among its most significant recent accomplishments:

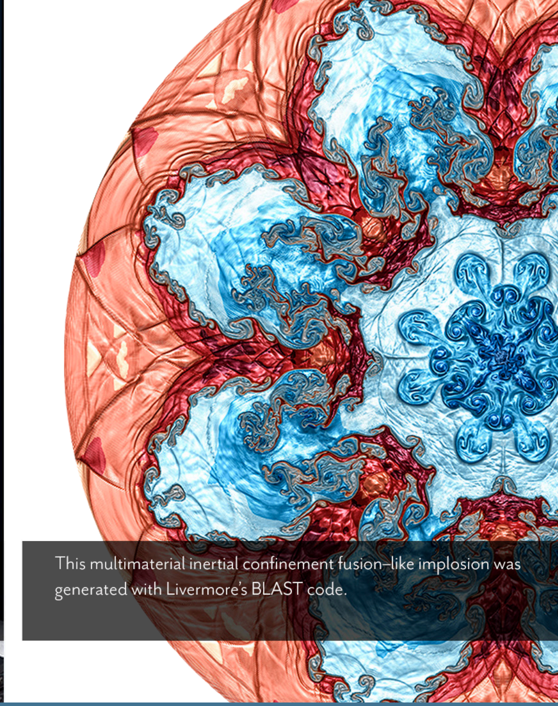
- Annually providing the simulation capability to assure the safety, security, performance, and reliability of the nation's nuclear deterrent during the National Nuclear Security Administration's stockpile assessment process.
- Helping lead the Department of Energy's Exascale Computing Project and delivering algorithms, libraries, and applications that are foundational to the success of exascale-class systems.
- Partnering with researchers at Livermore and elsewhere to solve science problems, such as:
    - Combatting COVID-19 with R&D activities that inform antiviral drug experimentation; create a software platform to optimize properties of antiviral drugs; and upgrade the computing systems that power these projects.
    - Developing a machine learning model that can quickly and accurately predict 3D crystalline properties of molecules (e.g., density) from their 2D chemical structures. Researchers are using the model to search for new insensitive high-explosive materials.
    - Understanding the life and death of a neutron to provide a window into the subatomic world and gain insight into the way the universe has evolved.



Livermore's BLAST code uses LLNL's Modular Finite Element Methods (MFEM) software library to simulate compressible hydrodynamic interactions.



Cerebras's CS-1 artificial intelligence computer is integrated into LLNL's Lassen.



This multimaterial inertial confinement fusion–like implosion was generated with Livermore's BLAST code.

Scientific Underpinnings

HPC at Livermore has developed over many decades in close association with the Laboratory's nuclear weapons mission. Today, HPC is critical to the Stockpile Stewardship Program. Where once nuclear testing provided performance data, now Livermore scientists use HPC to simulate the behavior of matter under extreme conditions of temperature and pressure.

LLNL's national security mission relies on simulation codes that investigate physical processes and material behavior. These highly specialized codes must be able to run on a variety of advanced HPC architectures, incorporate efficient solvers and numerical algorithms, and enhance researchers' predictive capabilities.

A few key Program facts:

- Among their many computational assets, Livermore Computing houses some of the world's most powerful computers. These computers use tens of thousands of cores (central processing and graphics processing units) running at the same time—known as parallel processing.
- Our flagship supercomputer, Sierra, with a peak speed of 125-petaflops,is playing a central role in assessing W80-4 and W87-1 warhead performance and certification.
- Exascale systems sixteen times more powerful than Sierra are planned for 2023. El Capitan's exascale capability will aid the country's effort in a significant, time-critical weapons modernization project.
- HPC advances are enabling a shift to regularly using 3D modeling in design and uncertainty quantification ensembles, which alleviates the need to rely on approximations that were required during the nuclear test era.
- LLNL's "cognitive simulation" style of computing integrates simulation training and inference for physics material science, optimization of fusion applications, and drug development. In partnership with Cerebras Systems, LLNL integrated the world's largest computer chip into the top-tier Lassen supercomputer, upgrading the system with cutting-edge artificial intelligence (AI) technology.

The Future

The continuing expansion in both scale and complexity of our mission drives LLNL toward exascale and beyond computing capability and new data-driven and AI-augmented approaches to scientific discovery and engineering design. We continue to build our expertise in computing hardware, software, application codes, and the physical sciences to simulate these phenomena with higher fidelity and more realism.

Livermore is also pushing the frontiers of:

- New simulation technologies and algorithms, especially design optimization and decision support.
- Computing beyond exascale: heterogeneous, neural, and quantum architectures.
- Novel paradigms for science enabled by large-scale data analytics, machine learning, and cognitive simulations.
- Studying the convergence of HPC and cloud computing paradigms.

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August 29, 2022

NIF and High Energy Density Science

Supporting stockpile stewardship, pursuing laser fusion ignition and high energy density science, furthering U.S. competitiveness, and operating as a national user facility.

World's Largest Laser

The National Ignition Facility (NIF), the world's largest and highest-energy laser system, creates the extreme temperatures and pressures necessary to advance science-based stockpile stewardship, pursue laser fusion ignition, and deepen our understanding of the universe. Tens of thousands of optics strengthen and guide light from NIF's 192 laser beams into a 10-meter-diameter Target Chamber and onto miniature, highly engineered targets.

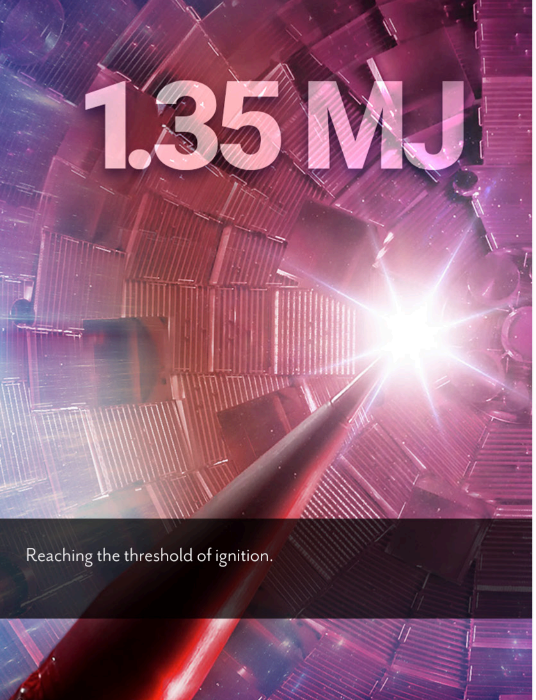
As the premier facility creating conditions relevant to understanding the operation of modern nuclear weapons, NIF is a crucial element of stockpile stewardship, producing experimental data that validates 3D weapon simulation codes, improves understanding of important weapon physics, and investigates questions remaining from underground nuclear tests. NIF experiments inform Life Extension Programs (LEPs), the regularly planned nuclear weapons system refurbishments that ensure long-term reliability.

And inertial confinement fusion (ICF) experiments also aid in investigating questions remaining from underground nuclear testing. These and other experiments study high energy density (HED) science, supporting a range of national security applications and the work of laboratory and university researchers to recreate astrophysical phenomena located light years away.

Accomplishments

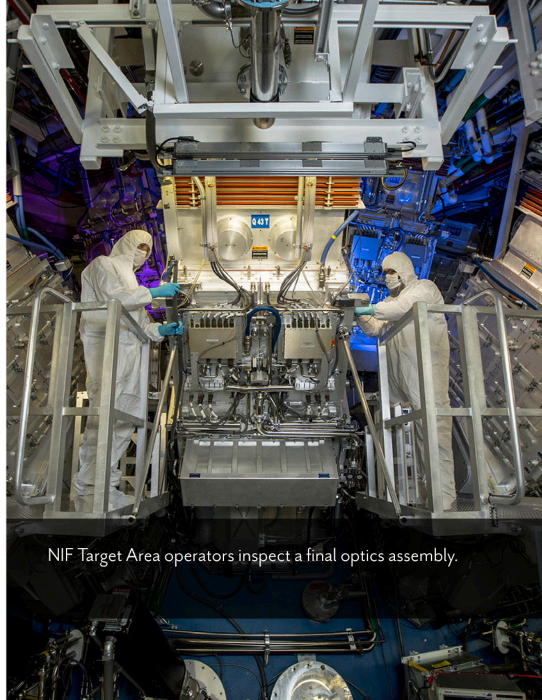
Since NIF became operational in March 2009, more than 3,000 shots have been conducted by researchers from national laboratories, the military, federal agencies, academia, and the international scientific community. NIF is proving itself a critical element of stockpile stewardship to maintain the effectiveness of America's nuclear weapons. NIF currently is the only facility capable of achieving fusion ignition and thermonuclear burn, a scientific grand challenge of the stewardship program.

- An experimental campaign achieved a fusion yield of 1.35 MJ of fusion energy output, at the threshold of ignition. This provides new opportunities to move toward high yield for stockpile applications and sets the scientific basis for an inertial fusion energy future.
- NIF has safely executed 17 plutonium diffraction experiments, returning important scientific data on plutonium's behavior at high pressure to support stockpile stewardship.
- NIF experiments have helped stockpile stewards answer questions important to the current Life Extension Program for the Air Force W80-4 warhead.
- LLNL scientists developed an experimental platform at NIF to measure the melting curve of iron to 1,000 GPa. The Discovery Science Program, which provides academic users access to NIF's HED regimes and enhances collaborations between LLNL scientists and academia, made this work possible.
- NIF produced a record 2.15 megajoules (MJ) of UV energy and 438 terawatts of peak power, a 15 percent improvement over NIF's original 1.8 MJ design specification.
- The Advanced Radiographic Capability (ARC), a high-energy, high-intensity laser embedded within NIF, can create more penetrating x rays for new radiography capabilities, revealing phenomena with never-before-seen clarity for classified weapons science experiments.
- Use of NIF by the radiation effects community is growing rapidly and NIF is studying how electronics and materials behave when exposed to extreme neutron pulses.



Reaching the threshold of ignition.


A cryogenic target used in NIF fusion experiments.


NIF Target Area operators inspect a final optics assembly.

Scientific Underpinnings

NIF embodies several LLNL core competencies, including HED science; lasers and optical science; advanced materials and manufacturing; ultrafast detectors and precision diagnostics; and nuclear, chemical, and isotopic science. HED research examines materials under pressures and densities found in stars, the cores of giant planets, and detonating nuclear weapons, helping to advance fields such as astrophysics and materials science. Advanced diagnostic instruments provide unprecedented insights into HED systems. Experimental data inform and validate 3D weapon simulation computer codes. Many NIF shots focus on advancing prospects of ICF ignition for the stewardship program. Experiments rely on miniature and intricate targets, leveraging LLNL's materials science and advanced manufacturing strengths.

- Designing successful experiments in NIF's often unprecedented regimes draws upon LLNL's expertise in many scientific disciplines, including high-pressure materials science and computational, atomic, radiation, nuclear, and plasma physics.
- LLNL scientists have made significant progress in preventing damage to optics in high-intensity laser light. Patented processes make optics' surfaces more resilient by removing impurities and absorbing microfractures; these breakthroughs extend the lifetime of optics and permit increased energy from NIF laser light.
- Experimenters rely on an array of more than 100 nuclear, optical, and x-ray diagnostic instruments — many designed and fabricated at LLNL in collaboration with universities and the other national labs — to record vital data from NIF shots at micrometer-length scales and picosecond (trillionths of a second) timescales. These instruments push the state-of-the-art in measurement capabilities.
- NIF experiments rely on a wide variety of targets that all have intricate assemblies of extremely small parts. Designing, machining, and assembling these parts with micro manipulators into precisely manufactured targets requires a complex interplay among target designers, physicists, materials scientists, chemists, engineers, and technicians. Continuous improvements in NIF targets is a key to progress toward ignition.

The Future

NIF is a cornerstone facility for stockpile stewardship. As the last underground tests recede into history, NIF experiments will become more critical to stewardship and for paving the way toward an inertial fusion energy future. The high rigor and multidisciplinary nature of NIF experiments also help LLNL attract, retain, and train future stockpile stewards.

NIF scientists and engineers are pushing on all fronts to increase NIF's capabilities to address challenges, including higher energy and power limits, next-generation optics, improved targets with tighter specifications, and better diagnostics.

With NIF implosions at the threshold of ignition, further improvements will lead to robust and reproducible fusion ignition, which will enable the stewardship program to conduct experiments in new physical regimes.

Continued research, together with sustainment and enhancements of NIF, will lead to better implosions and improved understanding of fusion ignition requirements.

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September 12, 2022

Advanced Materials and Manufacturing

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

Mission Impact

Lawrence Livermore National Laboratory (LLNL) brings a multidisciplinary approach to address our nation's need for rapid development of advanced materials and manufacturing processes. Our scientists and engineers develop innovative materials with tailored properties that can be used across a broad range of mission applications, including energy storage; advanced optical materials used in high-intensity laser systems; quantum materials; and components that can function effectively in extreme environments.

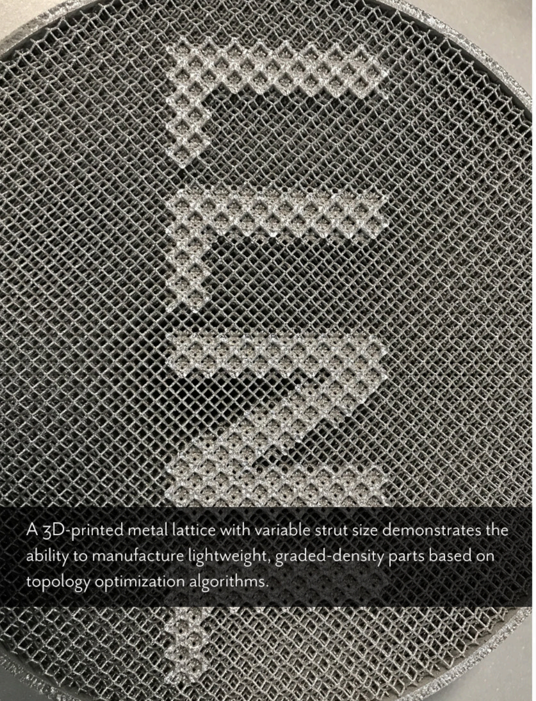
We continue to advance manufacturing technology, enabling us to develop customized feedstocks and unique fabrication techniques. We also develop novel diagnostic methods so we can accelerate testing and evaluation cycles—and deliver timely solutions.

Our overall aim is to create an advanced material development and manufacturing ecosystem that is more agile and more responsive to the needs of national security stakeholders. We explore ways to reduce manufacturing costs, reduce material and energy waste, and accelerate discovery and development timelines. In addition, we use multiscale predictive modeling and machine learning to reduce uncertainties regarding how a material will perform at scale, in relevant conditions, over its service lifetime.

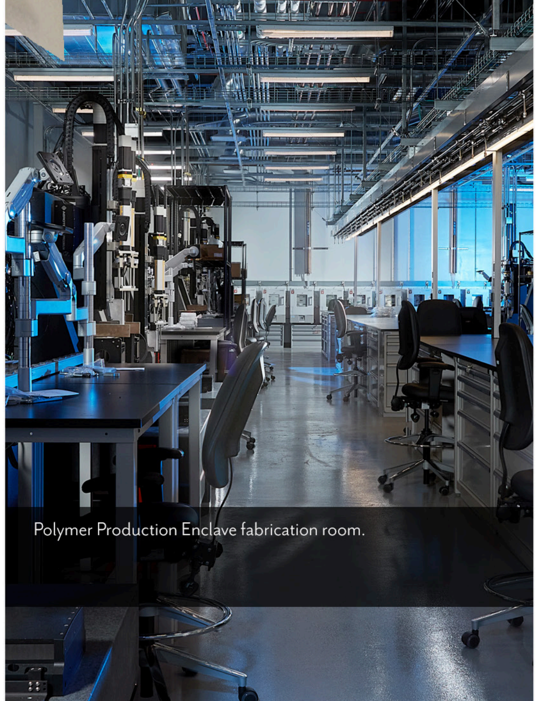
Accomplishments

At LLNL, today's research builds on decades of experience studying a broad spectrum of materials and mission-relevant applications. Our research spans the entire design-development-deployment cycle, including discovery and optimization of materials that can meet emerging mission needs, and manufacturing capabilities that can produce materials at scale, with structures that are tailored to meet specific performance requirements. Examples of our accomplishments include development of:

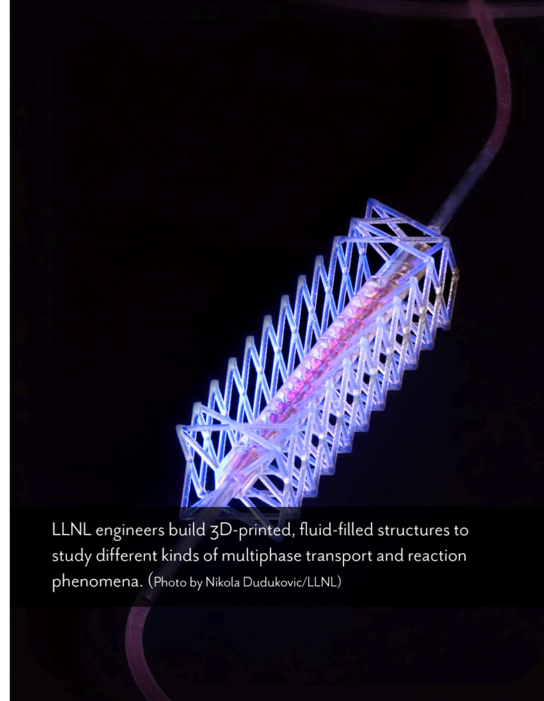
- Customized alloys for extreme environments, with thermally stable microstructures that are lightweight, corrosion-resistant, and radiation-tolerant, and use of predictive models to identify aging-resistant designs—with applications such as hypersonic vehicles, space science, high-power lasers, and nuclear reactors.
- Highly permeable polymer microcapsules filled with sorbents that can capture carbon dioxide from our atmosphere and facilitate long-term sequestration.
- A method to 3D-print microbes in controlled patterns, expanding the potential for using engineered bacteria to recover rare-earth metals, clean wastewater, and detect actinides.
- A laser-based volumetric additive manufacturing (AM) technique, known as computed axial lithography, which can be used to fabricate layer-less micro-optics with complex architectures and extremely smooth surfaces in only seconds.
- A groundbreaking method to control the flow of liquids and gases using 3D-printed, micro-architected structures—a novel approach to cellular fluidics with applications such as conversion of carbon dioxide to fuel, desalination, air filtration, heat transfer, and delivery of fluids in zero-gravity environments.
- Composite materials with the ionic conductivity needed to increase voltage, storage capacity, and thermal stability—providing new options for fast-charging, lightweight batteries.
- Additively manufactured transparent ceramics with customized composition and structure, optimized for use as laser-amplification media.



A 3D-printed metal lattice with variable strut size demonstrates the ability to manufacture lightweight, graded-density parts based on topology optimization algorithms.



Polymer Production Enclave fabrication room.



LLNL engineers build 3D-printed, fluid-filled structures to study different kinds of multiphase transport and reaction phenomena. (Photo by Nikola Dudukovic/LLNL)

Scientific Underpinnings

LLNL integrates expertise in engineering, materials science, physics, chemistry, data science, and manufacturing science to create innovative solutions. For example, we study the chemical, electronic, structural, and kinetic properties of materials—including polymers, alloys, ceramics, foams, and biomimetic materials. We explore ways to enhance feedstock development, fabrication techniques, and characterization methods, and we study material aging and degradation that can impact long-term performance. We use LLNL's high-performance computers to conduct predictive simulations of material properties, performance, and degradation, enabling us to optimize designs. The following LLNL resources accelerate development of innovative solutions:

- **The Advanced Manufacturing Laboratory** and the **Center for Engineered Materials and Manufacturing** develop new AM capabilities, including laser systems, advanced optics, and multi-material solutions, which are used to fabricate architected materials with unique properties, while also fostering partnerships with industry and academia.
- **The Polymer Production Enclave** enables rapid design and development of polymer parts for stockpile modernization programs, offering a unique space where design activities and production enhancements can be rapidly tested and evaluated.
- A suite of **advanced, in-situ, non-destructive characterization capabilities**, including 3D imaging, spectroscopy, x-ray computed tomography, and ultra-fast electron microscopy—enables researchers to rapidly assess a material's properties and identify defects introduced through the manufacturing process.
- **World-class supercomputing resources,** which data scientists use to conduct high-fidelity multiscale models of material synthesis and manufacturing processes—enabling rapid design, scale-up, and optimization of new, tunable materials and feedstocks.
- **The Laboratory for Energy Applications for the Future** (LEAF) fosters cross-cutting research aimed at accelerating development of scalable, optimized structures for energy production, storage, and transmission, such as batteries, supercapacitors, hydrogen energy systems, desalination, and carbon capture and conversion.
- **The Superblock facility** and other spaces designed to handle advanced radiological materials, where we develop and deploy customized actinide processing techniques and deliver high-purity, actinide-based materials for mission-critical experiments.

The Future

Our long-term vision involves leveraging LLNL's newest resources to expand collaborative research space. We will explore new partnerships with industry and research institutions at the Advanced Manufacturing Lab and the Polymer Production Enclave, boosting our ability to rapidly deliver solutions.

We will continue to take leadership roles in DOE-sponsored research collaborations to enable efficient hydrogen production, storage, and delivery solutions. We will continue participating in the DOE Energy Materials Network and related multilab consortia, while planning and executing DOE's long-term strategy aimed at addressing critical materials challenges.

Innovative solutions will be adapted for new environments, including applications in biosecurity, water security, space science and security, and materials for environmental remediation. LLNL ensures the long-term performance of energy production and delivery infrastructure as it faces climate-caused risks to material used in pipelines, turbines, and nuclear power plants. The Laboratory retains a continued focus on accelerating delivery of solutions that support the safety and reliability of our nuclear deterrent.

LLNL-MI-839849
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September 14, 2022

Energetic Materials

Strengthening the nuclear deterrent, conventional munitions, and homeland security with new energetic materials and applications.

Central to the Mission

Energetic materials (EM) such as explosives, thermites, propellants, and pyrotechnics are central to Lawrence Livermore National Laboratory's (LLNL's) national security mission. EM are utilized throughout a nuclear weapon and also provide the energy source for most conventional munitions.

LLNL is a Department of Energy/National Nuclear Security Administration Center of Excellence for the research, development, synthesis, formulation, and characterization of explosives. The primary mission of LLNL's EM Enterprise is to ensure the safety, security, and effectiveness of the U.S. nuclear deterrent.

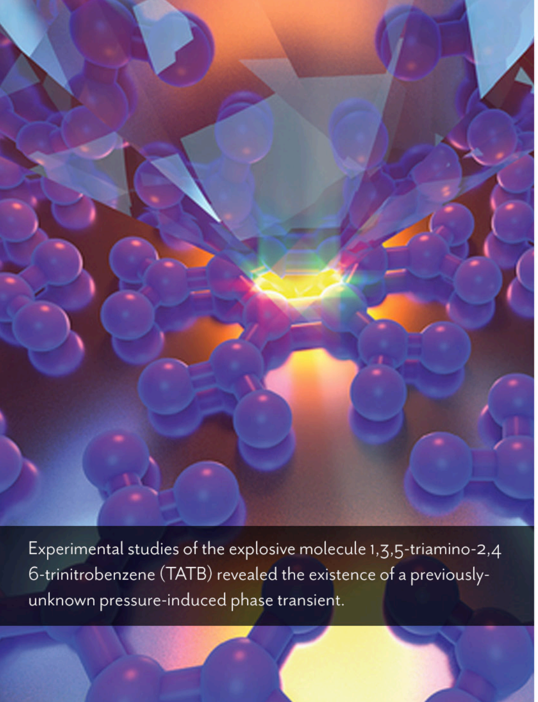
Researchers also apply their expertise to develop solutions for Department of Defense conventional weapons, explore new ways to detect and defeat home-made explosives for the Department of Homeland Security, and develop strategies to counter the threat of improvised explosive devices for nuclear counterterrorism.

Experimental facilities at Livermore's Main Site (Site 200) and remote Site 300 enable research, that, when coupled with high-fidelity modeling and simulation, help advance scientific discovery in EMs.

Building a Center of Excellence

LLNL scientists have developed numerous new energetic materials (EMs), especially high explosives (HEs), experimental techniques for their characterization, and computational models (e.g., Cheetah and ALE3D) to predict their behavior. These advancements form much of the scientific basis for the modern EM R&D community. EMs developed by LLNL are used by Livermore and Los Alamos nuclear weapon programs, and the Department of Defense (DOD) uses LLNL explosives, initiation systems, and models for their unique weapon designs. Accomplishments from the EM team include:

- LLNL invented and implemented the Mechanical Safing and Arming Device (MSAD) which prevents accidental or unintended detonation of a nuclear warhead.
- Developing LX-21 , the first new explosive to enter the stockpile without underground testing. LX-21 is based on the LLM-105 explosive molecule, invented by LLNL.
- Using pioneering additive manufacturing for complex, multi-material, explosive components resulting in three LLNL patents on the technology.
- Leading the remanufacturing of critical IHEs for W80-4 and W87-1 LEPs. LLNL researchers identified key production parameters and LLNL's Forensic Science Center developed chemical analysis protocols.
- Mitigating the risk of high-consequence subsea drilling operations (i.e. Deepwater Horizon), LLNL designed a linear shaped charge array for Shell Oil Company to sever a drill collar on-command.
- Predicting effects of material aging on explosives' performance and improving assessments of weapon service life through groundbreaking capabilities.
- Obtaining never-before-captured high-resolution data in the reaction zone of a detonating HE through research at DOE user facilities.
- Identifying new explosive threats to Homeland Security by using advanced x-ray, dual-energy, and computed tomography processing.
- Patented E.L.I.T.E.™ (Easy Livermore Inspection Test for Explosives) system for first-responders uses chemical reaction to quickly detect explosives.



Experimental studies of the explosive molecule 1,3,5-triamino-2,4 6-trinitrobenzene (TATB) revealed the existence of a previously-unknown pressure-induced phase transient.

A hemispherical pressing of the LX-21 explosive, the first addition to the nuclear stockpile since the 1990s.

LLNL commissioned a 100-gallon slurry coater for formulation of hundreds of pounds of explosives in a single batch.

Scientific Underpinnings and New Opportunities

Ensuring and assessing the nation's nuclear deterrent, countering threats from adversaries, and supporting DOD conventional munitions research requires outstanding inquiry performed by exceptional scientists working at world-class facilities. EM scientists explore the energy released during energetic chemical reactions, the mechanical response, and long-term aging characteristics. Taking advantage of LLNL's family of supercomputers and advanced simulation codes, scientists continually improve EM performance and safety. Objectives for the next decade include:

- **Predictive Performance:** Establish best-in-class predictive performance of explosive behavior. Integrated experiments are routinely predicted without additional calibration within LLNL's code framework for Weapons and Global Security designers and engineers.
- **Safety:** Science-informed safety basis enables rapid new explosive and process adoption.
- **Material Aging and Compatibility:** Age-aware performance models incorporating the latest data science are integrated into LLNL's code framework.
- **Manufacturing Modernization and Material Development:** Novel HE components and manufacturing technologies are routinely transitioned to production in response to new requirements.
- **World-Class Facilities:**
  - High Explosives Applications Facility extension: integrates new technologies
  - Site 300 Energetic Materials Development Enclave Campus: synthesizes, formulates, manufactures, tests, and transitions HE to production
  - Contained Firing Facility: houses hydrodynamic experiments up to 60 kg
  - Engineering Test Complex: ensures the lifetime of systems
  - Forensic Science Center: supports ultratrace chemical analysis of explosive materials and decomposition products for weapon and global security programs

The Future

LLNL will uphold high confidence in the safety, security, reliability, and effectiveness of EMs used in our nation's nuclear deterrent.

Researchers will attain program goals, transform our enterprise, develop our capabilities, and advance the science, technology, and engineering of EMs.

We maintain a steadfast commitment to our national security partners. This includes addressing the needs of the Department of Homeland Security and its Transportation Security administration while countering the threat of nuclear proliferation.

LLNL-MI-834369
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April 26, 2022

Biosciences and Biotechnology

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

Security: Health and Energy

Bioscience and biotechnology research at Lawrence Livermore National Laboratory (LLNL) delivers transformative biological solutions for the security needs of the nation. Integrated, multidisciplinary teams of biologists and bioengineers combine experimental and computational approaches for making scientific discoveries and developing innovative technologies.

Bringing together state-of-the-art capabilities and partnerships in quantitative biology, computing, and precision measurement, Laboratory bioscientists provide early biological threat assessment and accelerated drug discovery and vaccine development. Extending biological models to include climate and ecology research, LLNL researchers provide innovative solutions for biofuels, carbon storage in soils, and biomining of critical minerals. They also develop bio-enhanced manufacturing processes for biomaterials.

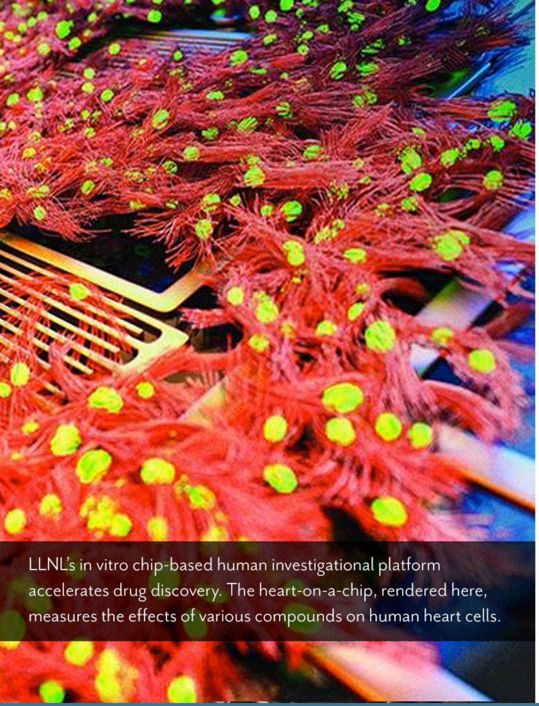
The ability to deliver innovative solutions is supported by a deep understanding of complex biological systems and microbial communities, scientific discoveries, and cutting-edge capabilities. Integrating state-of-art analytical capabilities, synthetic biology techniques, and high-performance computing, Laboratory staff evaluate the mechanisms of disease and engineer microbial communities to counter biosecurity, health, and ecological threats.

Accomplishments

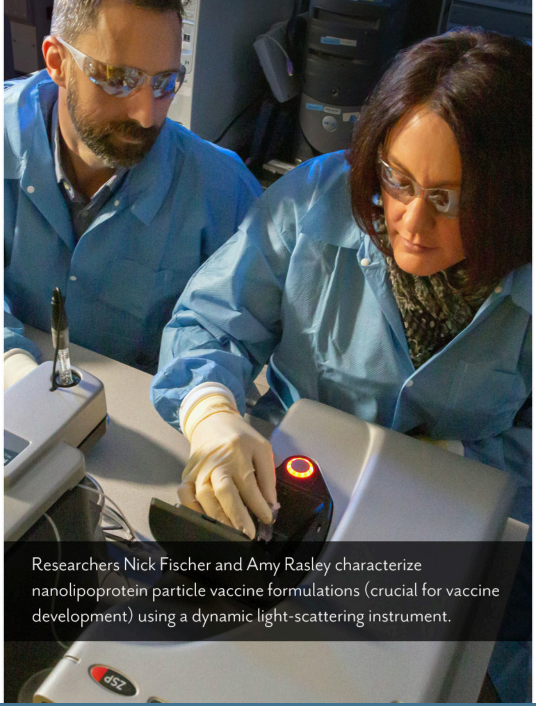
LLNL is one of the few places in the nation focused on coupling multidisciplinary biological expertise with world-class resources in high-performance computing and unique experimental facilities to solve health and environmental problems of national importance. Emerging areas of research include microbiome engineering for health, energy, and the environment; rapid response to the emergence of novel pathogens; and the development of diagnostics and treatment approaches for cognitive impairment.

Examples of LLNL bioscience and biotechnology achievements:

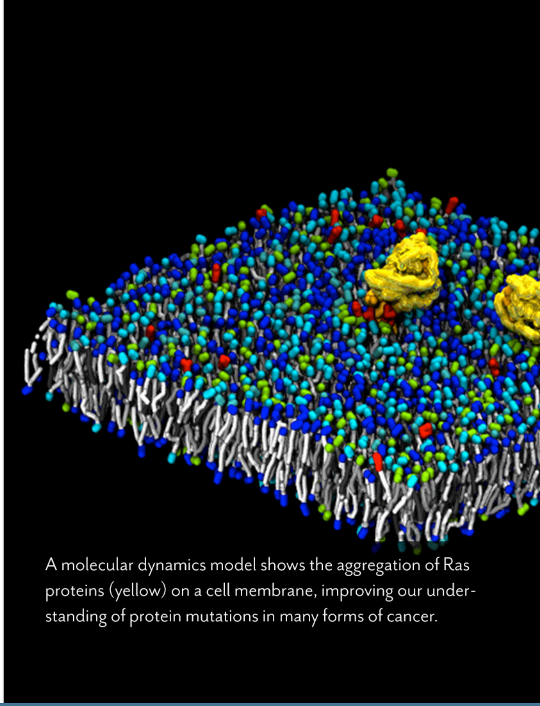
- LLNL researchers designed the Lawrence Livermore Microbial Detection Array, a pangenomic platform for rapid detection of more than 12,000 microorganisms within a day. It is now used for applications as diverse as biodefense, drug and food safety, and space biology.
- Integrated computational and experimental efforts led to the development of the LLNL therapeutic antibody design platform. With this platform, experts were able to revive an approved COVID-19 therapy that had lost effectiveness and use it to combat the Omicron variants.
- LLNL's nanoparticle-based vaccine delivery platform advances vaccine development for human health and biosecurity pathogens. Novel vaccine formulations are being tested in animals for their ability to protect against chlamydia and other pathogen infections.
- Laboratory bioscientists are accelerating drug discovery and development by combining physics-based modeling and simulation platforms with machine-learning algorithms.
- Livermore researchers detected microbial signatures that inform the treatment of wounds from combat injuries in soldiers using a combination of microbial metagenomic DNA sequencing and machine learning.
- LLNL bioscientists developed sustainable biomining approaches for the extraction and purification of rare-earth elements to ensure the domestic supply of critical minerals for the clean-energy transition.



LLNL's in vitro chip-based human investigational platform accelerates drug discovery. The heart-on-a-chip, rendered here, measures the effects of various compounds on human heart cells.



Researchers Nick Fischer and Amy Rasley characterize nanolipoprotein particle vaccine formulations (crucial for vaccine development) using a dynamic light-scattering instrument.



A molecular dynamics model shows the aggregation of Ras proteins (yellow) on a cell membrane, improving our understanding of protein mutations in many forms of cancer.

Scientific Underpinning

Multidisciplinary teams of scientists and engineers combine biological science, high-performance computing, and precision measurement and engineering to understand, predict, and engineer the behaviors of complex biological systems. By coupling world-class computational resources with targeted experiments, the Laboratory applies the central principles of the design–build–test–learn cycle to engineer biological molecules and systems with the desired functionality.

Some examples of cutting-edge capabilities include:

- High-performance computing to simulate biological systems at various scales, including atomistic and coarse-grained molecular dynamics; quantum simulations; constraint-based genome-scale simulations; reaction–transport dynamic simulations; and agent-based, whole-organ, and pharmacokinetic and pharmacodynamic models.
- The National User Resource for Biological Accelerator Mass Spectrometry, the only user resource of its type in the United States, which provides ultra-high-sensitivity quantitative isotopic analysis for biomedical researchers measuring extremely low concentrations of radioisotopes.
- Experimental and computational platforms for the blood–brain barrier and central nervous system that can be broadly used for biological and chemical threat analysis and therapeutic development.
- A combination of stable isotope probing, advanced imaging, proteogenomic profiling, and computational modeling, which is used to probe microbial communities within their ecological context.
- Synthetic biology techniques and secure biosystems design for engineering safe and effective microorganisms and communities for environmental applications and medical countermeasures.
- A Select Agent Center, which is the only Biosafety Level-3 laboratory in the U.S. Department of Energy national laboratory complex; additive manufacturing with bioprinting and biomaterials expertise; and forensic sciences capabilities at the Laboratory's Forensic Science Center.

The Future

Bioscience and biotechnology researchers are targeting the following challenges to address pressing issues in disease prevention, ecosystem sustainability, and biomanufacturing:

- Providing early biological threat assessment and accelerating the development of countermeasures to human exposures and disease, including next-generation diagnostic and surveillance systems, broad-target antibodies, and novel therapeutics and vaccines.
- Expanding our understanding of cellular mechanisms and the interaction among cells, both within tissues and within communities to inform genotype-to-phenotype predictions and genome engineering strategies to combat disease and develop biomaterials.
- Designing and engineering nanostructured materials and advanced characterization tools for national security applications.

LLNL-MI-839345
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
August 29, 2022

Energy Security

Secure and expand the supply and delivery of affordable, clean energy with technologies that are resilient to evolving natural and adversarial risks.

Secure and Resilient Energy

LLNL is exploring ways to ensure access to diverse, domestic energy resources through efficient and reliable energy generation, storage, and delivery systems.

In addition, we protect energy delivery infrastructure from natural and human-caused threats by enhancing the resiliency of these systems against physical and cyber attacks.

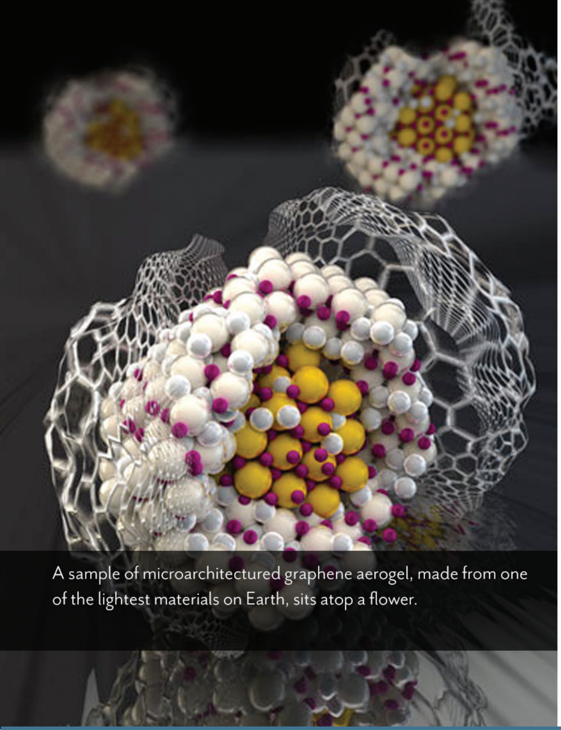
The Laboratory is also exploring novel ways to capture and recycle carbon dioxide (CO_2) into value-added products, and to store CO_2 indefinitely in terrestrial, soil, and geologic systems to reduce the concentration of atmospheric CO_2 and other greenhouse gases.

LLNL's researchers are also pioneering development of new energy sources to meet the needs of a future focused on renewables and carbon reduction goals.

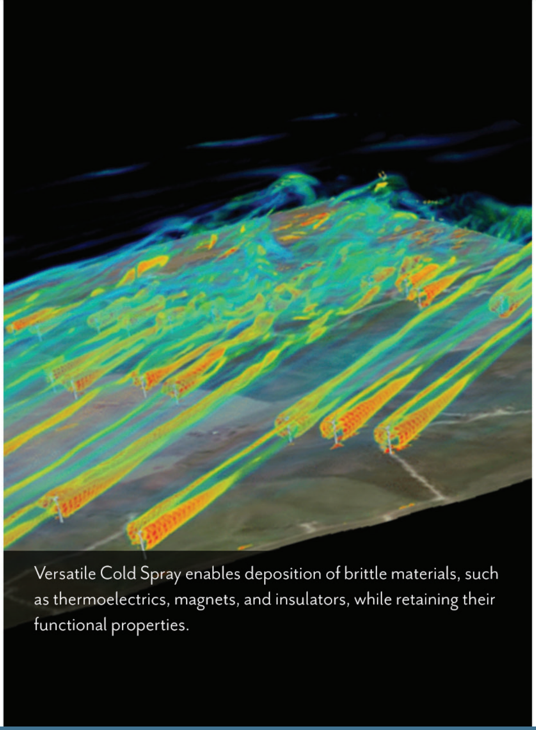
Accomplishments

Today's energy security mission at LLNL has a broad scope. Researchers are developing technologies to expand the use of low-carbon energy and identifying new clean energy resources. By exploring how to make energy-intensive processes more efficient, scientists are developing innovative technologies to sequester carbon underground, extract minerals by using less energy, and desalinate and detoxify water more efficiently. This expanded focus has produced the following accomplishments:

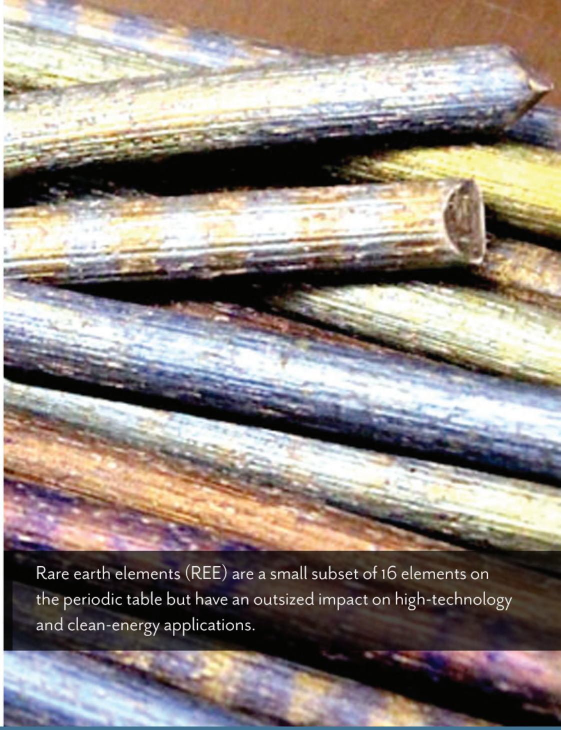
- Developed GEOSX, an open-source simulation platform that illustrates the mechanical, hydrologic, and geochemical response of subsurface reservoirs to carbon storage.
- Leveraged the power of high-performance computing to model and evaluate ways to better harness the potential of geothermal energy as a clean power source.
- Explored new composite materials with ionic conductivity for increased voltage, capacity, and stability—providing new options for fast-charging, lightweight batteries.
- Pioneered a new additive manufacturing technique to create thermoelectric generators that can harvest heat that would otherwise be lost and use it as an energy source.
- Demonstrated how biocatalysts that use live microbes can more efficiently convert carbon sources into valuable end-product chemicals, including biofuels.
- Developed new lightweight aluminum alloys that are structurally stable up to the melting point for improved energy efficiency in cars and trucks.
- Bioengineered a protein that can extract rare earth elements from electronic waste and purify it for use in clean energy applications, using a one-step, environmentally friendly process.
- Contributed to Getting to Neutral: Options for Negative Carbon Emissions in California report, exploring the capacity and costs of carbon capture on a national scale.



A sample of microarchitectured graphene aerogel, made from one of the lightest materials on Earth, sits atop a flower.



Versatile Cold Spray enables deposition of brittle materials, such as thermoelectrics, magnets, and insulators, while retaining their functional properties.



Rare earth elements (REE) are a small subset of 16 elements on the periodic table but have an outsized impact on high-technology and clean-energy applications.

Scientific Underpinnings

Energy security research at LLNL draws on the Laboratory's strengths in geoscience, atmospheric science, chemistry, physics, bioscience, materials science, engineering, advanced manufacturing, data science, and high-performance computing. In this multidisciplinary research environment, teams leverage a suite of unique experimental and computational resources to drive innovation.

- LLNL's high-performance computing resources enable scientists to model complex systems and optimize the energy efficiency of production.
- Advanced materials science and additive manufacturing research enables less-wasteful production while developing new materials for energy efficient and resilient technology.
- Earth and atmospheric science expertise is used to improve the detection and extraction of energy resources and the use of renewable energy, including wind and solar energy.
- Bioscience experts collaborate with chemists to develop catalysts capable of generating biofuels and microbes that can extract rare earth elements from electronic waste.
- High-energy-density science research and laser physics at the National Ignition Facility advance the quest for clean energy through inertial confinement fusion.
- Laboratory expertise in artificial intelligence plays an expanding role in making power grids more resilient by leveraging a network of distributed, autonomous resources.
- LLNL collaborations accelerate solutions. The DOE's Energy Materials Network focuses on research involving national laboratories, industry, and academia.

The Future

LLNL's long-term vision for the U.S. energy system relies on low-carbon sources. To achieve this aim, we must ensure a secure, sustainable, resilient, and reliable national energy infrastructure.

Tomorrow's power grid will utilize smart technology and storage and distribution channels that fully incorporate renewable energy. Hydrogen continues to be a low-carbon fuel option, as scientists explore solutions for production, solid-state storage, and subsurface storage in geologic formations.

We will develop new ways to balance supply and demand in a diversified energy delivery system based on a decentralized network that shares sensor data, validates remote commands, and decreases vulnerabilities.

LLNL researchers improve our capability to predict and mitigate chemical degradation, oxidation, and corrosion of energy production and delivery infrastructure. Thermally resistant power turbines, radiation-tolerant material for nuclear power plants, and corrosion-resistant pipelines are crucial components of current and future energy systems.

LLNL-MI-836646
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
June 23, 2022

Climate Science

Providing world-class tools and expertise to analyze climate change, forecast impacts on critical resources, and foster climate resilience.

An Issue of National Security

The Laboratory's climate research enables us to provide decision makers with actionable information to help predict the probability, magnitude, and impact of climate change.

LLNL scientists develop and refine state-of-the-art climate models that bring together billions of data points—from across the globe, in the Earth's subsurface, and in our atmosphere and oceans—and use it to model complex systems employing some of the world's most advanced supercomputers.

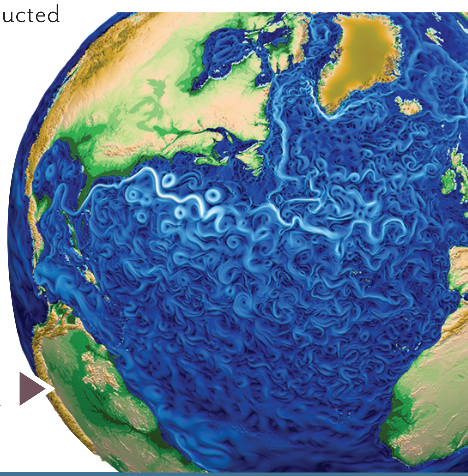
Climate change poses risks to our national security, including our defense capabilities, homeland security, energy security, and our ability to anticipate new types of cyber and biothreats.

Anomalous weather events, especially extreme temperature, severe wind, and unprecedented flooding affect our energy, transportation, water delivery, and defense infrastructures. Climate disruptions expand the geographical range of vector-borne diseases and negatively impact public health, especially among economically challenged segments of the population. Beyond our borders, disruptions can alter migration patterns and affect U.S. military personnel serving abroad, contributing to increased security risks.

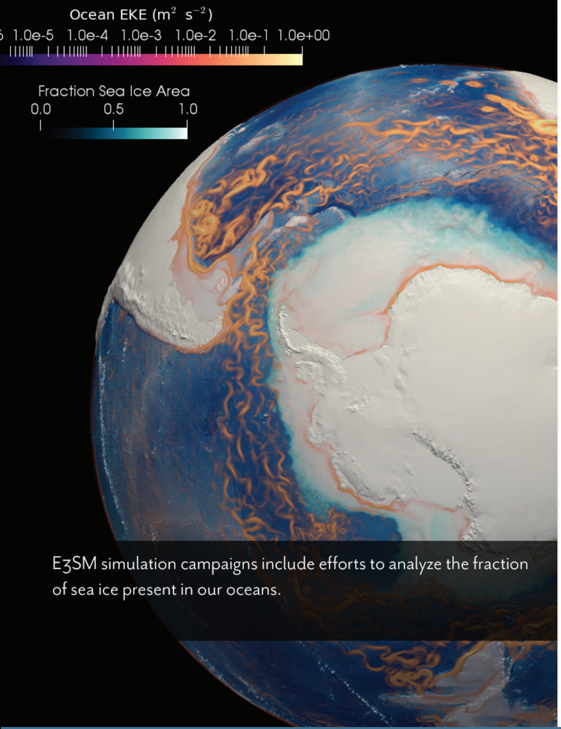
Accomplishments

Lawrence Livermore National Laboratory (LLNL) has been leading climate science research since our 1960s development of the world's first atmospheric general circulation model. Our work continues today as we develop, compare, and improve sophisticated climate models that enable us to identify regional and global climate patterns and predict how future changes may shape our national security and energy resilience. The Laboratory collaborates with other institutions to share insight and expand our work, including leadership roles in the following national and international efforts to study climate change:

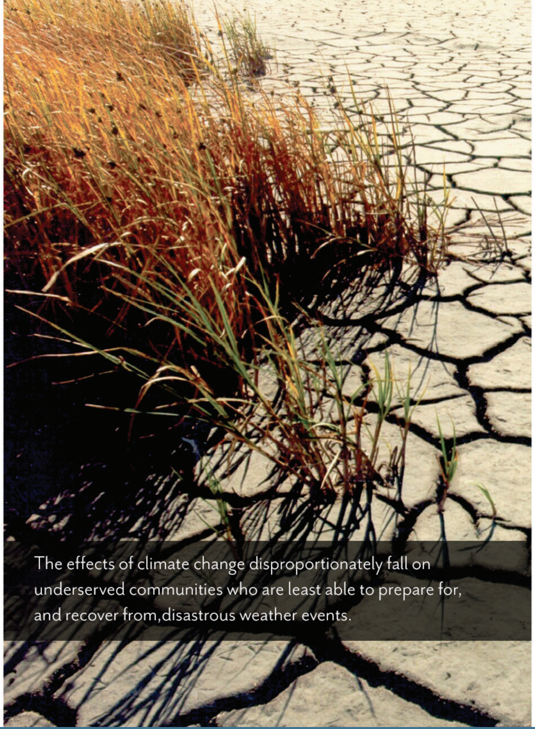
- In 1989, LLNL took the lead in the **Program for Climate Model Diagnosis and Intercomparison,** an international collaborative effort aimed at evaluating nearly 50 climate models. Researchers developed standard benchmarks for model components, addressed common modeling errors, tracked changes in model performance, and quantified projection uncertainties.
- LLNL is the lead institution in the **Energy Exascale Earth System Model** (E3SM) Project, linking Earth system and energy models to assess how energy use impacts our ecosystem. Launched in 2018, its research scope continues to expand.
- From 1995 through 2020, LLNL led the **Earth System Grid Federation,** an international, inter-agency data management system that lets researchers share observational data, models, analyses, and results with fellow scientists and policymakers.
- 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.

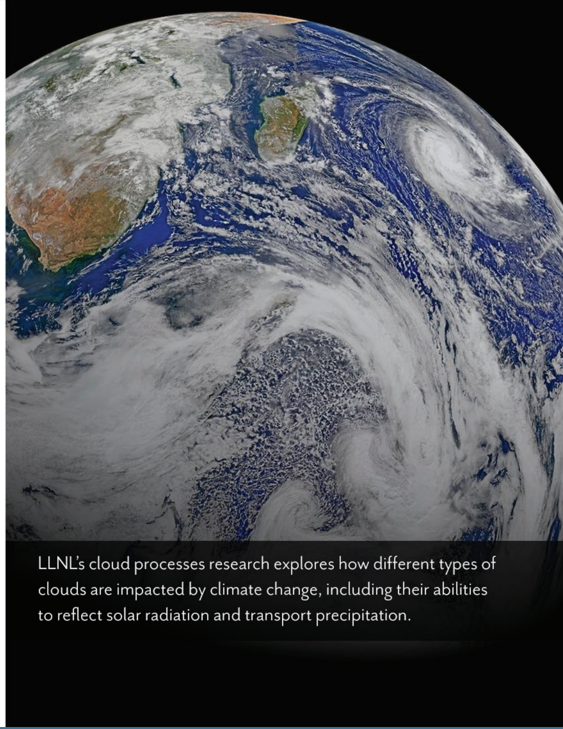


The E3SM project will reliably simulate aspects of earth system variability and project decadal changes that could critically impact the U.S. energy sector.



E3SM simulation campaigns include efforts to analyze the fraction of sea ice present in our oceans.


The effects of climate change disproportionately fall on underserved communities who are least able to prepare for, and recover from,disastrous weather events.


LLNL's cloud processes research explores how different types of clouds are impacted by climate change, including their abilities to reflect solar radiation and transport precipitation.

Scientific Underpinnings

LLNL's decades-long investments in studying complex Earth systems have enabled us to gain extraordinary insights into global climate trends, develop more accurate models, and improve our ability to forecast future change. Supercomputers power our rigorous analysis of Earth and atmospheric data while we assess climate models to ensure that they reflect the changing dynamics of highly complex systems and better understand how human activities influence climate change.

- **Teams.** Climate science research is a multidisciplinary effort. Our experts in atmospheric science, meteorology, hydrology, geoengineering, predictive modeling and simulation, data science, and machine learning combine rigorous analysis with high-fidelity modeling to accelerate innovation.
- **Resources.** LLNL is home to some of the world's most powerful supercomputers, capable of handling the extremely high volume of data that inform climate models. Machine learning and advanced data collection tools help analyze large, multivariate observational and experimental datasets, enabling researchers to better predict climate change.
- **Regional Solutions.** Scientists continue to refine climate models to predict the frequency and severity of extreme events, such as heat waves, droughts, and wildfires. Data is shared with local decision makers through reports and briefings to better allocate resources and mitigate changing local ecosystems.
- **Science.** LLNL's climate science research covers a broad array of topics. We conduct hydrology studies that analyze access to fresh water, explore precipitation patterns and shrinking snowpacks, examine how wildfires affect local ecosystems, study pollution in our oceans, analyze how temperatures impact Arctic ice sheets, and more.

For more information, visit Climate Science at LLNL

The Future

As exascale computing resources become more widely available, our predictive modeling, machine learning, and artificial intelligence capabilities will continue to evolve.

Advanced computational capabilities will help our scientists refine future climate models including precipitation patterns and extreme weather events. We are also leveraging new technology to expand our data collection capabilities, including the emerging use of small satellites to collect precise climate-related data.

Looking ahead, LLNL will drive collaborative, inter-agency efforts to study climate change, share knowledge, and recommend solutions. We will invest in efforts aimed at increasing access to modeling codes and data, expanding use of these resources by a broader cross-section of specialists.

It's crucial that we provide decision makers, including U.S. agencies tasked with ensuring our national security, with data needed to foster climate resilience. LLNL's climate science research supports planning and decision-making that can reduce risk and improve resilience.

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
June 23, 2022

24/7 Emergency Response

Providing round-the-clock expertise and technical capabilities to support civil-emergency response and preparedness, military operations, and the intelligence community.

Scientific Expertise on Call

As a long-established Department of Energy / National Nuclear Security Administration (NNSA) partner and member of the interagency nuclear and radiological emergency-preparedness and response community, Lawrence Livermore National Laboratory (LLNL) provides round-the-clock expertise and technical capabilities. These strengths support civil-emergency scenario planning, crisis assessment and analysis of chemical, biological, radiological, nuclear, and explosive (CBRNE) threats against the U.S., as well as tactical research and tools for military operations and the intelligence community.

The Laboratory's trained, certified interdisciplinary teams of subject-matter experts possess an unparalleled collection/array of skills, experience, and abilities across a range of disciplines from atmospheric modeling to inorganic chemistry and data science and can be deployed on-site or off, within minutes, 24 hours a day, seven days a week.

LLNL's teams and facilities are available to respond to hazardous release of chemicals in the atmosphere, support the U.S. government to identify an unattributed nuclear detonation, should one occur, and provide forensic and radiological assistance to the intelligence community and law enforcement, homeland security, and health professionals.

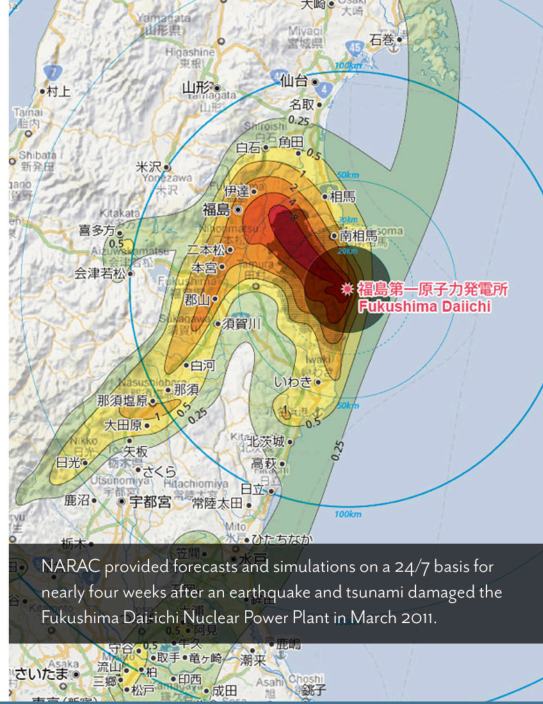
Accomplishments

LLNL's strong record of emergency preparedness and response relies on its interdisciplinary teams of subject-matter experts who possess a keen understanding of risks and threats; preparation and execution of policies, plans, and procedures; and development of innovative technologies to prevent, mitigate, and respond to threats. LLNL has provided urgent support to the U.S. government during several recent incidents and emergencies including:

- **Chernobyl Fires (2020):** National Atmospheric Release Advisory Center (NARAC) analyzed smoke patterns in the Chernobyl Nuclear Plant exclusion zone in Ukraine due to concerns that large wildfires in the region could resuspend radioactive materials from the 1986 accident. Simulations identified potential regions of elevated radiation levels outside of the exclusion zone.
- **PATHFINDER Exercise (2019):** This interagency, post-detonation nuclear forensics exercise presented a worst-case, nuclear-terrorism scenario in real time, challenging LLNL experts to make technical assessments of the hypothetical device and its materials based on limited information. After successfully completing the exercise, the LLNL team is now one of NNSA's operational emergency response assets.
- **Ruthenium Detections Acrss Europe (2017):** When a mildly radioactive plume of Ruthenium-106 appeared in the atmosphere across Europe, NARAC quickly estimated the probable sources.
- **Apex Gold (2016):** LLNL hosted the first, minister-level exercise to identify national and international actions to address a simulated nuclear crisis and help advise heads of government how to best prepare 24/7 responses to a nuclear-security crisis or emergency.
- **PG&E Substation Sniping (2013):** After this domestic terrorism incident at an electric power station in California, LLNL conducted immediate after-action analysis, assessed security vulnerabilities, and recommended security enhancements.
- **Fukushima Daiichi Nuclear Disaster (2011):** LLNL deployed a Radiological Assessment Program team, developed plume modeling predictions, analyzed environmental samples, and analyzed radionuclides 24/7 for many weeks.

In 2020, NARAC simulations aided fire response in Ukraine's Chernobyl Nuclear Plant exclusion zone amid concerns of possible resuspension of radioactive materials from the 1986 accident.

NARAC staff supported the launch of NASA's Perseverance Rover as part of the DOE/NNSA's Nuclear Emergency Support Team. (Photo Credit: NASA)



NARAC provided forecasts and simulations on a 24/7 basis for nearly four weeks after an earthquake and tsunami damaged the Fukushima Dai-ichi Nuclear Power Plant in March 2011.

Scientific Underpinnings

LLNL's interdisciplinary teams of subject-matter experts, scientists, engineers possess critical skills and experience, as well as access to cutting-edge computing, facilities, and equipment to support CBRNE threat preparation and response, military operations, and the intelligence community within a moment's notice. Sophisticated dispersion modeling tools, air-monitoring data, Bayesian statistical techniques, and machine learning support atmospheric monitoring, emergency preparedness and response to hazardous releases. LLNL's nuclear weapon expertise and stockpile stewardship capabilities support emergency planning and response operations.

- NARAC responds 24/7 to hazardous atmospheric releases anywhere in the world—predicting their evolution, exposure levels, and trajectories to protect the public and the environment.
- Aeolus, a fast, high-resolution, fluid-dynamics computational model, simulates the dispersion and deposition of hazardous materials in urban environments.
- As one of two U.S. laboratories with international certification to handle chemical warfare agents in environmental samples, the Forensic Science Center provides 24/7 weapons of mass destruction-related sample analysis and identification of toxic industrial compounds and chemical warfare agents (CWA).
- The Counterproliferation, Analysis, and Planning System (CAPS) provides critical reach-back support to combatant commands and warfighters in CBRNE mission areas.
- Critical Infrastructure Protection and Security Experts evaluate electrical grids, oil refineries, natural gas transmission networks, rails, ports, and waterways for physical and cyber security.
- International Nuclear and Radiological Security works worldwide to secure and protect nuclear and radiological materials from theft, sabotage, and terrorism.
- The Nuclear Forensics laboratory is a trusted partner in the U.S. interagency's Bulk Special Nuclear Material Analysis Program, ensuring precise and accurate analyses of nuclear material.
- The Post-Detonation Device Assessment Team acts as one of NNSA's critical, operational-emergency response assets, standing by to identify the provenance of unattributed nuclear detonations at a moment's notice.

The Future

LLNL continues to advance its technical capabilities and contribute to the nation's credible response posture.

By applying advances in high-performance computing, artificial intelligence, and machine learning, the Laboratory's ability to rapidly gather and interpret intelligence, anticipate, and assess credible threats, and support first responders will improve.

As LLNL researchers develop innovative technologies, emergency response times will decrease and the quality of intelligence-informed conclusions, recommendations, supporting rationale, and other relevant observations will prove to be increasingly invaluable.

LLNL-MI-839900
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September 15, 2022

Fueling California's Economy

Through business and community partnerships, LLNL's science, technology, and engineering strengthens the state's economy by providing jobs and economic opportunities.

LLNL's Economic Impact

Lawrence Livermore National Laboratory (LLNL), located in Livermore, California, is a research and development facility for science and technology solutions to some of our nation's greatest challenges. Managed by Lawrence Livermore National Security, LLC, (LLNS), LLNL has an annual budget of nearly $2.8 billion and has roughly 8,100 LLNS employees. It is largely funded by the Department of Energy's National Nuclear Security Administration.

LLNL's economic impact in California manifests through payroll to employees and procurements awarded to local companies. The Laboratory stimulates commercial activity through the transfer of its technologies to licensees ranging from startups to FORTUNE 500® companies. LLNL also develops research-based public-private partnerships to improve business access to world-class scientific capabilities to help them improve their technologies.

In fiscal year 2021, LLNL awarded more than $908 million in procurements to businesses, both in California and across the nation, for a broad range of products and services that support the Laboratory's overall mission. In the past five years, nearly $1 billion worth of products containing LLNL technology have been sold worldwide.

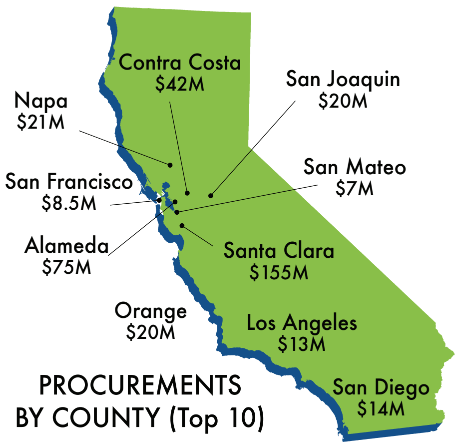
California Success Stories

DYNA3D: Developed at LLNL by John Hallquist, this software analyzes and visually portrays the effects of stresses on computer-generated 3-dimensional objects. Hallquist launched Livermore Software Technology Corporation (LSTC) in Livermore, California and matured the original software into LS-DYNA. The automobile industry, among others, uses LS-DYNA to simulate crashes and conduct safety testing. LSTC was sold to ANSYS Inc. in 2019 for $775 million.

Micro Impulse Radar (MIR): Pioneered at LLNL, MIR single-handedly revolutionized radar technology. A compact, low-power, low-cost, short range radar system, it is used around the world in a wide range of applications. For example, MIR operates automatic doors or gates, serves as a motion detector for alarm systems, and enables automobile blind-spot detection and anti-crash systems.

DNA-TRAX: Foodborne diseases cost the U.S. an estimated $150 billion annually. SafeTraces, Inc. licensed an LLNL-developed spray-on DNA-based barcode technology that can track the source of contaminated food in the supply chain in just minutes rather than days or weeks. SafeTraces aims to reduce food safety concerns such as contaminated and counterfeit food.

LLNL FY21 Fueling California's Economy

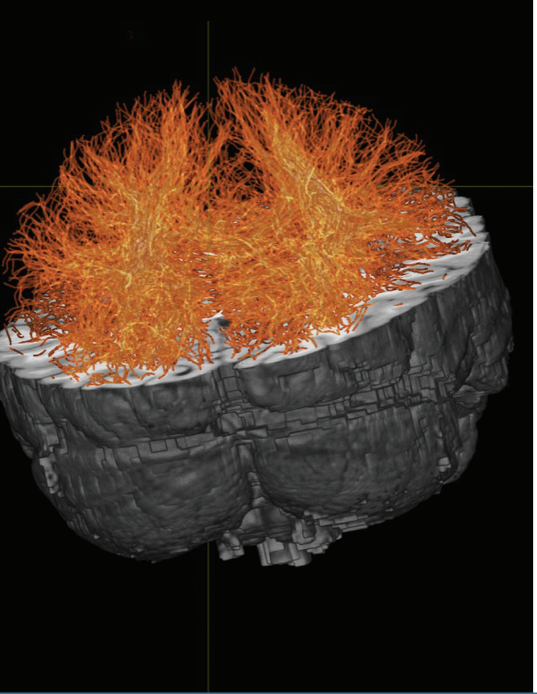


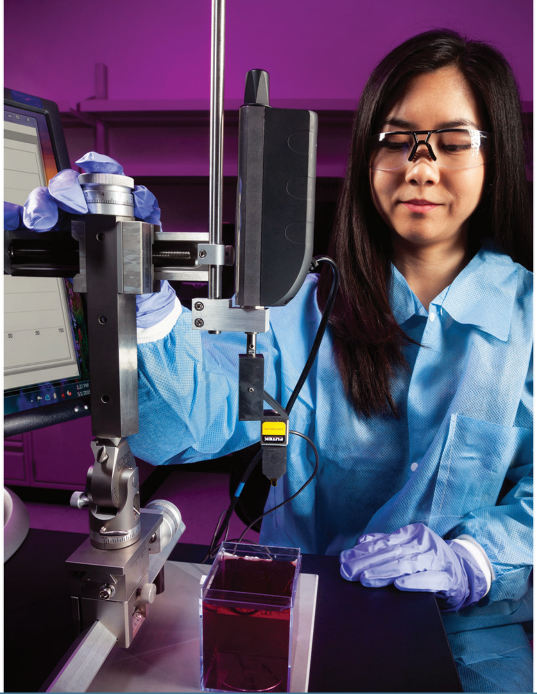
PROCUREMENTS BY COUNTY (Top 10)

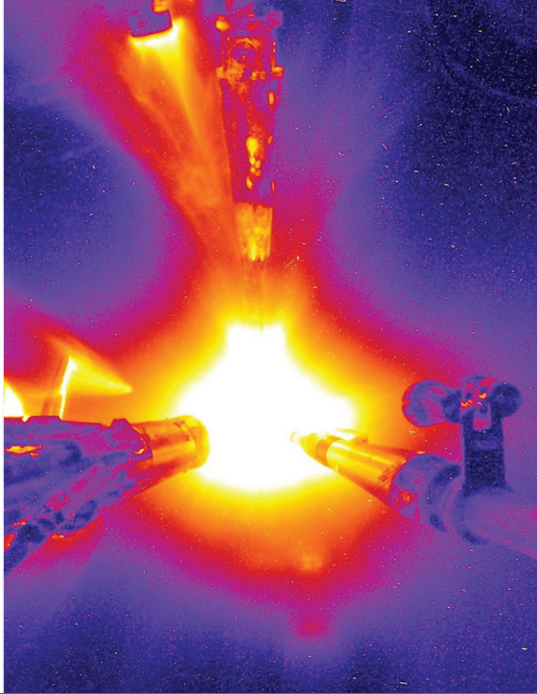
$401 M CA PROCUREMENT AWARDS

$908 M TOTAL PROCUREMENT AWARDS

- **76** companies with active commercial licenses, **35** based in California
- **$1.09** billion total California payroll







LLNL as a Business Partner

The Laboratory focuses on innovation initiatives that will develop public-private partnerships and grow high-technology business opportunities in the Tri-Valley and greater San Francisco Bay region. Furthering these goals are LLNL's relationships with regional organizations such as the California Clean Energy Fund, the Bay Area Council, East Bay Economic Development Alliance, Silicon Valley Leadership Group, and the Innovation Tri-Valley Leadership Group.

LLNL's Innovation and Partnerships Office (IPO) spearheads the Laboratory's engagement with industry. Whether through technology commercialization, encouraging entrepreneurship, or business development activities, the primary mission is to grow the economy by advancing the development and commercialization of scientific discoveries.

IPO has active commercial licenses with 76 companies as well as dozens of cooperative research and development agreements (CRADAs). Licensing and royalty income topped $5.8 million in 2021, while roughly $1 billion worth of products based on LLNL technology have been sold over the past five years. LLNL-licensed technologies have enabled the launch of numerous new businesses that help drive economic growth locally, regionally, and beyond. Additionally, the Laboratory participates in events and organizations that support technology innovation and business development. Here are some examples:

- **University Partnerships:** LLNL and Stanford University collaborate to create multi-scale models and prototype devices for the electromechanical production of chemicals from CO_2. The project aims to improve carbon capture, storage, and utilization technologies to help reduce CO_2 and reliance on fossil fuels.
- **Industry/Non-Governmental Organizations:** The High Performance Computing for Energy Innovation program (HPC4EI) offers U.S. industry access to LLNL's superior computing power to improve their global competitiveness. LLNL works with Santa Clara materials engineering firm Applied Materials to improve a process for depositing thin-film materials on wafers used in LED lights.
- **Community Partnerships:** LLNL supports the i-Gate innovation hub, located in the city of Livermore, California, for regional entrepreneurs.
- **State Government Partnerships:** The California Energy Commission funded an LLNL effort to reduce the cost of water desalination and increase water reuse to help California through future droughts.

Expanding Partnerships

The Advanced Manufacturing Lab (AML) is a new collaborative hub for developing next-generation materials and manufacturing technologies. The 13,000-square-foot facility is located in LLNL's growing Livermore Valley Open Campus and features two laboratories (a reconfigurable "wet" chemistry lab and a "dry" instrument lab), a collaboration space, conference area, and support rooms with potential for future expansion.

Expanding on LLNL's existing infrastructure and expertise in materials science, engineering, and additive manufacturing, the AML combines high-performance computing, modeling, and simulation to rapidly advance research into emerging manufacturing technologies.

The AML enables two-way learning and transfer of technology and capabilities between industry and LLNL.

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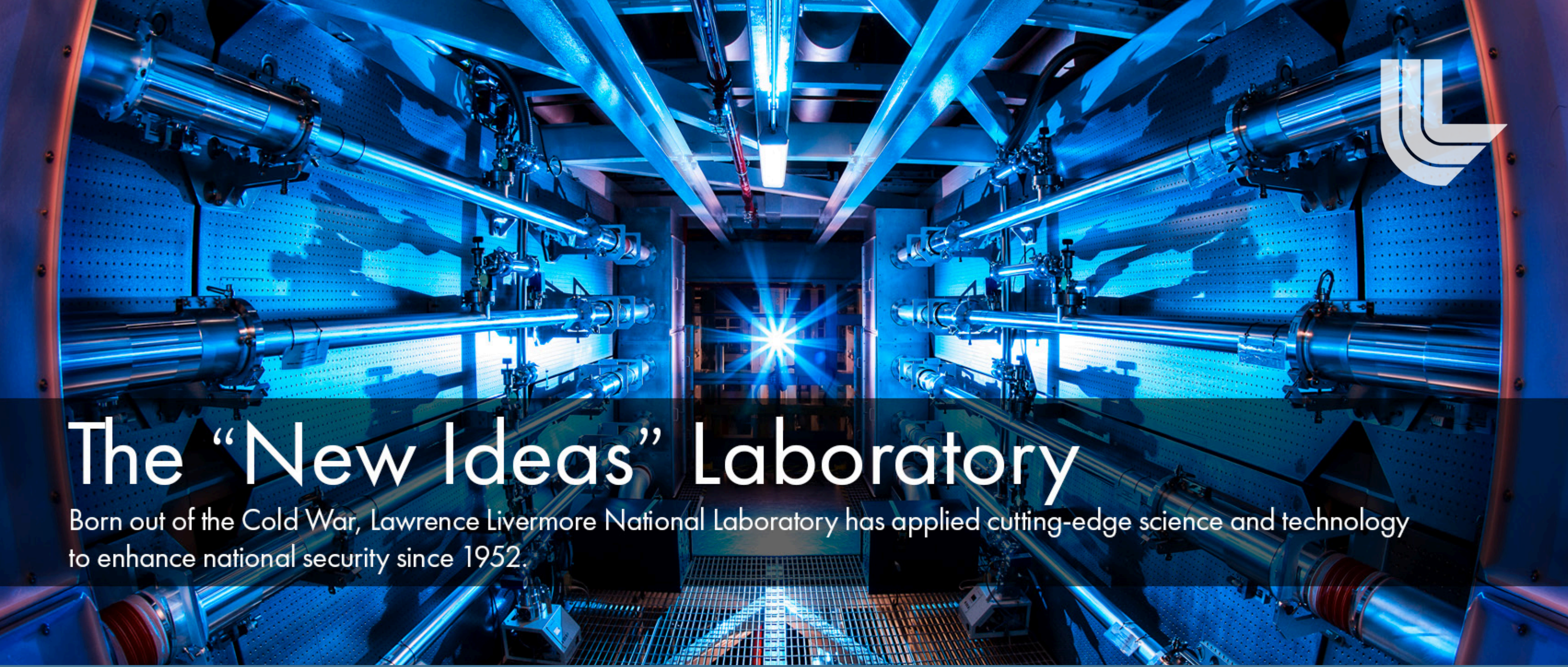
February 14, 2022



The “New Ideas” Laboratory

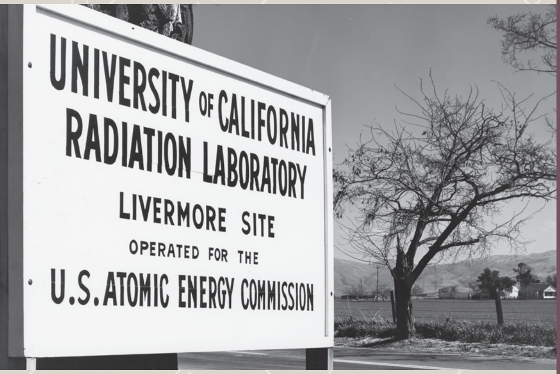
Born out of the Cold War, Lawrence Livermore National Laboratory has applied cutting-edge science and technology to enhance national security since 1952.

Eight Decades of Cutting-Edge Science

Lawrence Livermore National Laboratory (LLNL) was established in 1952 at the height of the Cold War to meet urgent national security needs by advancing nuclear weapons science and technology.

Renowned physicists E.O. Lawrence and Edward Teller argued for the creation of a second laboratory to augment the efforts of the laboratory at Los Alamos. Activities began at Livermore under the aegis of the University of California with a commitment from its first director, Herbert York, to be a “new ideas” laboratory and follow a multidisciplinary, team-science approach to research that Lawrence had pioneered on the Berkeley campus of the University of California.

Since then, LLNL researchers have conducted eight decades of cutting-edge science to meet national security needs.



1950s

Livermore made its first major breakthrough with the design of a thermonuclear warhead compact enough to be carried on ballistic missiles launched from submarines. For decades, the Laboratory led the development of compact high-yield warheads.

Livermore aggressively pursued advances in computer simulations to support nuclear weapons and other research activities, including fusion energy. After acquiring one of the first UNIVAC computers, the Laboratory subsequently drove industry’s development and integration of increasingly powerful machines.

1960s

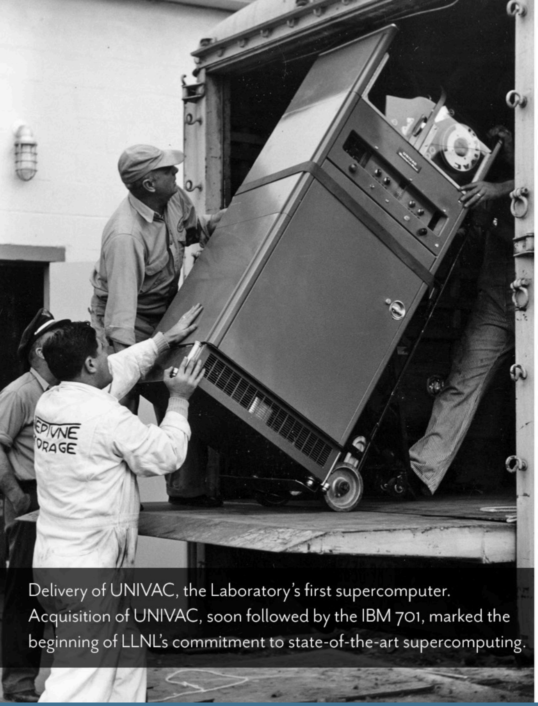
In addition to supporting nuclear deterrence, the Laboratory explored the peaceful use of nuclear explosives and made significant advances in magnetic fusion research. Strong research efforts in atmospheric sciences and a new bioscience program addressed concerns about fallout and the effects of ionizing radiation on human health. Continued research led to successes in genomic sequencing and sensors for biosecurity as well as capabilities for modeling atmospheric releases and global climate change.

Livermore also established a formal working relationship with the Intelligence Community (IC) to analyze Soviet nuclear test activities and develop technologies for the IC. That effort has continued to grow with the IC’s need for all-source analyses of nuclear programs in countries of concern.

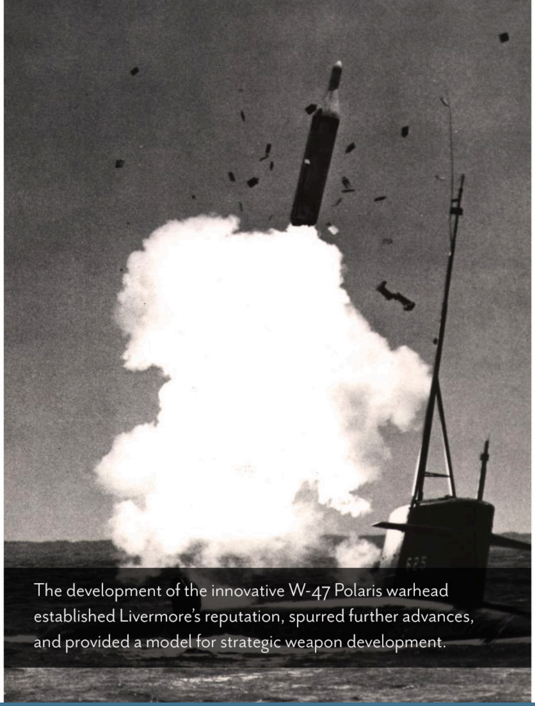
1970s

The decade began with Livermore’s most ambitious nuclear test, the design of a high-yield warhead for ballistic missile defense. Lasers gained attention as a new technology for achieving fusion in a laboratory setting. As interest remained high in ballistic missile defense, scientists designed new weapons to enhance deterrence and developed new explosives to improve the safety of nuclear weapons.

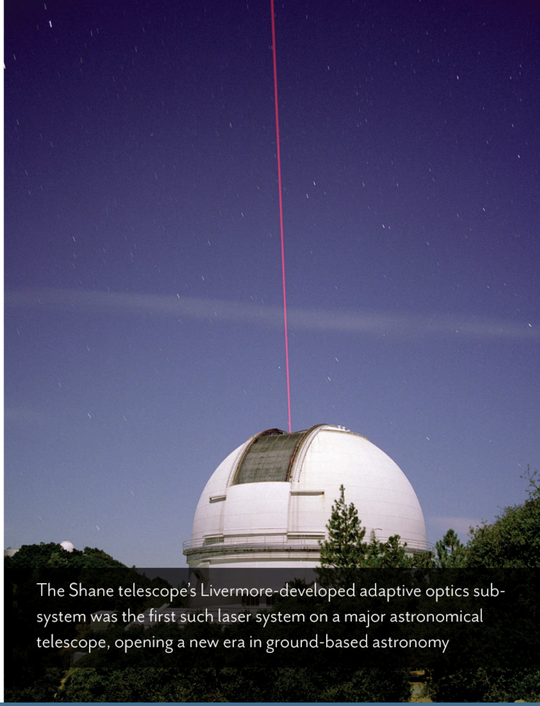
A looming energy crisis invigorated the search for reliable, affordable, clean sources of energy. Notably, Livermore scientists studied human impact on Earth’s ozone layer and the newly developed Atmospheric Release Advisory Capability helped manage the crisis response to the Three Mile Island reactor accident in 1979.



Delivery of UNIVAC, the Laboratory's first supercomputer. Acquisition of UNIVAC, soon followed by the IBM 701, marked the beginning of LLNL's commitment to state-of-the-art supercomputing.



The development of the innovative W-47 Polaris warhead established Livermore's reputation, spurred further advances, and provided a model for strategic weapon development.



The Shane telescope's Livermore-developed adaptive optics subsystem was the first such laser system on a major astronomical telescope, opening a new era in ground-based astronomy

1980s

To help win the Cold War, Livermore developed a new strategic bomb and a ballistic missile warhead for the U.S. Air Force. One of the computer simulation tools, DYNA3D, was adopted by industry and has been widely used in vehicle crash testing. In support of the Strategic Defense Initiative, LLNL created the first x-ray lasers and developed small-satellite technologies deployed on the future Clementine mission to map the Moon. Laser science in support of national security and fusion energy applications advanced with the development of the 10-beam Nova laser system.

In 1987, Livermore bioscience researchers spearheaded DOE's initiative to map the DNA sequence of the human genome. LLNL developed key chromosome-sorting capabilities to make genome sequencing possible, and DOE's effort evolved into the Human Genome Initiative.

1990s

The Berlin Wall fell in 1989, and LLNL helped DOE define the Stockpile Stewardship Program to ensure the safety, security, and performance of the nation's nuclear deterrent. Livermore provided leadership in achieving a million-fold improvement in computing capability over a decade and began construction of the National Ignition Facility (NIF) to perform physics experiments at weapon-like temperatures and pressures. LLNL also pursued the development of analytical and detection capabilities to address the threat posed by weapons of mass destruction.

World-class capabilities established at Livermore included the High Explosives Applications Facility, the Forensics Science Center, the Center for Accelerator Mass Spectrometry, and the Program for Climate Model Diagnosis and Intercomparison.

2000s

LLNL successfully completed a life-extension program for the nation's modern ICBM warhead to ensure its presence in the U.S. strategic arsenal well into the 21st century. Studies conducted at Livermore and Los Alamos concluded that the plutonium in weapons was aging gracefully. A new facility was constructed to house successive generations of powerful supercomputers, and NIF was dedicated in 2009.

LLNL programs in counterterrorism and counterproliferation gained importance after the 9/11 attacks. Innovative technologies were developed to detect biological and chemical threats, explosives, and nuclear materials. Livermore researchers also contributed to the discovery of the first extrasolar planet and began work on the Gemini Planet Imager.

Into the Future

High-performance computing (HPC) has become the "third pillar" of research throughout the 2010s and 2020s, joining theory and experiment as an equal partner. HPC enables discovery and innovation through extraordinary simulation capabilities. Precision experiments and advances in exaflop-scale computing enable the development of predictive simulation models for stockpile stewardship.

NIF is proving to be a remarkably flexible and valuable tool for creating conditions that exist in giant planets, providing data needed for stockpile stewardship, and progressing toward fusion ignition. On Aug. 8, 2021, an experiment at NIF made a significant step toward ignition by achieving a yield of more than 1.3 megajoules.

Innovations based on advances in material science range from plastic scintillators for radiation detection to biocompatible microelectronics and sensors for myriad healthcare applications. Livermore researchers' advances in additive manufacturing are creating materials with previously unimaginable properties to enable cost-effective production processes within the nuclear weapons complex and across American industry.

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May 24, 2022

Veteran and Military Outreach, Recruiting, and Education at LLNL

LLNL is committed to helping veterans, transitioning military, active duty members, and military students acquire critical job-related skills needed for today's workforce to fulfill the Laboratory's mission.

Vets Make a Difference

Since its founding in 1952 at the site of an old U.S. Navy air station, Lawrence Livermore National Laboratory (LLNL) has forged strong ties with the nation's armed forces.

Through the decades, LLNL scientists, engineers, and technicians have worked closely with all four military branches. LLNL researchers have developed innovative, advanced technologies to identify and address threats to national security and enhance the capabilities of today's warfighters.

The Laboratory helps returning veterans and student military program participants acquire the science, technology, engineering, and math (STEM) skills required by LLNL and other high-tech Bay Area employers. Additionally, LLNL actively recruits veterans to fill critical workforce needs. 516 reported veterans currently work at LLNL in nearly every discipline, and more are being recruited every day.

LLNL veterans have established a reputation for technical excellence and intangible skills like leadership, problem solving, and a sound work ethic.

LLNL and other high-tech Bay Area employers depend on talented technical staff. In particular, LLNL managers estimate they will need to hire 300 technicians over the next few years for assignments ranging from operating the world's largest laser to developing advanced materials.

Veteran and Military Outreach, Recruiting and Education Programs at LLNL

- **Veteran Internship Program (VIP)**
  In partnership with California community colleges and the Alameda County Workforce Investment Board, LLNL annually hosts 10 to 15 vets for 10 weeks of hands-on training in information technology, computer science, engineering, and other fields.
- **Engineering Technology Program (Vets2Tech)**
  Provides veterans with education and hands-on training. (See more on reverse.)
- **Military Academic Research Associates Program**
  An average of 25 to 30 cadets, midshipmen, and faculty from the military academies complete a four- to six-week summer assignment at LLNL every year.
- **ROTC Internship Program**
  LLNL hosts 25 to 30 cadets and midshipmen from universities across the country for 12 weeks during the summer to support Laboratory research efforts, and an annual ROTC Day for regional students and faculty to learn more about LLNL.
- **Air Force Fellows Program**
  Assigns two to four active-duty majors and civilians to LLNL for a one-year period to become familiar with Stockpile Stewardship and defense-related activities.
- **Army Training with Industry Program**
  Assigns one Army Environmental Science and Engineering Officer to the Laboratory's Environmental, Science, and Health office for best business practices and R&D efforts.
- **Air Force Academy Outreach Program**
  Provides lectures to cadets on nuclear deterrence and associated weapons, technical, and policy issues.
- **Newly Commissioned Officer Program**
  Newly Commissioned Officers participate in Livermore research programs prior to their service appointment.
- **SkillBridge/Career Skills Program**
  Transitioning military service members can intern at LLNL in their last four to six months of service.

Engineering Technology Program (Vets2Tech)

Established by LLNL in 2014, the Engineering Technology Program (Vets2Tech) at Las Positas College helps veterans and minority students acquire industry-standard skills required in the fast-growing field of mechanical engineering technology. The program recognizes that many veterans, despite strong leadership and problem-solving skills, lack the required math skills to enter high-paying tech jobs. Participating community colleges provide accelerated math curricula and priority positions in semiconductors, industrial instrumentation, bioengineering, additive manufacturing, and lasers and optics. Students also receive access to tutoring, soft skill devleopment, employer enagagement, and personal coaching during their internship to ensure a successful transition into the civilian world of work. Program participants are well positioned to work towards their Associate of Science (A.S.) degree and employment as STEM technologists. On average, 20% of graduating students go on to register for their Bachelor's degree.

Upon completing the first year, students are provided an opportunity to work in paid internships at local employers. During their 10-week summer internship, ETP participants have hands-on opportunities to apply their knowledge and connect with a tight-knit student community. The internship covers a variety of manufacturing and research roles.

To ensure that all students are placed, LLNL leads a local employer group known as Vets2Tech that hires students and graduates.

The Engineering Technology Program won an Award for Innovation in 2017 from the East Bay Economic Development Alliance.

> “The program has allowed me to acquire a new set of skills and see a career path I would have never considered before.”
>
> – Jeremy Taylor, former Army staff sergeant working at NIF

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