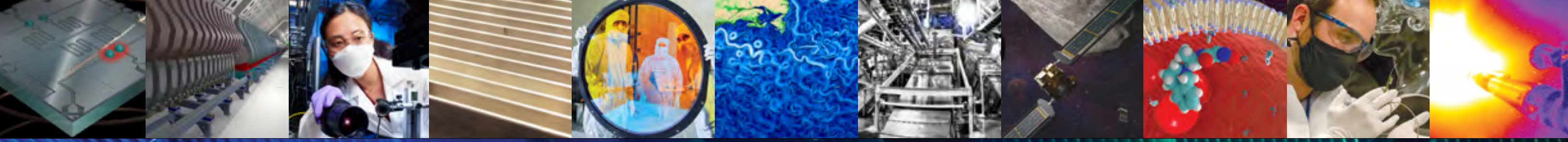
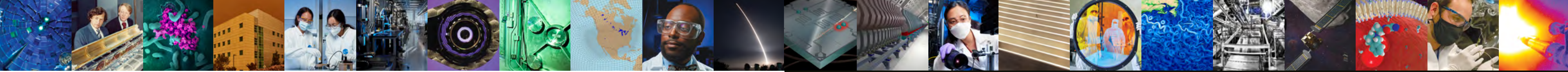


LAWRENCE LIVERMORE NATIONAL LABORATORY

FY 2021 ANNUAL REPORT

SCIENCE AND TECHNOLOGY ON A MISSION

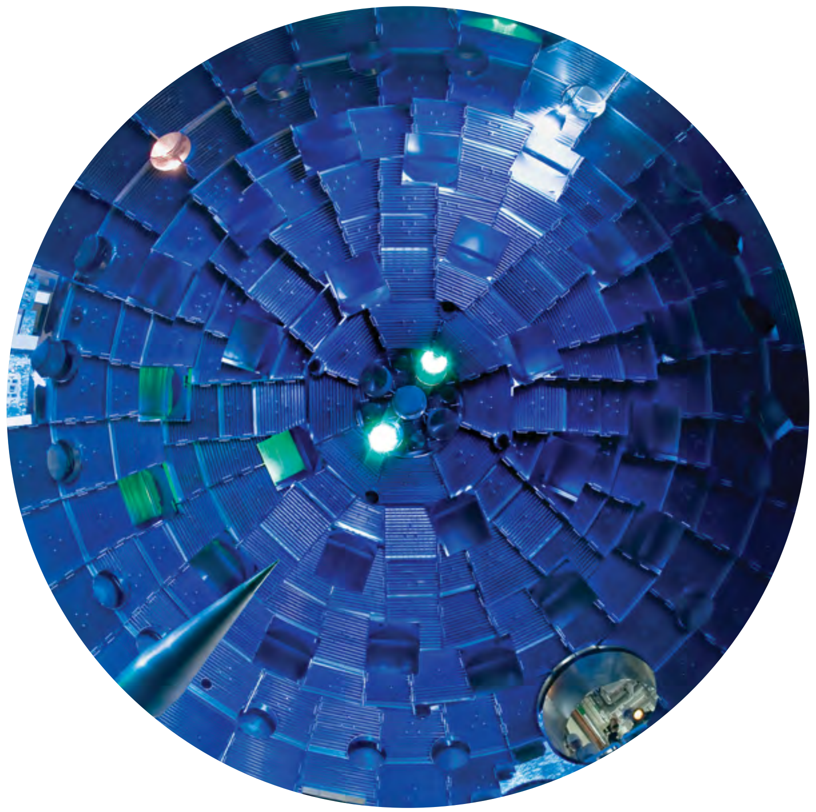


ABOUT US

Lawrence Livermore National Laboratory (LLNL) was founded in 1952 to enhance the security of the United States by advancing nuclear weapons science and technology and ensuring a safe, secure, and effective nuclear deterrent.

With a talented and dedicated workforce and world-class research capabilities, the Laboratory strengthens national security with a tradition of science and technology innovation—anticipating, developing, and delivering solutions for the nation's most challenging problems.

The Laboratory is managed by Lawrence Livermore National Security, LLC (LLNS), for the National Nuclear Security Administration (NNSA), a semi-autonomous agency within the U.S. Department of Energy (DOE).



ABOUT THE COVER

Fiscal year (FY) 2021 was filled with programmatic successes at the Laboratory. Notably, an experiment at the National Ignition Facility achieved 1.3 megajoules of fusion energy—nearly the amount of laser energy fired at the target. The cover shows the target positioner (bottom left) being inserted, as seen from the bottom of the 10-meter-diameter target chamber.

Managed and operated by

A limited liability company comprised of members

And supported by teaming contractor

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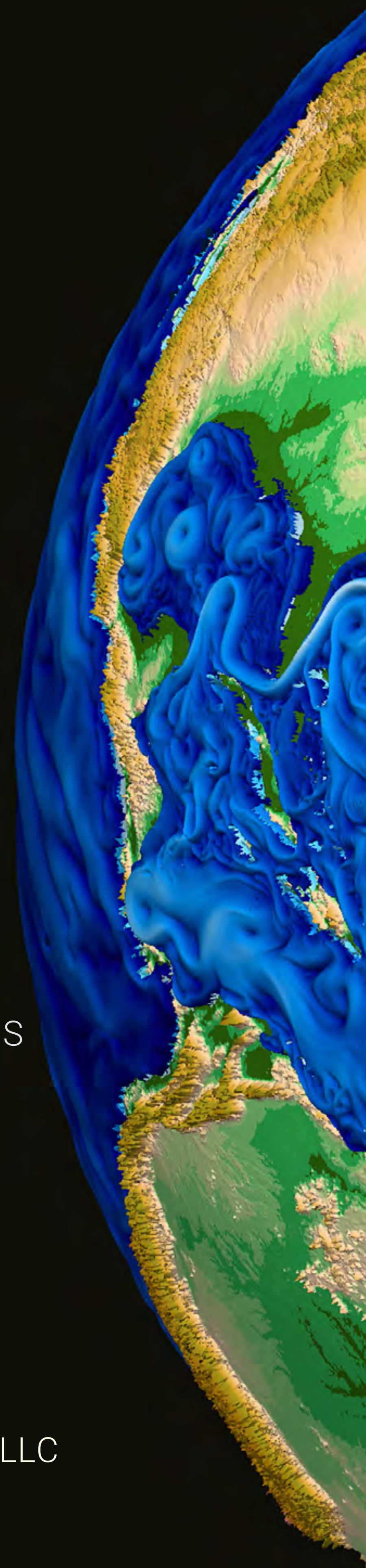
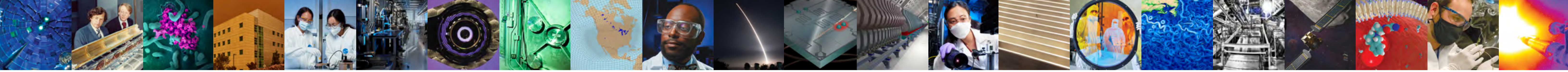
INSIDE FY 2021





SCIENCE AND TECHNOLOGY ON A MISSION

At Lawrence Livermore National Laboratory (LLNL), we pursue mission-directed science and technology (S&T) with a keen eye on the future.

LLNL Director Kimberly Budil

FY 2021 WAS A TRANSFORMATIONAL year for our Laboratory and the world. The ongoing COVID-19 pandemic and a rapidly changing security environment demonstrated the importance of looking over the horizon and anticipating an uncertain future. These challenges have also demonstrated the power of S&T to bring forward innovative solutions and strategies to make the world a safer place. This Annual Report describes Livermore's advances at the frontiers of S&T, as exemplified by the "shot heard round the world" at the National Ignition Facility (NIF). We translate our innovations into meaningful products with impact, often in partnership with others, to strengthen national security in an increasingly dynamic world.

Polymer Production Enclave

LLNL provides unique expertise and world-class scientific tools in support of national security with a core mission to sustain and advance nuclear deterrence. We are an essential part of the Department of Energy (DOE) national laboratory system and the National Nuclear Security Administration (NNSA) nuclear security enterprise. Our Laboratory is fully engaged in programs to modernize the nation's nuclear weapons stockpile and enterprise—developing and implementing innovations in design, engineering, and manufacturing in partnership with other laboratories, plants, sites, and federal stakeholders. We are striving to make the nuclear security enterprise agile, resilient, sustainable, and responsive to emerging national needs. As a national security laboratory, LLNL is chartered to apply our special scientific and engineering tools and competencies to address four strategic mission priorities.

STRATEGIC MISSION PRIORITIES

Nuclear Deterrence continues to be the defining responsibility of our Laboratory. We must assure the safety, security, and effectiveness of the U.S. nuclear stockpile in an evolving security environment. This mission drives major investments at Livermore, shapes our S&T strengths, and demands that we deliver on aggressive timelines. As highlighted in our Annual Report, we are delivering the first two modernized warheads of the stockpile stewardship era: the W80-4 warhead—to be carried on the all-new Long-Range Standoff missile—and the W87-1 warhead for the future Ground Based Strategic Deterrent system. These programs will modernize the warheads—improving safety, introducing new materials and components, and assuring robust performance—as well as the production enterprise. Through close partnerships with the production sites, called *enclaves,* we are developing and introducing advanced manufacturing technologies, development approaches, and business processes to improve efficiencies, lower costs, and provide greater agility in responding to emerging needs. We are also pursuing major advances in computing hardware and simulation, experimental capabilities, and diagnostics to provide critical support for weapons design and certification as well as enterprise transformation.

Threat Preparedness and Response is required to counter natural and human-made threats, prevent the use of weapons of mass destruction (WMD), and enhance global security. In support of Livermore's broader national security mission and NNSA's nuclear nonproliferation responsibilities, the Laboratory is a source of unique capabilities and expertise to anticipate threats and provide innovative solutions. We support the intelligence community, develop and apply cutting-edge forensic science to WMD attribution, and advance nuclear nonproliferation objectives. Our Annual Report highlights LLNL's leadership in biosecurity S&T, which began in the 1990s with the development of bioagent detectors in anticipation of the threat. In FY 2021, Livermore applied innovative high-performance computing tools and laboratory analyses in response to the COVID-19 pandemic, developed the first nerve-agent antidote effective in protecting the central and peripheral nervous systems, and engaged in partnerships to develop a universal vaccine.

LLNL's Center for Global Security Research serves the policy community as a "thought leader."

Climate and Energy Resilience is one of today's most pressing challenges and national security concerns. LLNL has been a leader in understanding the climate since the 1950s when the first climate model simulating large weather systems ran on Laboratory supercomputers. In FY 2021, high-resolution climate models were used to understand the regional effects of climate change, a critical step toward developing mitigation strategies and preparing communities to adapt. Groundbreaking reports issued by LLNL evaluated technologies that can lead California to carbon neutrality by 2045 and examined the challenges facing implementation of carbon-capture technologies. Our Annual Report also features the application of additive manufacturing to create efficient reactors for recycling captured carbon into useful industrial products.

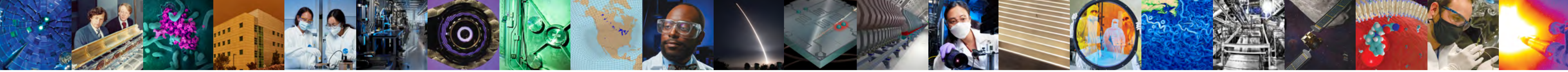
Integrated Deterrence and Competition seeks to create strategic advantages in an increasingly dynamic and dangerous multipolar world. LLNL's Center for Global Security Research serves the policy community as a "thought leader" about integrated deterrence to meet multifaceted challenges: WMD, cyber and space security, directed energy systems, and hypersonic conventional weapons. Livermore is focused on understanding the potential threats and developing advanced defense technologies and scenario modeling tools. Moreover, S&T leadership is paramount to strategic competition. NIF experiments at the threshold of ignition, preparation for delivery of the exascale El Capitan supercomputer, and advancement of cognitive simulation—integrating high-performance computing, big data, S&T simulations, and artificial intelligence—exemplify areas of LLNL leadership.

The $100 million Exascale Computing Facility Modernization project prepares the Laboratory for arrival of the El Capitan supercomputer in 2023.

TRANSFORMING THE LABORATORY

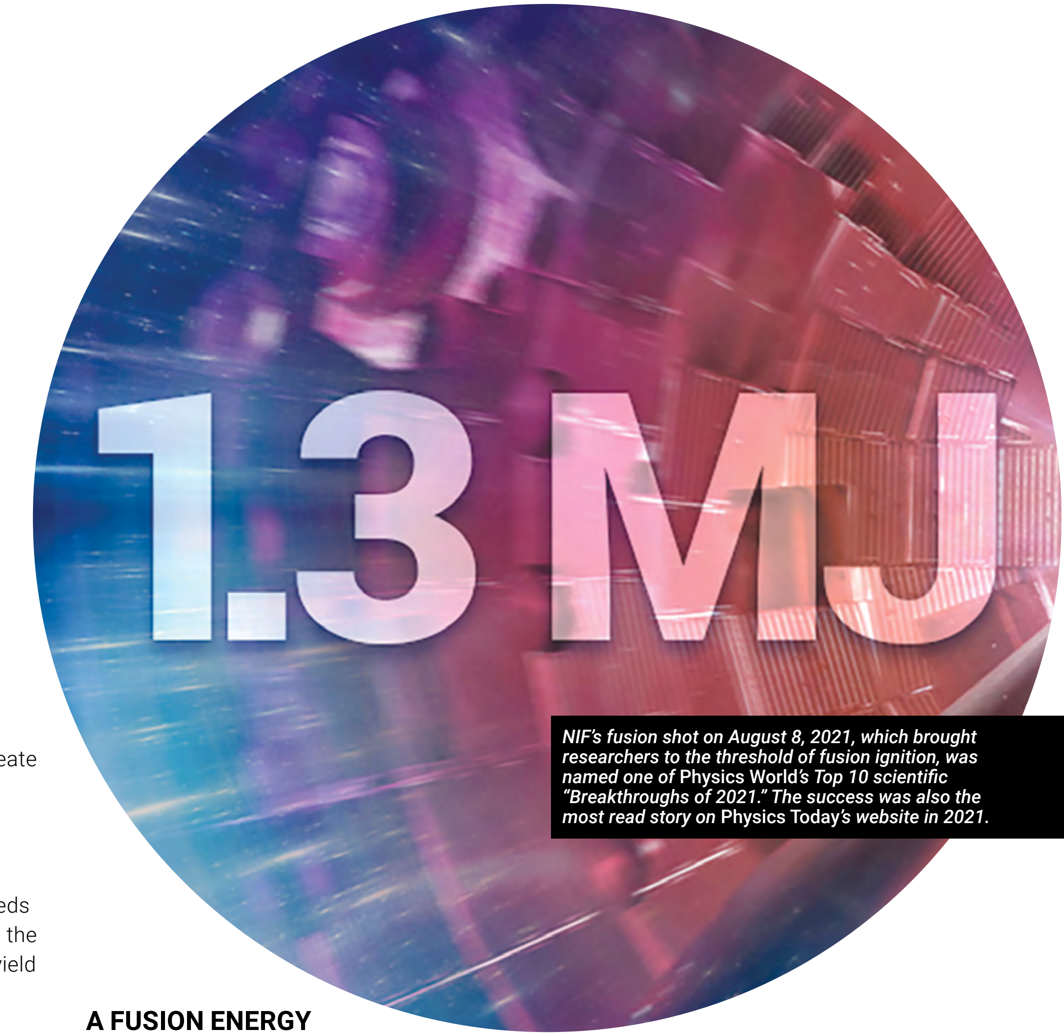
Livermore is changing—with new facilities, new staff, and a new mode of operation all focused on the future and our 21st-century mission priorities. Our Annual Report features major construction projects that contribute to revitalizing the Laboratory's infrastructure and S&T research capabilities. During the COVID-19 pandemic, LLNL continued to operate with measures to ensure worker health and safety and launched the process of a "Return to New Normal." Telework and hybrid work schedules are now part of everyday operations, and our use of video teleconferencing technology continues to advance. This added flexibility enables individuals to attain a better work–life balance and the Laboratory to operate under changing conditions.

Outstanding people are the Laboratory's most important resource, and we continue to recruit the very best to join our team. Our culture is adapting to the generational change, building on and advancing the heritage established by Livermore's founders. We thrive on serving as a "new ideas" laboratory, pursuing multidisciplinary "big science" in the national interest.



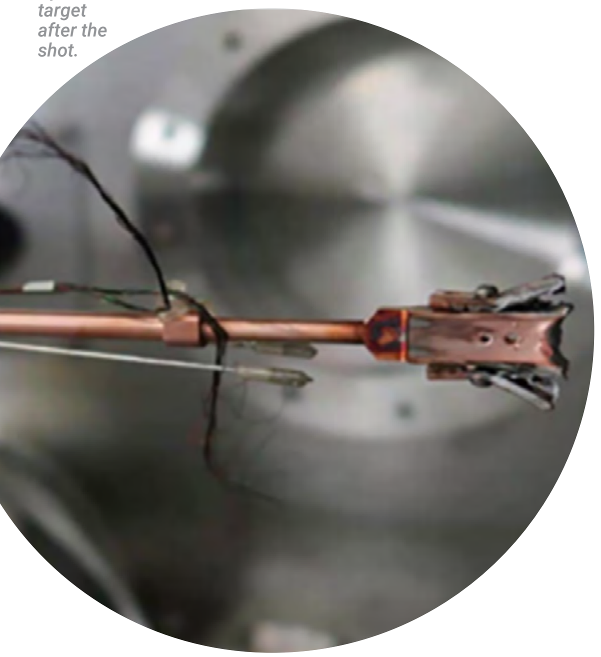
AT THE THRESHOLD OF IGNITION

Producing 1.3 megajoules (MJ) of fusion energy at the National Ignition Facility (NIF) by imploding a deuterium–tritium (DT) fuel capsule with 1.9 MJ of laser energy



NIF's fusion shot on August 8, 2021, which brought researchers to the threshold of fusion ignition, was named one of Physics World's Top 10 scientific "Breakthroughs of 2021." The success was also the most read story on Physics Today's website in 2021.

ON AUGUST 8, 2021, NIF LASER beams imploded a target capsule to create a central hot spot of dense DT fuel and trigger a self-sustaining wave of fusion reactions. As defined by the National Academy of Sciences, ignition occurs when the fusion energy produced exceeds the amount of laser energy delivered to the target chamber. The measured fusion yield was about 70 percent of that goal.



Hybrid-E target after the shot.

A FUSION ENERGY BREAKTHROUGH

The historic experiment conducted at NIF on August 8, 2021, produced 1.3 MJ of fusion energy. Researchers are at the threshold of achieving fusion ignition. The laser system delivered 1.9 MJ of energy, which squeezed the DT fuel within the capsule to 8 times the density of lead and generated more than 10 quadrillion watts of fusion power for 100 trillionths of a second. The fusion yield was 25 times higher than the record set in 2018 and 8 times higher than results achieved earlier in FY 2021.

The efforts in FY 2021 focused on a target design (called Hybrid-E) with a large high-density-carbon (diamond) capsule. Hybrid-E couples more energy to the fuel capsule than the baseline design, compresses it faster, and increases hot-spot pressure and temperature.

To achieve a symmetric implosion with the larger capsule, the wavelength of each laser beam is slightly adjusted to help balance x-ray energy that compresses the fuel. This design approach led to higher than previous yields in shots fired in November 2020 (100 kilojoules [kJ]) and February 2021 (170 kJ). For the test in August, the entrance holes that let laser light into the hohlraum (enclosing the target capsule) were reduced in size to increase the coupled energy. To further improve implosion symmetry, the tube that fills DT into the capsule was reduced in diameter from 5 micrometers (μm) to 2 μm and the target fabrication team supplied a much more uniform capsule with 10 times fewer and smaller defects. The result was a dramatic increase in fusion yield.

SUCCESS THROUGH TEAMWORK

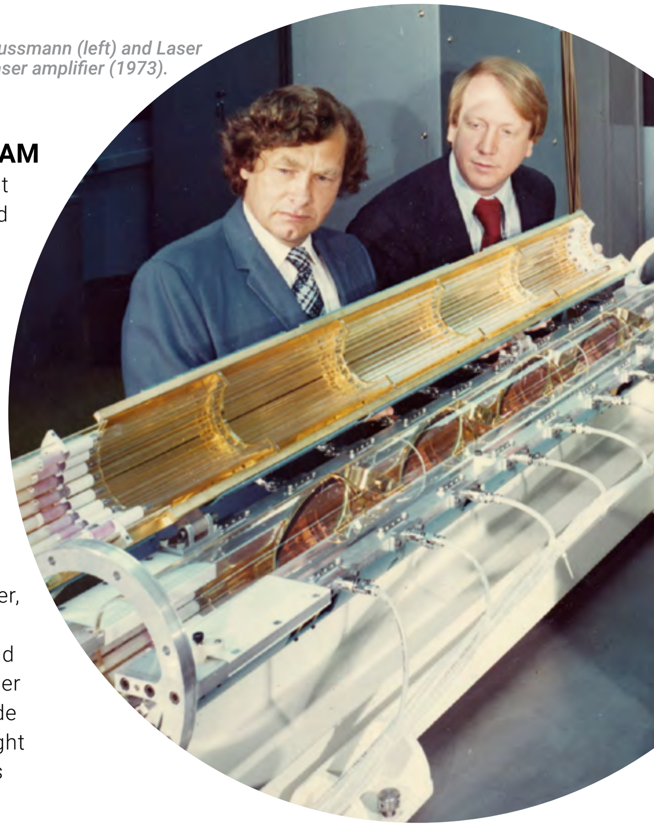
This experimental result is a huge step forward for inertial confinement fusion (ICF) research, opening a fundamentally new regime to explore and advance our critical national security mission. Gaining access to thermonuclear burn in a laboratory setting will enable experiments that more rigorously check theory and validate simulations of high-energy-density physics pertinent to weapons performance. Fusion ignition is also an important gateway toward pursuit of high fusion yields, which would be necessary for fusion energy applications.

This significant achievement was made possible by the hard work of the ICF community over many decades and benefited from key advances gained over the last several years. Supporters of the effort include LLNL; industry and academic partners; and collaborators at Los Alamos National Laboratory, Sandia National Laboratories, the University of Rochester's Laboratory for Laser Energetics (LLE), and General Atomics. The achievement builds on the work of the entire team, including the people who pursued and advanced ICF research since the Laboratory's earliest days.

FOUNDING OF THE ICF PROGRAM

In the late 1950s, Laboratory physicist (and later Director) John Nuckolls and colleagues ran the latest computer codes and found that radiation could implode a capsule of DT fuel and initiate a very small-scale fusion explosion. At about the same time, Theodore Maiman built the first laser, and laser experiments began at the Laboratory soon after. In 1971, Associate Director at Large Carl Haussmann took charge of a newly created Laser Program; proposed to the Atomic Energy Commission (AEC) the construction of a high-power, solid-state 10-kJ laser; and recruited John Emmett to the Laboratory to lead the AEC-approved, 20-beam Shiva laser project. Experiments using Shiva made clear that shorter wavelength laser light would be necessary, and experiments at LLE demonstrated a way to triple laser-light frequency. Construction of the next large laser, the 10-beam Nova laser, began in 1979, and in the 1980s, experiments at Nova and underground ICF nuclear tests uncovered no showstoppers to achieving ignition with a larger laser.

Associate Director at Large Carl Haussmann (left) and Laser Program leader John Emmett inspect a laser amplifier (1973).



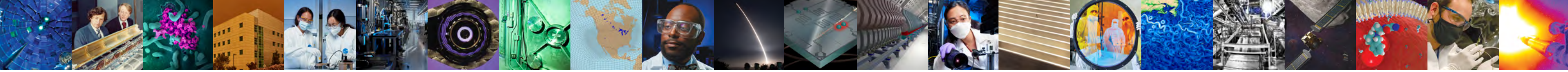
THE SEVEN WONDERS OF NIF

NIF team scientists, engineers, and technicians had to overcome a daunting array of technical issues. Working closely with industrial partners, they found solutions for precision ***preamplifier modules*** and addressed challenges in continuous-pour ***laser glass***, ***rapid-growth crystals***, and coatings and finishing techniques for ***optical switches*** and ***deformable mirrors*** to withstand extremely high energies. The team also worked with vendors to develop pulsed-power electronics, innovative ***control systems***, and advanced manufacturing capabilities for ***target fabrication***.

THE GIANT STEP TO NIF

From a technology point of view, NIF was a giant step. The 60-fold increase in laser capability required significant advances in laser architecture and many other technologies including optical materials (see the box) as part of a multibillion-dollar construction project. In recommending that NIF be built at an energy of about 2 MJ, the National Academy of Sciences expected that the probability of achieving ignition would be at best a 50-50 proposition. Yet, it was appropriate as a next step toward ignition and a vital component of the Stockpile Stewardship Program.

The initial ignition campaign began the long process of bringing into operation improved diagnostics, developing experimental platforms, increasing the damage resistance of optics, and discovering and overcoming barriers to achieving ignition. With the high-foot campaign launched in 2013, researchers experimented with a laser-pulse shape to obtain more stable implosions and first demonstrated alpha heating. A systematic process of identifying and overcoming implosion deficiencies ensued, accelerated progress, and led to hybrid target capsule designs and the successes that bring the ICF community to the doorstep of ignition.



NUCLEAR DETERRENCE

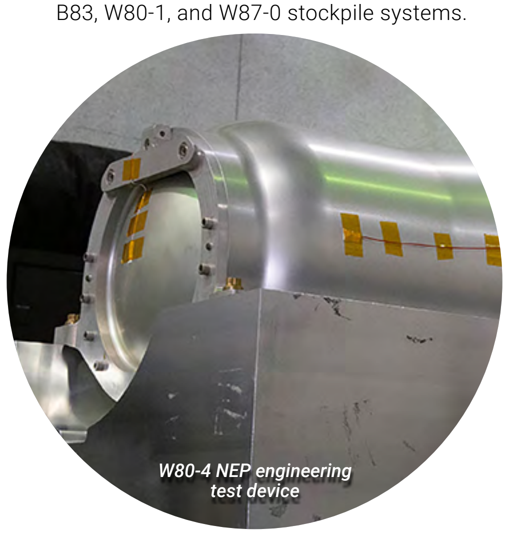
Striving for a modernized safe, secure, and effective nuclear weapons stockpile

LLNL is partnered with Sandia National Laboratories as the design agencies to develop and certify the W80-4 warhead for the bomber-delivered Long-Range Standoff missile.

LLNL's FOREMOST RESPONSIBILITY is to ensure the performance of the nation's nuclear arsenal without nuclear testing. Knowledge gained through experiments, theory, and simulations is applied to assess the condition of current weapons and pursue programs that jointly modernize the stockpile and weapons production processes.

ANNUAL STOCKPILE ASSESSMENT

In FY 2021, LLNL completed Cycle 26 of the annual stockpile assessment. The process included a formal comprehensive peer review between LLNL and Los Alamos National Laboratory (LANL) of each other's weapon systems. Laboratory scientists performed experiments and enhanced physics and engineering simulation codes to improve predictability and strengthen the technical foundation that supports assessments and certification of weapons. LLNL also completed needed surveillance, testing, and analysis activities to assess the condition of and sustain the B83, W80-1, and W87-0 stockpile systems.



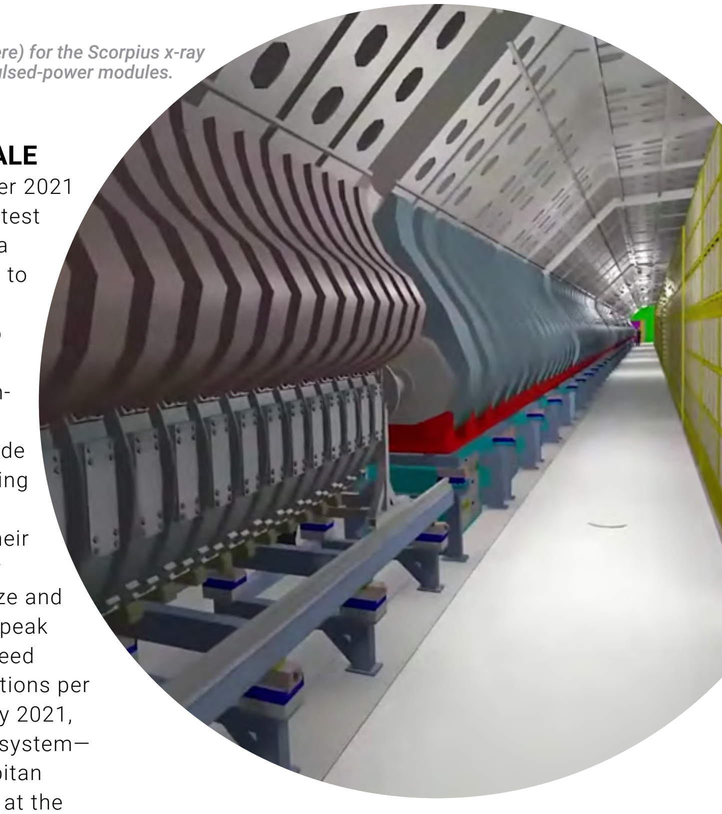
W80-4 NEP engineering test device

STOCKPILE MODERNIZATION PROGRAMS

LLNL is partnered with Sandia National Laboratories (SNL) as the design agencies to develop and certify the W80-4 warhead for the bomber-delivered Long-Range Standoff missile. The Laboratory is making excellent progress in Phase 6.3 (development engineering) of the W80-4 Life-Extension Program (LEP) and preparing to enter Phase 6.4 (production engineering) in FY 2022. The design of the nuclear explosives package (NEP) has matured, and the team is preparing for formal system reviews. One notable accomplishment was LLNL's completion of its first high-fidelity engineering ground test. An NEP engineering test device demonstrated that the baseline design can survive expected thermal and vibrational environments. The plans to refurbish or replace aging components and materials in the W80-4 include using new manufacturing methods that minimize costs, increase throughput, and reduce the need for environmentally sensitive materials and processes.

The W87-1 Modification Program completed Phase 6.2 (program feasibility) in August 2021 and moved to Phase 6.2A. During this phase, the Weapon Design and Cost Report will be developed. LLNL is NNSA's design agency for the NEP for a ballistic-missile warhead to replace the aging W78. To be deployed on the U.S. Air Force's Ground Based Strategic Deterrent in 2030, the W87-1 will be the first modern warhead in the stockpile that is 100 percent newly manufactured. Technical activities are focusing on maturing weapon design options and modern manufacturing methods.

The next-generation particle accelerator (depicted here) for the Scorpius x-ray imaging system will include LLNL-developed pulsed-power modules.



ENCLAVES AND PARTNERSHIPS

The W80-4 and W87-1 programs require the full array of NNSA's computational, experimental, and manufacturing capabilities, which must be upgraded and better integrated to meet stringent production deadlines in an efficient, cost-effective manner. The use of enclaves is a pioneering approach to accelerate design-to-deployment. LLNL's new Polymer Production Enclave, established in partnership with the Kansas City National Security Campus (see p. 18), exemplifies this approach. Additional partnerships include work with the Y-12 National Security Complex on minimal-waste uranium component production and with the Holston Army Ammunition Plant on manufacturing insensitive high explosives (HEs). Stockpile modernization also requires partnerships in weapon pit manufacturing with LANL and Savannah River National Laboratory and in the LANL-led Scorpius project to deliver greatly enhanced subcritical experimental capabilities at the Nevada National Security Site.

PREPARING FOR EXASCALE

Ranking third on the November 2021 TOP500 list of the world's fastest supercomputers, LLNL's Sierra provides outstanding support to the three NNSA laboratories. Scientists use the machine to run high-fidelity multiphysics simulations that address high-priority issues. In FY 2021, LLNL computer scientists made excellent progress in developing a next-generation, production quality, multiphysics code. Their attention is on the next major advance in supercomputer size and architecture: El Capitan, with peak performance expected to exceed 2 exaflops (quintillion calculations per second). Delivered in February 2021, the "RZNevada" early-access system—small and as similar to El Capitan as feasible—provides experts at the NNSA laboratories an opportunity to develop and test applications ahead of El Capitan's arrival in 2023, perhaps as the world's fastest supercomputer.

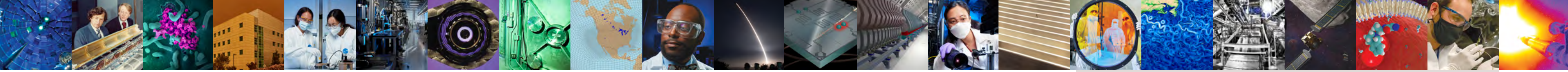
The $100 million Exascale Computing Facility Modernization project is preparing LLNL for this delivery (see p. 21). Laboratory researchers are also fully engaged in DOE's seven-year $1.8 billion Exascale Computing Project, which is addressing the many technological challenges that the leap to exascale presents (see p. 15).

STOCKPILE STEWARDSHIP EXPERIMENTS

Despite COVID-19 protocols, wildfires, hazardous air quality, and extreme heat, LLNL successfully conducted nearly 100 experiments at remote Site 300 in FY 2021, including key integrated weapons experiments that supported critical design decisions for the W80-4 LEP. In addition, more than 650 shots were fired at the High Explosives Applications Facility. In combination with simulations, these shots helped scientists to better understand details about the shock initiation and detonation properties of HEs. Experiments at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility and the National Ignition Facility (see p. 9) provided essential data about materials at extreme conditions. JASPER experiments in FY 2021 supported pit certification for the W87-1 Modification Program.

FLIGHT TEST OF MINUTEMAN III/W87-0

In February 2021, a Minuteman III intercontinental ballistic missile was launched from Vandenberg Space Force Base. A W87-0 nonnuclear joint test assembly, designed by LLNL and SNL, was on board. The stockpile flight test program serves to validate and verify the safety, security, effectiveness, and readiness of the weapon system. Data gathered from such tests are analyzed and incorporated into the annual assessment of the W87-0.



NATIONAL IGNITION FACILITY

Supporting stockpile stewardship through a wide range of experiments and pursuit of fusion ignition; and operating as a national user facility for high-energy-density (HED) science

The neutron imaging system produces an image of high-energy and lower energy "down-scattered" neutrons produced by fusion reactions. Researchers use the image to determine the hot-spot size and fuel asymmetry and to infer key properties describing the surrounding fuel.

IN FY 2021, THE NATIONAL IGNITION Facility (NIF) maintained fully scheduled shot-weeks while managing safe operations according to established COVID-19 protocols and procedures. The NIF team completed 368 shots during the year that supported stockpile stewarship priorities, including properties of plutonium under extreme conditions, nuclear survivability, fusion ignition, and others.

DIAGNOSTICS IN SUPPORT OF THE FUSION MILESTONE

NIF's highly specialized and sophisticated measuring instruments—referred to as diagnostics—were integral to the success of the record-setting inertial confinement fusion (ICF) experiment conducted on August 8, 2021 (see pp. 4–5). About 20 diagnostics were used in the 1.3-megajoule shot and all performed well. Multiple complementary and redundant state-of-the-art nuclear, x-ray, and optical diagnostics gathered data. For example, fusion yield was measured by three independent diagnostics. Instruments provided time-integrated and time-resolved x-ray imaging. Three lines of sight were used for time-integrated neutron imaging, and neutron spectra measurements were gathered along six lines of sight. The 3D neutron imaging system (NIS), developed by researchers at Los Alamos National Laboratory (LANL) in collaboration with LLNL colleagues, was particularly valuable. NIS data provides a 3D analysis of the neutron-emitting hot spot and the surrounding deuterium–tritium (DT) fuel, an important measure of the quality of the implosion. In addition, 48 real-time nuclear activation detectors were used to infer DT fuel uniformity.

A NIF hohlraum with a diamond capsule inside

The multilaboratory National Diagnostic Working Group guides the development of state-of-the-art instruments for all the HED science laboratories funded by NNSA. Diagnostics at NIF, which are used for a wide variety of HED experiments, have benefited from decades of experience and ongoing collaborations with national and international partners, including LANL, Sandia National Laboratories, the University of Rochester's Laboratory for Laser Energetics, General Atomics, the Massachusetts Institute of Technology, the Nevada National Security Site, the University of California at Berkeley, and the atomic energy agencies in the U.K. and France. A priority moving forward is the upgrade of several diagnostics to support even higher neutron yields that are expected as future experiments build on the success of the August result.

STOCKPILE STEWARDSHIP HED SCIENCE EXPERIMENTS

HED science experiments at NIF in FY 2021 provided crucial data to support stockpile modernization and helped scientists study wide-ranging physical phenomena central to stockpile stewardship. Scientists investigated the properties of materials at extreme conditions, hydrodynamics and the behavior of shocks, and material mixing. The data are used to improve and validate 3D simulation models of weapons performance. Of note, researchers fired the first-ever NIF shot to study a high-explosive (HE) sample in FY 2021. The shot was the first in a series of experiments to help scientists unlock the mysteries of HE chemistry. NIF has the unique capability to shock compress a sample with a 60-nanosecond-long laser pulse and follow it with two x-ray probes to view resultant product formation. These shots will greatly expand the Laboratory's HE experimental toolbox and provide data to critically evaluate the predictive computational capabilities of LLNL's world-class thermochemical code, Cheetah.

DISCOVERY SCIENCE AT NIF

Experiments at NIF provide unique opportunities to explore the conditions found at the cores of giant planets and dwarf stars as well as energetic phenomena in the universe. In FY 2021, an international team of researchers led by LLNL and Oxford University studied carbon at pressures reaching 2,000 gigapascals (GPa), nearly doubling the highest pressure at which any crystal structure has been probed. Scientists have predicted several new structures of carbon that could be found above 1,000 GPa (2.5 times the pressure at Earth's core and relevant for modeling exoplanet interiors). The NIF experiments surprisingly revealed that at 2,000 GPa carbon does not transform to any other predicted phase. Solid carbon retains its diamond structure far beyond its regime of predicted stability. In another effort, Laboratory researchers developed an x-ray source that can be used as a backlighter in experiments that probe conditions of extreme temperature, such as those at the center of planets. These tests, called extended x-ray absorption fine structure (EXAFS) experiments, can be performed at NIF over a wide range of materials and conditions that were not previously possible at any other facility.

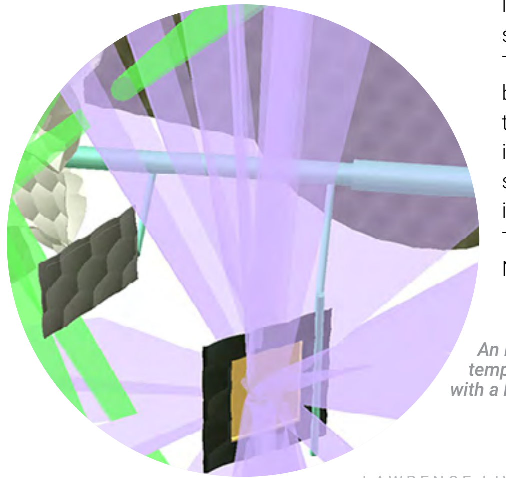
TESTING NUCLEAR SURVIVABILITY IN SPACE

Under development, the Direct Laser Impulse project aims to provide a new NIF capability to test the survivability in space of vital strategic defense and weapon delivery systems near a nuclear explosion. In experiments, two NIF beams will be directed at a square-foot-size target system placed inside a large, unused compressor vessel (shown) located outside the target chamber. Vaporized material will blow off the surface and shock the target's interior—perhaps causing system failure.

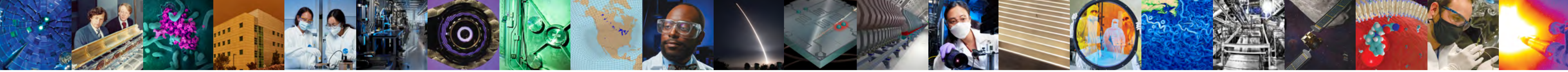
NIF TRANSFORMATION AND SUSTAINMENT

FY 2021 was an exceptional year for NIF with ICF experimental results at the threshold of ignition. The achievement creates opportunities to better understand the fundamental processes of fusion ignition and burn and enhance simulation tools supporting stockpile stewardship and modernization. Fusion ignition is also an important gateway for accessing high fusion yields. New diagnostics, innovations in ICF target designs, improved laser precision and optics damage mitigation, and transformational improvements in target fabrication were paramount to this success. Other ongoing transformational projects include developing an optical Thompson scattering detection system to probe hohlraum dynamics in detail and exploring "magnetized" ICF to achieve higher fusion yields.

Many NIF subsystems, designed with 1990s technology, are now over 20 years old. Obsolescence concerns and the need for refurbishment have resulted in degradation of some systems, and equipment-related delays are increasing. To assure that NIF continues to support its burgeoning role in stockpile stewardship through its 2040 design lifetime, the NIF team conducted a systematic review of the NIF enterprise. To sustain NIF operations, needs have to be met in three categories: refurbishment to address deferred maintenance; investments in updated equipment for selected systems; and improvements to increase productivity and reduce costs. The results are reported in a five-year NIF Sustainment Plan.

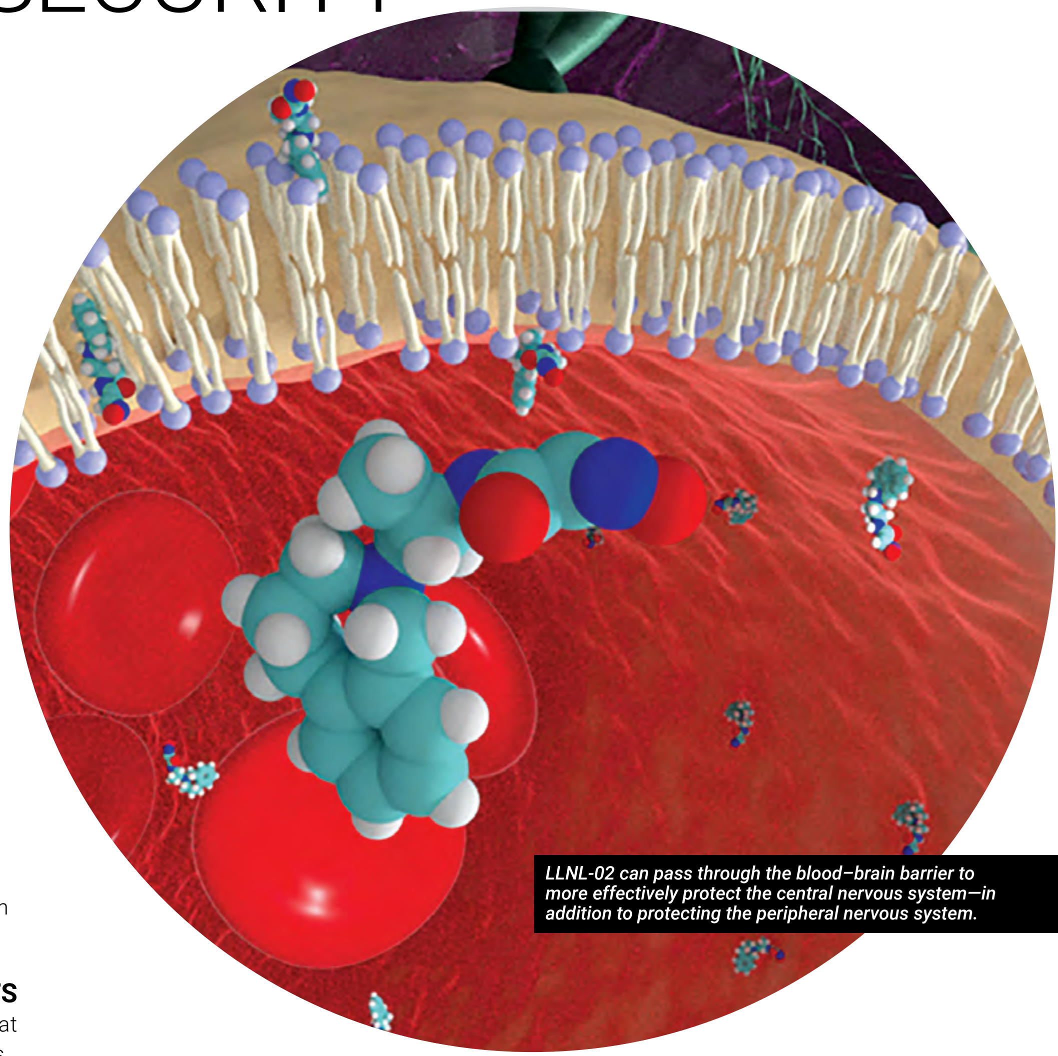


An EXAFS experiment (depicted here) measures the temperature of a NIF laser-compressed target with a broadband backlighter x-ray source.



GLOBAL SECURITY

Reducing the threat from terrorism and weapons of mass destruction and enhancing global strategic stability



LLNL-02 can pass through the blood–brain barrier to more effectively protect the central nervous system—in addition to protecting the peripheral nervous system.

LLNL DEVELOPS INNOVATIVE advanced technologies to help the government anticipate, identify, and address global security threats. Guided by intelligence-based science and technology and applying expertise in chemical, biological, radiological, nuclear, and explosive weapons, we strive to implement tools to enhance threat preparedness, prevention, protection, and response and recovery. In addition, Livermore innovations in space situational awareness and cyberdefense help strengthen security in an increasingly interconnected world.

AN ANTIDOTE TO NERVE AGENTS

In work performed for the Defense Threat Reduction Agency, Laboratory scientists developed LLNL-02, a new, versatile antidote to counteract exposure to nerve agents. Chemical weapon nerve agents, such as Sarin, typically function by blocking the transmission of messages from the central nervous system (CNS), composed of the brain and the spinal cord, to the peripheral nervous system (PNS), which controls processes such as respiration. The brain's natural protection, the blood–brain barrier (BBB), keeps potentially harmful molecules from entering and affecting the CNS but makes it difficult to get an antidote across the threshold. LLNL-02 is the first antidote able to cross the BBB and effectively protect the CNS and PNS.

LLNL-02 was discovered through the use of the Laboratory's supercomputers combined with medicinal chemistry to test viability. Promising candidates required hundreds of simulations involving 5 quadrillion equations. In tandem, Livermore scientists synthesized selected compounds and tested them for BBB permeability to validate simulation results. In a highly iterative collaboration, the U.S. Army Medical Research Institute of Chemical Defense and LLNL showed that LLNL-02 is nontoxic and works as well in animal models as the "gold standard" antidote. Continued testing is underway.

An LLNL researcher works on software for Livermore's payload on the Tactically Responsive Launch-2 spacecraft.

LLNL TECHNOLOGIES IN ORBIT

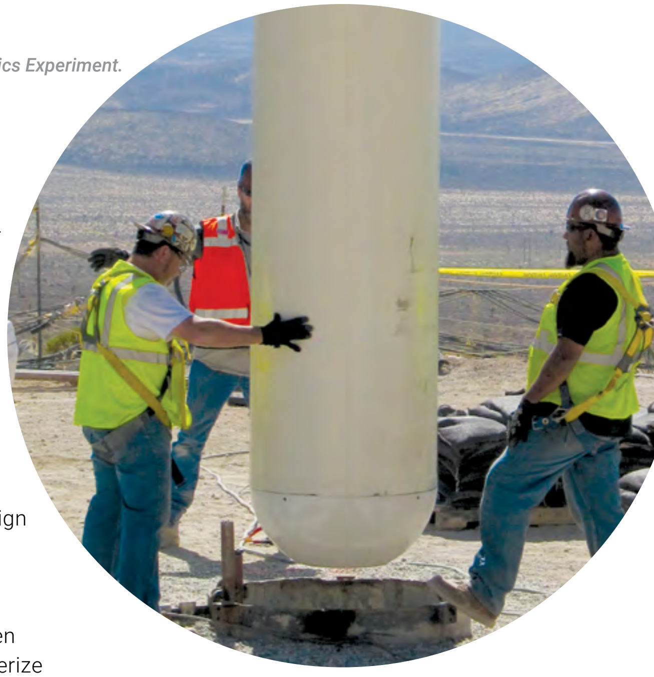
Launched from Vandenberg Space Force Base in June 2021, the U.S. Space Force's Tactically Responsive Launch-2 (TacRL-2) mission carried a payload designed and built in record time. Within four months of project initiation, LLNL researchers provided a three-mirror reflective telescope and sensor for the payload, which they designed, tested, and delivered to collaborators for system integration. Earlier in the year, two Laboratory-designed space telescopes had been launched into orbit on a 25-pound nanosatellite. GEOStare2, developed in collaboration with Tyvak Nano-Satellite Systems, has taken thousands of images of Earth and space.

TacRL-2 was the first mission led by the Space Safari Program within the U.S. Space Force's Space and Missile System Center. With this mission, the Space Safari Office successfully demonstrated their end-to-end approach to tactically responsive missions—an approach that seeks to introduce speed, agility, and flexibility into the space enterprise. Together, the team, which included LLNL, Space Dynamics Laboratory, and the Air Force Research Laboratory, delivered a complete technology demonstration satellite for launch in 11 months, significantly faster than the two to five years historically required.

FORENSIC SCIENTISTS SHOW THEIR SKILLS

In FY 2021, researchers at LLNL's Forensic Science Center (FSC) demonstrated their wide-ranging analytical skills. As part of an international exercise of a simulated nuclear smuggling incident, FSC scientists received mock evidence consisting of two uranium oxide fuel pellets. Within 24 hours, they identified unexpected uranium isotopic heterogeneity in the particles—a discovery made possible using Livermore's NanoSIMS high-spatial resolution secondary ion mass spectrometer. Analysis details provide law enforcement with clues about the process history and origin of materials.

Other FSC researchers found a biomarker that might be used to confirm use of chlorine gas as a chemical weapon. Chlorine gas disperses so rapidly that evidence of its release can be hard to find. The team exposed *Aegilops tauschii*, a type of grass native to parts of Asia, including Syria, to chlorine gas at various concentrations over a range of durations. They isolated proteins from grass tissue and found chlorine-containing compounds, including a promising molecular biomarker candidate—2,4,6-trichlorophenol—which the plant does not make. This biomarker is a likely indicator of chlorine exposure.



Workers lower an explosive package into a borehole for a prior Source Physics Experiment.

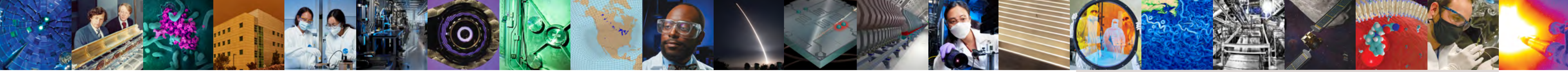
PROGRESS IN NUCLEAR NONPROLIFERATION

In FY 2021, despite the pandemic, LLNL made significant progress to improve detection and monitoring of nuclear proliferation activities. The Low Yield Nuclear Monitoring (LYNM)/Physics Experiment 1 (PE-1) venture, led by Livermore, completed a number of important project milestones. This work included tasks related to mining operations at the Nevada National Security Site, experiment design reviews, and creation of a detailed fielding schedule that culminates with PE-1 (planned for FY 2023). The LYNM experiments are designed to strengthen U.S. capabilities to detect and characterize low-yield and evasively conducted underground nuclear explosions.

LLNL also leads the Adaptive Computing Environment and Simulation (ACES) effort, which is coupling fissile material–production modeling with an adaptive computational environment that supports and effectively integrates modeling and data analytics. ACES will enhance NNSA's capability to predict strategic material production and provide an advanced computational environment where future nonproliferation challenges can be readily explored.

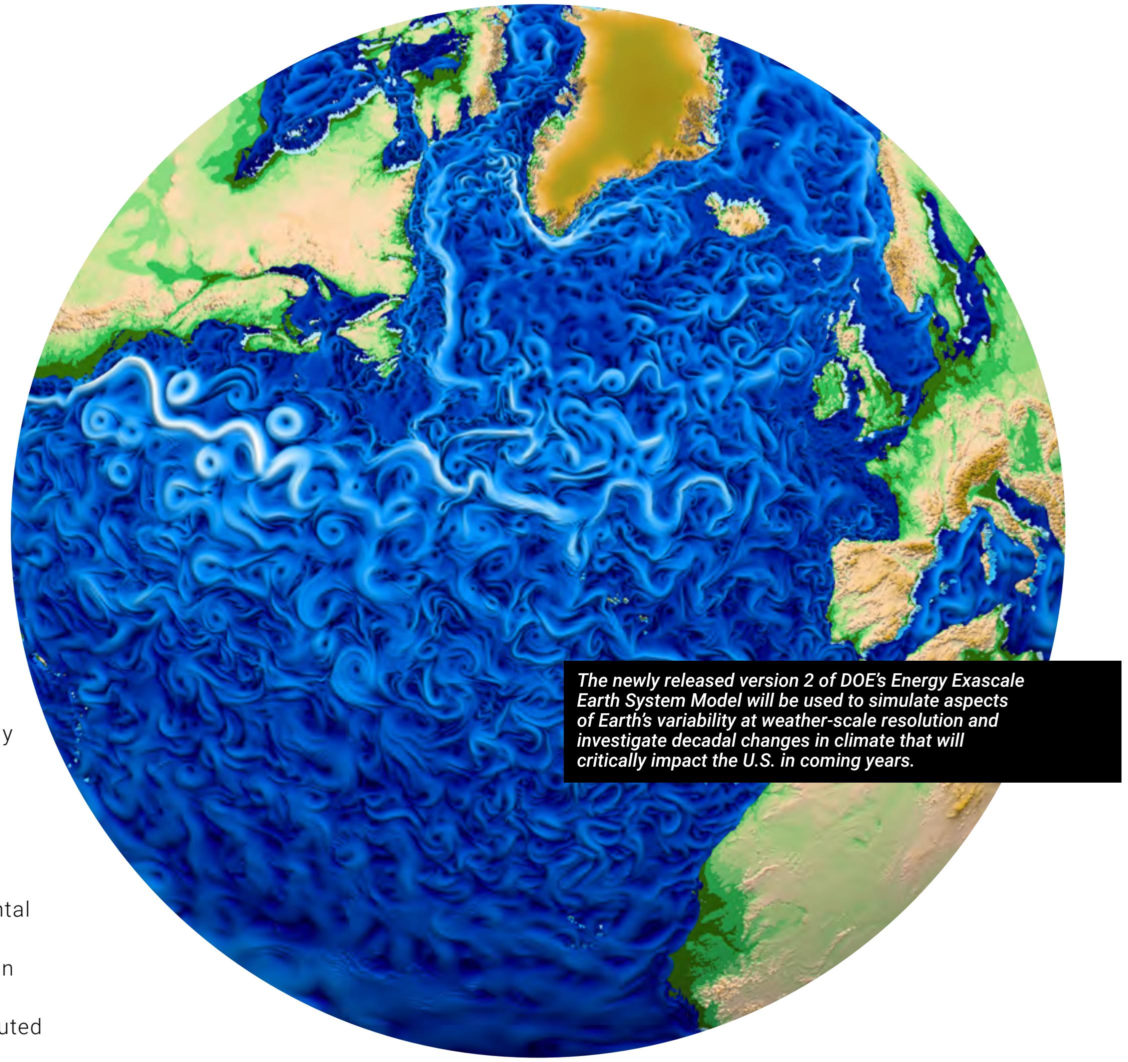
COLLABORATIVE AUTONOMY IN FLIGHT

Researchers in LLNL's collaborative autonomy group are shown flight testing a drone under the netting of the OS-150 Robotics Laboratory. The 50-foot-tall, 8,000-square-foot enclosure serves as a proving ground for autonomous drones, vehicles, and robots of the future. In projects for the Department of Defense, the group is working to develop "swarms" that can collectively gather data, make real-time decisions, and complete tasks deemed too hazardous for humans to perform.



ENERGY AND ENVIRONMENT

Using science and technology to improve national energy security and surety, protect the environment, and understand and mitigate climate change



The newly released version 2 of DOE's Energy Exascale Earth System Model will be used to simulate aspects of Earth's variability at weather-scale resolution and investigate decadal changes in climate that will critically impact the U.S. in coming years.

LABORATORY RESEARCHERS apply leading-edge capabilities to develop efficient and environmentally benign energy technologies and to investigate the processes behind climate change.

STUDYING CLIMATE CHANGE

In August 2021, the Intergovernmental Panel on Climate Change (IPCC) released the Working Group I portion of IPCC's Sixth Assessment Report (AR6). Four LLNL scientists contributed to this report, which examines the physical science underpinnings of climate change. Laboratory researchers have been principal contributors and provided scientific leadership in all five previous IPCC assessment reports dating back to 1990. AR6 strongly emphasizes evidence of "unequivocal" human influence on the climate and the occurance of "widespread and rapid changes" in the biosphere. Multiple, different effects are occuring regionally, and the report provides evidence of those changes to inform risk assessments and adaptation strategies. In FY 2021, studies by LLNL researchers focused on regional changes, for example, the amplification of warming through a reduction in marine clouds and changes in the ecosystem of Sierra Nevada mountain lakes. Livermore scientists and collaborators also made important contributions to reconciling satellite data collected since the late 1970s with model simulations.

Regional climate change studies with a higher resolution grid over the U.S.

UNDERSTANDING THE CARBON CYCLE

The terrestrial biosphere removes about 30 percent of the carbon dioxide (CO_2) emitted by human activities each year. A Livermore-led research team investigated how this sequestration rate would change at elevated atmospheric CO_2 content (eCO_2). They synthesized data from more than 100 eCO_2 experiments in various ecosystems to assess carbon absorption by the soil. Where plant biomass is weakly stimulated by eCO_2 (e.g., grasslands), soil organic carbon (SOC) accumulates. Conversely, SOC declines where the plant biomass is strongly stimulated by eCO_2 and mines nutrients from the soil (e.g., forests). These results highlight the need for ecosystem models to include more sophisticated representations of soil nutrient cycling and microbial activity. In another study, LLNL and collaborating researchers found that just a few bacterial groups in ecosystems across the planet are responsible for more than half the carbon cycling in soils. Gaining a better understanding of how individual organisms contribute to carbon cycling has important implications for managing soil fertility to reduce climate change.

CONVERTING CO_2 TO USEFUL PRODUCTS

Combining additive manufacturing with multiscale computer modeling, Livermore researchers are rapidly cycling the design and testing of modular electrochemical reactors with enhanced performance. The versatility and precise control offered by 3D printing makes it possible to tailor reactors to specific operating environments. The Laboratory's innovative work aims to transform the way many carbon-based products are manufactured. Reactors are used to convert CO_2 into hydrocarbons that are valuable industrial feedstocks. Compared to larger thermochemical systems now widely used by industry, the 3D-printed electrochemical reactors are much smaller and operate at ambient temperature and low pressure, making them more energy efficient and less expensive to produce and operate.

Guided by multiscale models that span atomic to continuum levels, Laboratory teams are also designing and 3D printing flow-through electrodes (FTEs) from graphene aerogels. The researchers can precisely tailor the flow in FTEs and the 3D microstructure (e.g., individual grains and crystal facets) of the metal catalysts to optimize performance.

A 3D-printed modular electrochemical reactor was tailor-designed for enhanced performance.

STORING RENEWABLE ELECTRICITY

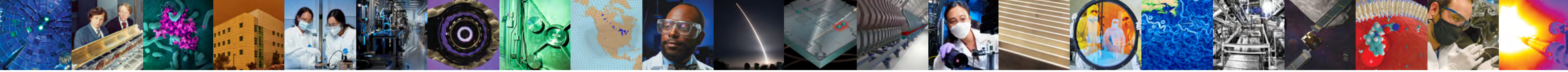
With support from DOE's Technology Commercialization Fund, LLNL researchers and industrial partners are developing an electrobioreactor. When electrical supply exceeds demand, the device can store excess renewable electricity in chemical bonds as renewable natural gas. The team's electrobioreactor uses the renewable electricity to convert water into hydrogen and oxygen. Microbes then use the hydrogen to convert CO_2 into storable methane, which is a major component of natural gas.

A SWITCH TO REDUCE GLOBAL CO_2 EMISSIONS

Laboratory engineers and collaborators developed a light-activated switch that, if fully deployed, could reduce carbon emissions by more than 10 percent. The device, called the Optical Transconductance Varistor (OTV), is especially well suited for energy grid applications. It is capable of sending high-voltage, direct-current power along grid lines and switching high voltages up to 10 times faster than today's solid-state devices, a feature that could cut energy losses in half to save 1 billion kilowatt-hours of electricity per year. If widely adopted for the grid, the OTV device could eliminate 750 million tons of greenhouse gases annually by 2050. The LLNL-patented technology is being commercialized by Opcondys Inc., based in Manteca, California. The OTV team won an R&D 100 Award in 2021.

CARBON NEUTRALITY IN CALIFORNIA

In March 2021, Laboratory researchers released *Permitting Carbon Capture & Storage Projects in California*—after the 2020 groundbreaking study *Getting to Neutral: Options for Negative Carbon Emissions in California*, in which LLNL scientists identified a robust suite of technologies to help California become carbon neutral by 2045. The report issued in 2020 assesses the advanced carbon reduction technologies now available as well as the tradeoffs necessary to reach the state's decarbonization goal. Concerted efforts in carbon capture and storage (CCS) are needed to achieve this objective. The follow-on study focuses on CCS projects in the context of California's rigorous and robust regulatory framework, which aims to protect the environment, public health, and safety. However, this framework may not be agile enough to handle timely permitting and deployment of enough CCS projects to reach the state's climate goals. Both studies serve as valuable resources for policymakers, government entities, interest groups, academia, and industry as California starts to address the carbon-neutrality challenge.



SCIENCE AND TECHNOLOGY

Expanding the boundaries of scientific knowledge and advancing the technological state of the art to solve problems of national and global importance

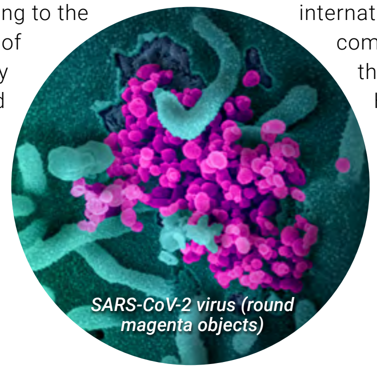
In addition to LLNL's extensive use of high-performance computing to support response to the COVID-19 pandemic, experiments at the Laboratory showed that thermal inactivation is a potential widely deployable method for reuse of N95 respirators.

THROUGH ITS SCIENCE AND technology capabilities, Livermore makes fundamental discoveries about nature, develops innovative technologies that improve life and drive the economy, and carries out its mission to improve national security.

ADVANCES IN MACHINE LEARNING

Machine learning (ML) is finding wide-ranging applications at LLNL, with many focused on accelerating scientific discovery. For example, Laboratory materials and computer scientists developed an ML 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. Crystalline density is closely correlated with an energetic's potential performance. LLNL researchers are also pioneering the application of neural networks to study ion acceleration from targets impacted with a high-intensity short laser pulse. The space of experimental parameters of interest is extremely large. The neural network was trained by an ensemble of more than 1,000 simulations, which only sparsely filled the space. The network acted as a surrogate physics model to explore and discover intriguing features in regions of scientific interest. This approach is widely applicable. LLNL researchers co-authored a paper—in the May 21, 2021, issue of the journal *Nature*—that discusses future directions and challenges in similarly applying ML to accelerate nuclear fusion research.

In December 2020, two LLNL scientists presented papers at the 34th Conference on Neural Information Processing Systems, the world's most prestigious ML conference. They addressed issues pertaining to the reliability and robustness of ML algorithms. Laboratory researchers also presented a paper in May 2021 at the International Conference on Learning Representations. They developed a novel framework for a type of discrete optimization called symbolic regression. It outperforms several common benchmarks, including commercial software gold standards. At LLNL, the framework is being used to find short mathematical expressions that fit large data sets gathered from experiments.



SARS-CoV-2 virus (round magenta objects)

RESPONDING TO COVID-19

LLNL provided high-performance computing (HPC) resources to the international research community in FY 2021 through the COVID-19 HPC Consortium and the National Virtual Biotechnology Laboratory formed by DOE. Among the Laboratory's many contributions to the overall HPC effort, a team of biologists and computer scientists developed an ML-training capability that greatly assists the search for therapeutics (e.g., small molecule antivirals). They trained a novel, high-quality molecular design model on 1.6 billion compounds in 23 minutes. The previous state-of-the-art solution required a day for only 1 million compounds. A complementary computational pipeline focused on developing therapeutic antibodies. Promising candidates from both efforts were screened for antiviral properties using a suite of in-vitro and in-vivo assays.

Experimental activities also supported our nation's COVID-19 response. LLNL scientists determined that heating N95 respirators up to 75°C for 30 minutes deactivates a surrogate coronavirus without compromising the device's fit and its ability to filter airborne particles. This type of thermal inactivation offers a widely deployable method for reuse of N95 respirators in emergency situations. Other LLNL research teams leveraged their extensive experience studying the dispersion of airborne hazards to better understand the movement of virus-like particles, supporting efforts to identify countermeasures. A Laboratory-developed tool, DNATrax, allows scientists to study the movement of low concentrations of airborne particles.

MOVING TO EXASCALE COMPUTING

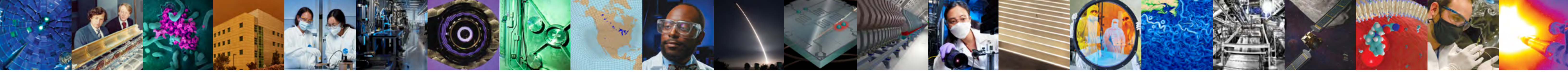
With the future delivery of El Capitan (see p. 7), LLNL is fully engaged in the next phase of supercomputing. Exascale machines will be able to process an exaflop—a quintillion (10^{18}) calculations per second. This technological leap offers DOE exciting opportunities to advance its national security, science, and technology-transfer missions; but it also presents enormous challenges. Funded by NNSA and DOE's Office of Science, DOE's Exascale Computing Project (ECP) is focused on application development, software technologies, and hardware and integration, with the goal of providing a comprehensive and reliable exascale computing ecosystem. Livermore staff hold key leadership positions in ECP and participate in many projects. ECP coordinates development activities through six co-design centers that draw on multidisplinary expertise from across the DOE laboratories. An LLNL computer scientist leads the co-design Center for Efficient Exascale Discretizations, and LLNL researchers are engaged in two other centers.

An important focus within the Laboratory is the development and usage of sustainable software—ensuring that it is interoperable across computer architectures, maintainable, and dependable. LLNL's RADIUSS project is deploying and encouraging use across the institution of a common base of foundational scientific software consisting largely of open-source products, many of which have been developed at the Laboratory. This strategy will reduce long-term software costs and increase Livermore's ability to respond rapidly to emerging programmatic needs. LLNL is a global leader in the development of open-source scientific software solutions that attract collaborators and benefit from their contributions. RADIUSS parallels similar efforts within ECP, in which a Livermore computer scientist heads the project's Extreme-Scale Scientific Software Development Kit effort.

The exascale El Capitan supercomputer (depicted here) is scheduled to arrive at LLNL in 2023.

PLANETARY DEFENSE STUDIES

In April 2021, LLNL researchers took part in the seventh International Academy of Astronautics Planetary Defense Conference (PDC). The virtual conference brought together an international group of experts, with Laboratory participants giving presentations on a wide range of topics. The scenario featured at PDC was asteroid disintegration into well-dispersed fragments, which would be necessary if there is little warning and if deflection (the preferred method) is not feasible. Livermore scientists have performed detailed simulations of high-yield nuclear device detonations a few meters from a 100-meter-diameter asteroid two months before expected impact. The fraction of impacting mass would be reduced by a factor of 1,000. Livermore researchers are conducting modeling studies in support of the National Aeronautics and Space Administration's upcoming planetary defense test, which is targeted at an asteroid called Dimorphos.



SCIENCE AND TECHNOLOGY

A COSMIC CHALLENGE TO QUANTUM COMPUTING

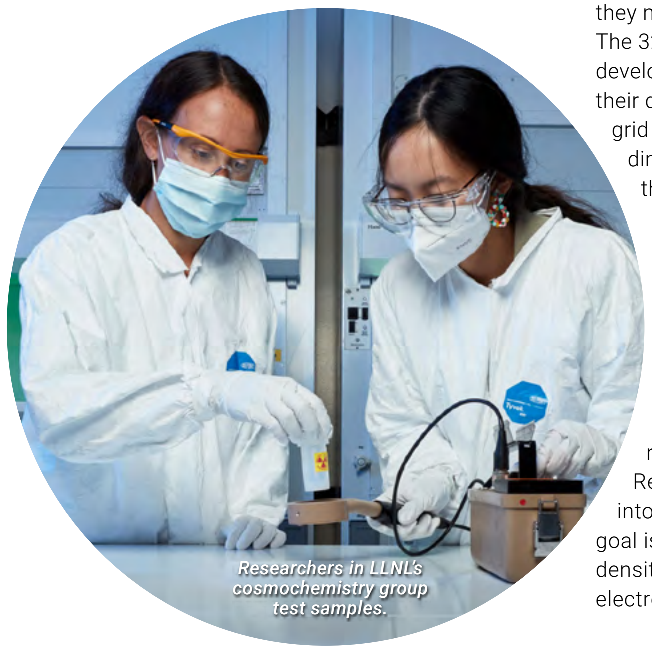
Research by an LLNL physicist and lead collaborators at the University of Wisconsin–Madison shed light on one of the major challenges to realizing the promise and potential of quantum computing—error correction. When errors are caused by an outside energy event, such as absorption of a cosmic ray, the fluctuations in electrical charge of multiple quantum bits ("qubits") can be highly correlated, as opposed to completely random and independent, and very difficult to correct. The team linked small error-causing perturbations in the qubits' charge state to the absorption of cosmic rays, a finding that is already impacting how quantum computers are designed.

UCSF neurologists placed thin-film multielectrode arrays developed at LLNL on the exposed hippocampus of patients undergoing surgery to detect traveling waves of neural activity.

NEW INSIGHTS INTO HUMAN BRAIN ACTIVITY

In FY 2021, surgeons at the University of California at San Francisco (UCSF) reported results from groundbreaking studies of human brain activity. LLNL-developed thin-film electrode arrays were used in human patients and generated never-before-seen recordings of brain activity in the hippocampus, a region responsible for memory and other cognitive functions. The arrays recorded electrical signals across the surface of the exposed hippocampus during surgery. While awake, patients were given visual cues and spoke words while their neural activity was recorded. The researchers detected traveling waves and identified new properties about them, including how they may contribute to human cognition. The 32-channel, multielectrode arrays, developed by the Laboratory, enabled their detection. The arrays' high-density grid layout, small size (smaller than a dime), and their ability to conform to the hippocampal surface provided researchers with a critical bird's-eye view of how the signals moved over the surface like waves in water.

Since the UCSF study concluded, LLNL engineers have doubled the number of electrodes on the flexible thin-film devices to 64 channels, enabling higher resolution sensing and stimulation. Researchers also formed the arrays into a penetrating (or depth) probe. The goal is to increase the channel count and density to hundreds, or even thousands, of electrodes per device. Combining hybrid polymer materials with microfabrication and 3D printing, engineers have also developed an ultracompact, lightweight and minimally invasive optoelectronic neural implant. Capable of delivering light for neural activation, the devices could be used for high-resolution diagnoses of brain disorders.



Researchers in LLNL's cosmochemistry group test samples.

EXPLORING OUR SOLAR SYSTEM

A team of Livermore scientists and collaborators concluded that our Sun and the solar system formed very quickly—over a time span of less than 200,000 years. The evidence was found in trace quantities of molybdenum (Mo) from calcium-aluminum-rich inclusions (CAIs) that were later incorporated into meteorites. The oldest dated solids in the solar system, CAIs formed near a young Sun over the above-mentioned time span. The team found that distinct isotopic compositions of Mo in CAIs cover the entire range of material formed in the proplanetary disk, indicating the material must have accreted quickly.

In other studies, Laboratory researchers deduced that the current locations of many planetary bodies in our solar system are not where they were formed. The giant planets formed early and as they grew they migrated to gravitationally stable orbits, which reshuffled other planetary bodies that were forming at the time. In addition, high-energy-density science experiments validated the possibity of helium rain inside Jupiter and Saturn. Furthermore, quantum simulations coupled with ML are being used to study the behavior of superionic water expected to be found in ice giants Uranus and Neptune.

PRINTED "CELLULAR FLUIDICS"

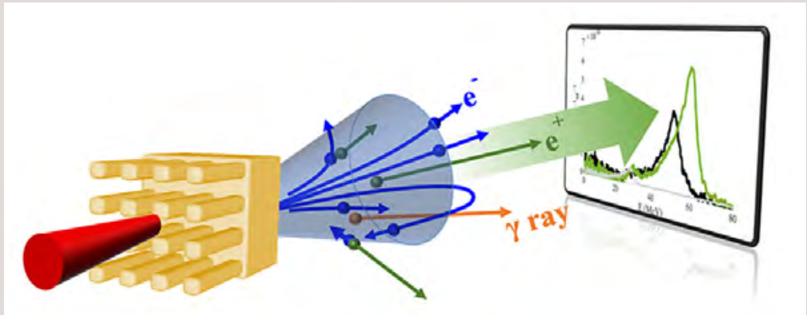
Inspired by the way plants absorb and distribute water and nutrients, Livermore researchers developed a groundbreaking method for transporting liquids and gases using a 3D-printed lattice design and capillary action phenomena. The 3D-printed microarchitected structures contain and promote fluid flow to create extensive and controlled contacts between liquids and gases. The ordered, porous, and open-cell structures facilitate surface tension–driven capillary action—akin to a tree pulling water from soil or a paper towel soaking up a spill—and enable liquid and gas transport throughout the structures. The researchers demonstrated absorption of gaseous carbon dioxide (CO_2) into a liquid; evaporation of a liquid into a gas phase; and transpiration, where they showed the structures were capable of cooling themselves by evaporating liquid into the atmosphere. The breakthrough technique could have transformative implications for many fields, including electrochemical or biological reactors used to convert CO_2 or methane to energy, advanced microfluidics, solar desalination, air filtration, heat transfer, transpiration cooling, and the delivery of fluids in zero-gravity environments.

Volumetric additive-manufacturing techniques produce 3D objects by using a laser to illuminate a rotating container of photosensitive syrup-like resin.

ADVANCES IN ADDITIVE MANUFACTURING

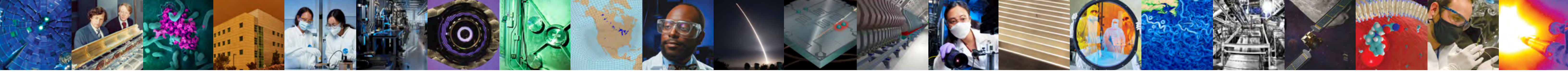
Researchers at LLNL adapted a new class of materials as resins for their groundbreaking volumetric additive-manufacturing (VAM) techniques that produce objects almost instantly. Photosensitive syrup-like resin rotates in a container as it is illuminated by projected laser light. After a few-minute exposure, the fluid is drained, leaving a cured, fully formed 3D object. The newly adapted materials for VAM are called thiol-ene resins. Previously, researchers worked with acrylate-based resins that produced brittle and easily breakable objects. The new resin chemistry, created by carefully balancing three different types of molecules, provides a wider range of mechanical performance. Researchers are able to build tough and strong, as well as stretchable and flexible, objects with VAM and thiol-ene resins. Using molecular dynamics simulations, LLNL scientists continue to push the boundaries of 3D printing to discover new custom photosensitive resins.

Exploratory research projects at the Laboratory supported innovative 3D-printing applications. Livermore researchers developed a technique to print transparent ceramics with extremely fine feature sizes (tens of micrometers) for use as laser-amplification media. They also used multimaterial 3D printing to create tailored gradient refractive index glass optics that could make better specialized military eyewear and virtual reality goggles. Other Livermore scientists developed a new method for 3D printing living microbes in controlled patterns, expanding the potential for using engineered bacteria to recover rare-earth metals, clean wastewater, and detect uranium. In addition, a Laboratory team 3D printed the first-ever living aneurysm, which can be used to improve surgical procedures and personalize treatments.



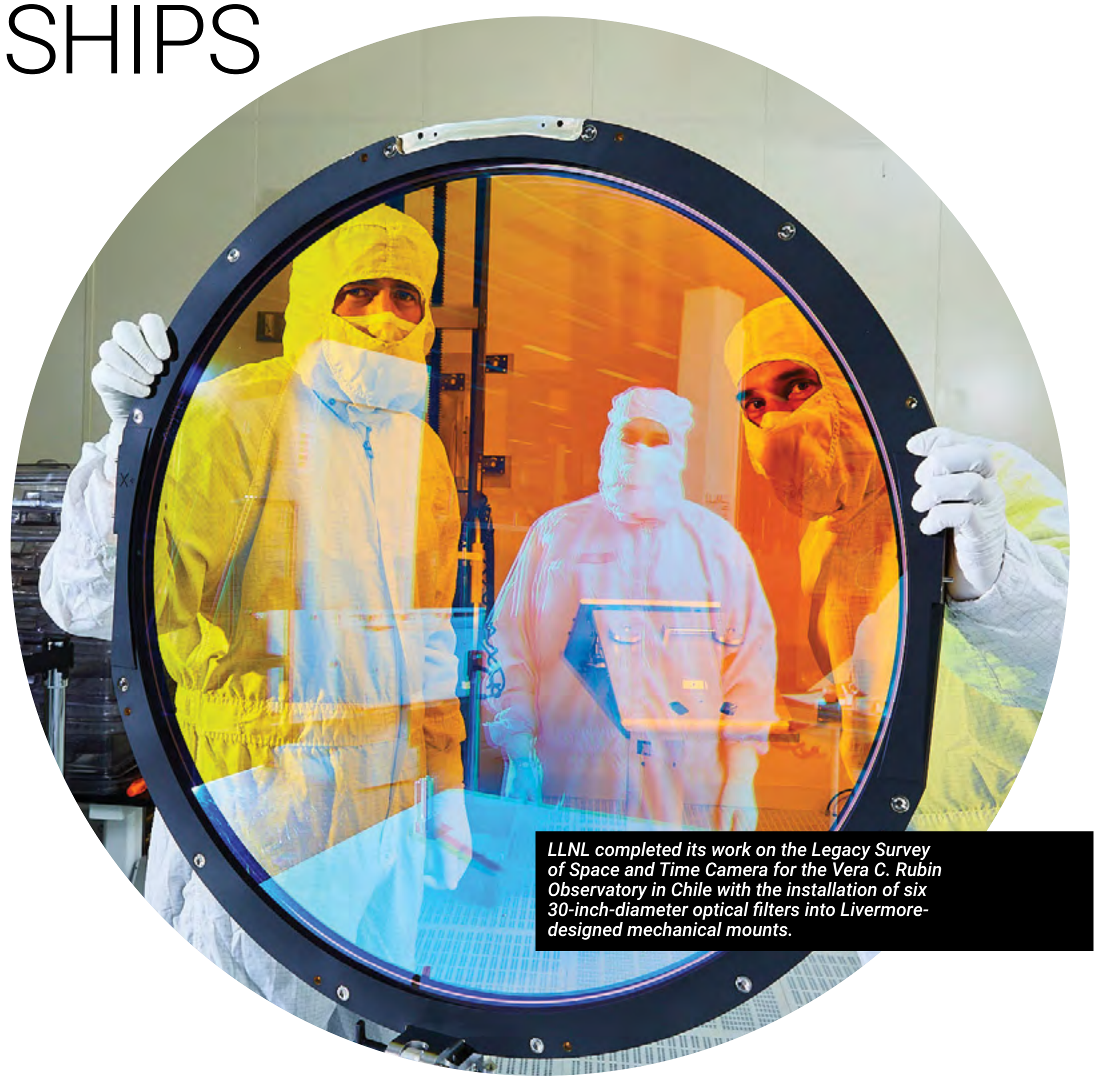
DOUBLING ANTIMATTER PRODUCTION

Laboratory scientists achieved a near 100 percent increase in the amount of antimatter created in an experiment using the same laser energy. The team shot a high-intensity laser through a gold target that included specially designed microstructures on the front surface, which increased antimatter production from about 100 billion particles of antimatter to twice that number. The advance, which has many applications, is a key step toward the goal of making enough electron–positron pairs to study the physics of gamma-ray bursts.



PARTNERSHIPS

Sharing science and technology (S&T) expertise and capabilities to meet our nation's most important needs



LLNL completed its work on the Legacy Survey of Space and Time Camera for the Vera C. Rubin Observatory in Chile with the installation of six 30-inch-diameter optical filters into Livermore-designed mechanical mounts.

LLNL ENGAGES IN WIDE-RANGING partnerships with sister laboratories and research institutions, academia, and industry. Many collaborations integrate disparate, special expertise and capabilities that combine to meet challenging mission objectives. Others serve to transition S&T breakthroughs into new applications and products.

THE POLYMER PRODUCTION ENCLAVE

In partnership with the Kansas City National Security Campus (KCNSC), LLNL established the Polymer Production Enclave—an innovative approach to accelerating the timeline from early technology development to first production units. Enclaves are vehicles for better integrating activities, modernizing, and increasing the agility and cost effectiveness of the NNSA enterprise. This first enclave is focusing on polymer parts for the W80-4 Life-Extension and the W87-1 Modification programs. LLNL brings to the collaboration more than a decade of experience in additive manufacturing applied to creating complex components and parts. KCNSC brings expertise needed to adapt the technologies to scale and meet demanding production schedules. An enclave with the Pantex Plant on high-explosives production is also being established to support modernization efforts.

At Livermore, the focal point of the Polymer Production Enclave's activities is the newly opened Applied Materials and Engineering campus, which collocated a synergistic set of capabilities into new and repurposed buildings to gain efficiencies. In May 2020, construction began on Building 225, home of the enclave, and building occupancy took place in April 2021. In summer, LLNL and KCNSC personnel began work in support of the stockpile modernization programs. All programmatic equipment has been installed and is now fully operational.

KCNSC and LLNL representatives pose in front of the new Polymer Production Enclave.

LARGE-SCALE OPTICS FOR THE RUBIN OBSERVATORY

In September 2021, Laboratory researchers completed their work on the Legacy Survey of Space and Time Camera (LSSTCam) for the Vera C. Rubin Observatory in Chile. LSSTCam will start surveying the southern sky in 2024, taking digital images using optical assemblies designed by Livermore researchers and built by the project's industrial partners. Its camera will photograph the entire visible southern sky frame-by-frame every few nights, creating a time-lapse "movie" of the sky. The collected data will help researchers better understand dark matter and dark energy, detect galaxies and study their formation, track potentially hazardous objects, and observe exploding stars.

Livermore's finishing task in the LSSTCam project, managed by SLAC National Accelerator Laboratory, was to place six 30-inch-diameter optical filters into LLNL-designed mechanical mounts. This delicate operation benefited from the National Ignition Facility's state-of-the-art assembly building and skilled technicians who are experienced in handling large optics. With its expertise in large-scale precision optics, the Laboratory has been a key partner in developing Rubin Observatory technology since the project's inception in the early 2000s. LLNL has made major contributions to the overall telescope design, the camera optics, and project management. A key feature of the telescope assembly is the largest of three Livermore-designed camera lenses, which, at 5.15 feet in diameter, is the is the world's largest high-performance optical lens.

UNIVERSAL VACCINE DEVELOPMENT

The Laboratory brings more than a decade of experience exploring the use of nanolipoprotein particles (NLPs) as versatile platforms that can connect to other molecules and deliver vaccines and drugs inside the human body. LLNL is engaged in collaborations utilizing NLP platforms to defend against biothreats, develop customized vaccines, and deliver cancer therapeutics. For example, LLNL scientists and research partners have developed a candidate vaccine for tularemia, a pathogen considered to be a biosecurity threat.

In October 2021, LLNL joined the international Human Vaccines Project. The Laboratory will contribute its expertise and supercomputing resources to aid in developing a universal coronavirus vaccine and improve understanding of immune response. LLNL's prowess continues to grow from research performed as part of DOE's National Virtual Biotechnology Laboratory, which is helping to fight COVID-19, and as a founding member of the Accelerating Therapeutics for Opportunities in Medicine (ATOM) consortium to speed up drug development.

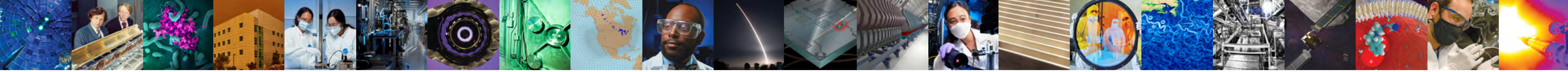
SuppleVent™ mechanical ventilator team

SUCCESSFUL INDUSTRIAL PARTNERSHIPS

LLNL is benefiting the U.S. economy with innovative technology and methodologies. In FY 2021, Livermore obtained 95 new patents, asserted 126 new copyrights, and executed 89 new licenses. Licensing income for the year totaled approximately $5.9 million. Among many honors, Livermore earned three R&D 100 awards from *R&D World* magazine (see the box). LLNL also won three national Federal Laboratory Consortium awards for Excellence in Technology Transfer for the following technologies: Droplet™ Digital Polymerase Chain Reaction to diagnose the SARS-CoV-2 virus, the SuppleVent™ mechanical ventilator to assist those suffering from Acute Respiratory Distress Syndrome, and the Radiation Field Training Simulator for realistic first-responder training. In addition, the Laboratory secured five major grants through the DOE's Technology Commercialization Fund and three projects with industry through the LLNL-managed DOE High Performance for Energy Innovation Program.

THREE TOP-100 INDUSTRIAL INVENTIONS

In FY 2021, the Laboratory and partners earned three R&D 100 awards from *R&D World* magazine. An LLNL-patented, light-activated switch is being commercialized that could significantly reduce carbon emissions from the electrical grid (see p. 13). LLNL and collaborators developed Flux, a next-generation toolset to efficiently schedule workloads and reduce bottlenecks at data centers. The third winner is an instrument to help emergency responders quickly identify and assess nuclear threats.



SAFE, SECURE, AND SUSTAINABLE OPERATIONS

Conducting safe, secure, and environmentally sound operations and modernizing the Laboratory's infrastructure to meet evolving mission needs

LLNL Director Kimberly Budil kept Livermore employees well informed about plans and progress toward a Return to New Normal (and COVID-19 related issues) through a series of Laboratory-wide virtual meetings.

COMMITTED TO THE HIGHEST level of operational performance, LLNL implements best practices in environment, safety, and health (ES&H) and security. Management systems support continuous improvement in work practices. Prudent risk management coupled with active measures to prevent accidents ensures the safety of employees and the public. Investments are targeted to modernize the Laboratory's infrastructure.

RETURN TO NEW NORMAL

In June 2021, LLNL Director Kimberly Budil announced the start of a deliberate process to "Return to New Normal" (RTNN) at the beginning of FY 2022.

Planning for RTNN had begun months earlier with a focus on designing a hybrid work environment with a flexible policy that would accommodate telecommuting—consistent with employee's work responsibilities—as part of the future work environment. Since July 2020, LLNL had been operating effectively under *Normal Operations with Maximum Telework* status. Most of the staff teleworked full- or nearly full-time. In this hybrid environment, LLNL delivered on its national security mission. Success depended on people—what they did, not where they worked. This positive result guided the crafting of the new policy. RTNN transforms LLNL into a hybrid workplace as the new normal for the future. The policy acknowledges the many possible ways employees and their work groups might operate most effectively. Employees partnered with their supervisors, project leaders, and group leaders to develop a telework agreement for approval.

RTNN represents a new and exciting way for LLNL to deliver on its national security mission, with an increased level of flexibility to meet the work–life balance needs of an exceptional workforce. The transition to RTNN is being conducted in partnership with NNSA and the Livermore Field Office through a deliberate process. The policy will be improved through adjustments as lessons are learned from experience.

ONSITE COVID TESTING AND VACCINATION

In early December 2020, LLNL officially launched onsite COVID-19 testing operations to enhance health and safety measures for the workforce. This capability has provided timely test results for workers that have been symptomatic and/or may have been exposed to the SARS-CoV-2 virus and has enabled random screening to reduce the potential of asymptomatic transmissions. LLNL's Health Services Department (HSD) worked diligently to field, staff, and coordinate a process for workers to order a test that is scheduled and conducted on premise. The team built and optimized the end-to-end testing process essentially from scratch. In addition, a new clinical testing laboratory was established and accredited. This process involved recruiting and hiring staff with extensive clinical testing experience, receiving certification for clinical testing in the State of California, and implementing steps to meet strict requirements. Called the Capability for Return of the Offsite Workforce Now (CROWN) Laboratory, this lab completed a rigorous verification test to demonstrate its proficiency with the chosen SARS-CoV-2 diagnostic test.

HSD also took on the challenging task of establishing LLNL as a Point of Dispensing (POD) for COVID-19 vaccines. The COVID Vaccination Clinic required staffing as well as development of processes and procedures for vaccination work flow, vaccine management and storage, and data management and reporting to meet POD requirements. More than 4,500 vaccine doses were successfully administered to LLNL, Sandia, and federal employees during a roughly 3-week period. Onsite COVID vaccination, which continues to be offered, is aiding in the RTNN process and supporting federal vaccine mandates.

ENSURING SAFETY IN THE WORKPLACE

In March 2021, prompted by the increasing number of employees returning to work onsite, the Laboratory established a task force to evaluate the safety, reliability, and effectiveness of LLNL's 3,200 heating, ventilation, and air conditioning (HVAC) systems in preventing the spread of SARS-CoV-2. Initial assessments led to hundreds of HVAC filtration upgrades. The task force also developed guidance on the use of high-efficiency particulate absorbing (HEPA) filters in offices as well as means and methods to improve ventilation where HVAC filtration could not be increased due to mechanical limitations. These engineered controls served to complement LLNL's safety guidance on occupancy limits and use of face masks.

INVESTING IN INFRASTRUCTURE

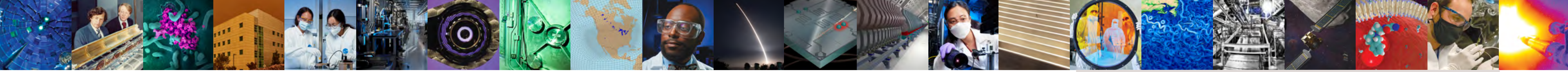
In FY 2021, LLNL's Institutional Project Management Office oversaw more than 300 projects amounting to approximately $1.2 billion in total project costs. More than one-third of these projects were completed—overall at $14 million under budget. Another third are actively being designed or constructed. The rest are in the pipeline or being planned. Completed projects include a new office building and a conference annex in the Livermore Valley Open Campus (see p. 23) and buildings in the 2200 block, which are part of the Applied Materials and Engineering Complex and the focal point for the Polymer Production Enclave (see p. 18).

In FY 2021, the ECFM project neared completion. Work in progress is shown near the new cooling towers.

Two major construction projects are nearing completion, and both are running under budget. More than 92 percent complete, the $100 million Exascale Computing Facility Modernization (ECFM) project provides the infrastructure needed to support El Capitan (see p. 7) and its successor later in the decade. The industrial-scale project required seven years of planning and multiple reviews, approval from the California Public Utilities Commission, and close collaboration with utility providers. ECFM will nearly double the energy capacity of the LLNL Computing Complex, while energy-efficient El Capitan will provide a factor of ten more computing capability. The upgrade will supply up to 85 megawatts—enough for about 75,000 modest-sized houses—to power the Laboratory's computers and triple the amount of cooling. Work crews also added six 3,000-ton cooling towers and requisite piping, pumps, and heat exchangers. Another project, construction of the new 20,550-square-foot Emergency Operations Center (EOC), is more than 70 percent complete and ahead of schedule. It will consolidate the Laboratory's emergency response functions and provide 24/7 operations. The EOC is an NNSA NA-50 Pilot Project that is successfully demonstrating the streamlining of commercial-like Line Item projects in the $20–$50 million cost range.

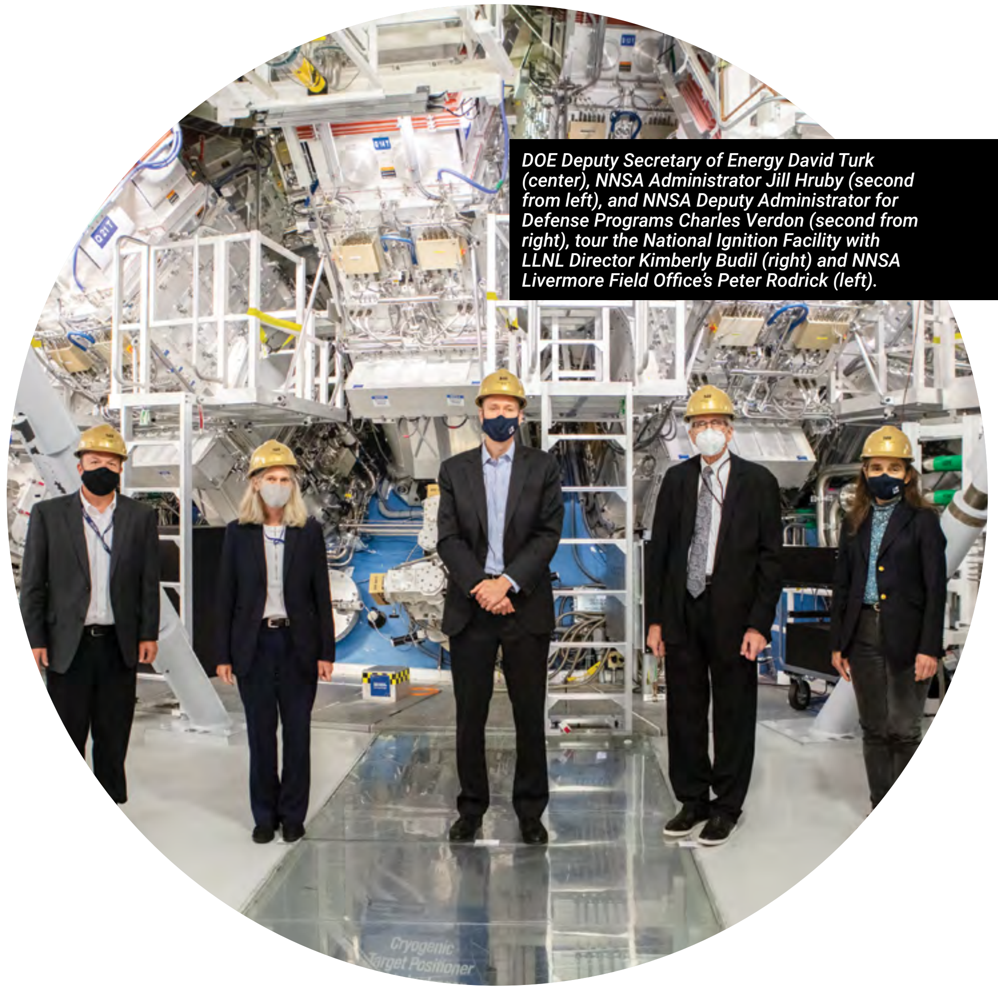
MONITORING AIR QUALITY DURING WILDFIRES

Following the major wildfires in California in 2020, LLNL recognized the need for better data to make critical ES&H decisions regarding personnel working outdoors. A multiorganizational team worked quickly to establish a real-time, site-specific air particulate monitoring network. The network, which includes one unit at the main Livermore site and two at remote Site 300, provides LLNL management high-quality data for taking proper protective actions to ensure worker safety.



MANAGING FOR THE FUTURE

Positioning the Laboratory for continuing science and technology excellence directed at important national missions



DOE Deputy Secretary of Energy David Turk (center), NNSA Administrator Jill Hruby (second from left), and NNSA Deputy Administrator for Defense Programs Charles Verdon (second from right), tour the National Ignition Facility with LLNL Director Kimberly Budil (right) and NNSA Livermore Field Office's Peter Rodrick (left).

FY 2021 WAS A YEAR OF BUILDING FOR future mission successes through new initiatives, attention to workforce needs, and expanding partnerships.

STRATEGIC LEADERSHIP

On March 2, 2021, Kimberly Budil became the 13th director of Lawrence Livermore National Laboratory and president of Lawrence Livermore National Security, LLC (LLNS). She brought to her new role proven scientific leadership and senior management experience across a broad range of Laboratory programs. During her career, Budil also undertook detailee assignments at NNSA and the DOE Office of Science and served as vice president for national laboratories in the University of California Office of the President. As LLNL Principal Associate Director for Weapons and Complex Integration, Budil recently led the development of a strategic framework for the weapons program that emphasizes attracting the best scientists and engineers and driving the creation of a more responsive and cost-effective nuclear weapons enterprise. Director Budil has launched transformative new initiatives, including actions to articulate a set of future mission focus areas; improve communications; implement a culture framework with attention to diversity, equity, and inclusion; and create a hybrid workplace as the new normal for LLNL operations (see p. 20).

LLNL Director Kimberly Budil (right) and former LLNL Director William Goldstein

Director Budil was selected after a rigorous national search that began in July 2020, when William Goldstein announced that he would step down as director upon selection of a successor. Goldstein had led the Laboratory for seven years—a period of myriad challenges, many science and technology innovations, and strong program growth. His exceptional leadership of the Laboratory and service to the nation were recognized with distinguished honors from NNSA and DOE (see p. 26).

A CHANGING WORKFORCE

An outstanding workforce is Livermore's principal strength. Recruiting, training, and retaining exceptional talent is a top priority at LLNL to sustain excellence at a time of rapid change in our workforce. Despite the ongoing pandemic, FY 2021 marked another year of successful hiring across the Laboratory. After COVID-19 struck, LLNL quickly developed the new virtual Onboarding Portal to expedite hiring. The portal significantly streamlines administrative steps and provides an interactive and engaging interface for incoming employees. New hires have a convenient resource to answer their questions, furnish important information about starting work, and participate in new employee orientation sessions that help launch their careers at LLNL.

LLNL's senior management team is using virtual townhall meetings and workshops to enhance communication within the Laboratory. For example, the "Our Culture" framework adopted by the team was featured in workshops that engaged more than 3,000 employees and served to emphasize the importance of promoting a more respectful work environment with attention to diversity, equity, and inclusion. Management attention to engaging all employees—and emphasizing shared success—contributed to LLNL ranking on Glassdoor's 2021 list of the top 25 "Best Places to Work" in the U.S. large company category.

NEW FACILITIES AT THE OPEN CAMPUS

DOE Under Secretary for Nuclear Security and NNSA Administrator Jill Hruby, Congressional representatives, and local elected officials gathered at the Livermore Valley Open Campus (LVOC) in August 2021 for a ribbon-cutting ceremony. The new office building and conference annex (Buildings 642 and 643) are providing modern office and meeting space for LLNL researchers and external collaborators. Residents include the Laboratory's Innovation and Partnerships Office and the High Performance Computing Innovation Center as well as researchers in predictive biology and materials and manufacturing. The interconnected buildings are the latest additions to the 110-acre LVOC, a joint initiative of the NNSA, LLNL, and Sandia National Laboratories.

Leaders from NNSA, Congressional representatives, and local elected officials gathered to celebrate the opening of new facilities at the Livermore Valley Open Campus.

LVOC was developed as an open and unclassified innovation hub for stimulating collaborative projects with external partners in government, industry, and academia. LVOC provides a unique opportunity for innovators and U.S. companies to leverage the talent and resources within the two laboratories.

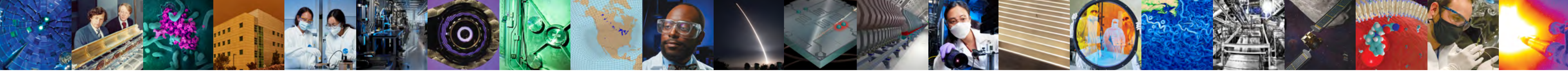
At nearly 25,000 square feet, Building 642 contains 105 offices, two double-size "hotel" offices, two conference rooms, and collaboration spaces. The adjacent 2,975-square-foot conference annex can accommodate about 90 people. The facilities, both LEED Gold certified for energy and resource efficiency, are connected by an open, outdoor collaborative environment for meetings and group gatherings.

LLNS BOARD OF GOVERNORS ACTIVITIES

The LLNS Board of Governors and its committees provide oversight to the Laboratory and delve into issues crucial to mission and mission-support activities. External review committees (ERCs), panels of independent experts including Board members, periodically met in FY 2021 to critically assess the quality of the Laboratory's technical workforce and the effectiveness of research efforts in meeting mission goals and future national needs. Their reports, which provided DOE/NNSA with an independent validation of work quality, consistently affirmed the mission relevance and high impact of LLNL research. The Board chartered functional management reviews (FMRs) on an as-needed basis. Five virtual FMRs, were completed in FY 2021 in topical areas including the Disposition Program and Endpoint Management, the Virtual Desktop Infrastructure, and the Transition to Digital Infrastructure Capability Expansion Project. Recommendations provided by Board committees, ERCs, and FMRs have led to substantive responsive actions.

THE DOE SECRETARY'S VIRTUAL VISIT

U.S. Secretary of Energy Jennifer M. Granholm virtually visited the Laboratory on June 25, 2021, where she met with leading scientists and engineers. After an all-hands meeting with LLNL employees, she toured the Advanced Manufacturing Laboratory (with the discussion of metal printing shown above), the Livermore Computing Complex, and the National Ignition Facility. Secretary Granholm also heard presentations about climate change, carbon neutrality, and electric grid security.



COMMUNITY CONNECTIONS

Partnering with our neighbors through science education and charitable giving

LLNL debuted a new virtual Discovery Center. Online visitors can click on an item in the visual display to learn more about a topic.

THE LABORATORY IS AN ACTIVE member of local communities, offering a wide variety of programs to enhance science, technology, engineering, and mathematics (STEM) education. Outreach extends beyond the classroom—each year LLNL staff and LLNS donate more than $3 million to local nonprofits, while hundreds of employees donate their time to local service agencies. During the pandemic, LLNL's vital community connections have been kept firmly in place largely through virtual interactions.

REACHING TEACHERS AND STUDENTS

The Laboratory debuted an all-new virtual Discovery Center, providing an interactive experience for visitors to learn about LLNL and its missions. In addition, nearly 500 high school students attended virtual National Ignition Facility (NIF) tours and the Laboratory's Scientist in the Classroom program. LLNL also conducted other virtual programs to help local teachers improve and broaden their STEM education offerings. For example, a Livermore computer scientist staged for 1,200 students two virtual Magic of STEM performances. Modesto teachers arranged these science-based magic shows in partnership with the city's State Theater and the local school district.

Magic of STEM

DATA SCIENCE EVENTS AND CHALLENGES

Coinciding with International Women's Day on March 8, LLNL's fourth Women in Data Science (WiDS) regional event attracted dozens of Livermore and regional data scientists to engage with speakers and panelists. They joined breakout sessions for networking, mentoring, and discussion of opportunities and challenges unique to women in the field. LLNL's event was one of more than 200 WiDS events organized in 60-plus countries. They were held in conjunction with a Stanford University conference featuring prominent women data scientists from around the world.

The Laboratory's third annual Data Science Challenge brought together students from the University of California at Merced with LLNL mentors in a virtual setting to discuss how machine learning can be used to tackle real-world scientific problems. Three times a week for three weeks, participants completed exercises and assignments, attended seminars, took virtual tours of the Laboratory, and worked on deep-learning models with their peers. This year's theme was "Astronomy for Planetary Defense" and focused on how machine learning could improve the identification of near-Earth objects such as asteroids, before they become threats to the planet.

THE LABORATORY GOES TO SCHOOL

Throughout FY 2021, LLNL worked directly with Livermore area schools to continue promoting science education and technical skills for students. In a collaboration between the Laboratory, the Livermore Lab Foundation, and the Livermore Valley Joint Unified School District, 25 high school girls met with former and current LLNL women scientists in the first-ever Girls Who Code–"Big" program. Over four days, students met for two hours after school with panelists to learn about high-performance computing through presentations, live demonstrations, exercises, and other group activities. Another program, MathCounts, drew 100 Livermore middle school students to help improve their math and problem-solving skills. In April, machinists at the Laboratory hosted a virtual Manufacturing Workshop for a group of 15 high school students. This after-school program helped participants learn about career paths in NIF target fabrication, additive manufacturing, optics, and many other fields. From December 2020 through March 2021, a total of 100 students from seven local high schools attended virtual meetings to shadow various LLNL experts in their jobs and learn more about high-performance computing, data science, web development, additive manufacturing, micro and nanotechnology, and bioengineering.

In April, machinists at the Laboratory hosted a virtual Manufacturing Workshop for a group of high school students.

A SUMMER OF SCIENCE

While schools were out of session, the Laboratory provided exciting opportunities for budding scientists to learn more about STEM fields and contribute to ongoing research projects. More than 600 college undergraduate and graduate students completed LLNL summer internships in FY 2021 through virtual interactions with mentors and various web-based learning activities. In June, 19 middle school students were introduced to robotics during the 8th Grade Tech Workshop and given programming instruction in Python and Blockly. After a year's hiatus, the Biotech Summer Experience returned in July 2021 to bring 29 local high school students together virtually for two weeks of immersion in biotechnology and bioinformatics. Students took a deep dive into the DNA of duckweed, a promising new source of biofuel.

LIVERMORIUM PARK

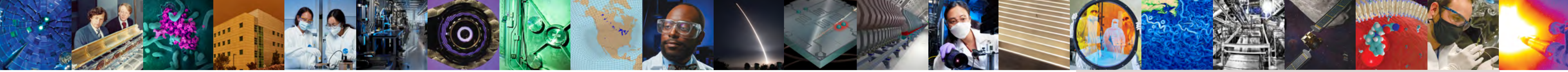
In December 2020, then Director William Goldstein broke ground on Livermorium Park alongside Livermore Mayor John Marchand and NNSA Livermore Field Office Deputy Manager Peter Rodrick. Located in downtown Livermore, the park is named in honor of element 116, Livermorium, which was discovered by Laboratory scientists and collaborators. The park will feature a five-foot-diameter floating granite sphere, representing the nucleus of a Livermorium atom. Seven orbitals will be populated with 116 electrons—20 of which will be illuminated to represent the element calcium. To create Livermorium, which only exists for 61 milliseconds before decaying, calcium atoms are accelerated to one-tenth the speed of light and collide with a cesium target.

HOME CAMPAIGN AND COMMUNITY GIFTS

Laboratory employees and LLNS raised more than $3.6 million in the 2021 HOME (Helping Others More Effectively) campaign. The charitable drive benefits community and nonprofit agencies in the Tri-Valley, San Joaquin Valley, and greater San Francisco Bay Area. Employees pledged more than $2.6 million, while LLNS contributed $1 million in matching funds. In December, LLNS announced the recipients of the 2021 Community Gift Program, with funds totaling $200,000. Many of the awards serve children in the Tri-Valley area as well as Contra Costa, San Francisco, and San Joaquin counties, with a focus on literacy, STEM education, and cultural arts. Other recipients target their charitable efforts toward children, families, senior citizens, and individuals in need of assistance.

SCIENCE ON SATURDAY

One of the Laboratory's longest-standing public programs continued in 2021 in a virtual format. A series of Science on Saturday virtual events took place in February 2021 under the theme "Combating COVID-19." Accomplished Laboratory researchers spoke to more than 600 middle and high school students about molecular diagnostics, swabs, ventilators, antibodies, and technological countermeasures to the virus.



WORKFORCE RECOGNITION

Acknowledging exceptional performance and expertise

SC21 General Chair Bronis R. de Supinski opens the conference's keynote session by welcoming remote and in-person attendees to St. Louis, noting the unique challenges of preparing a large international conference during the COVID-19 pandemic and presenting the theme for SC21—"Science and Beyond." Photo courtesy of SC Photography.

RECOGNITION BY THE SCIENTIFIC community and other stakeholders affirms the high quality of Livermore's work and innovative spirit. The awards on these pages showcase the efforts of the Laboratory's talented staff.

William Goldstein

DOE AND NNSA AWARDS

Early in 2021, retiring LLNL Director **William Goldstein** received honors in recognition of his dedication and service to DOE, NNSA, and the nation. Acting Secretary of Energy David Huizenga conferred the Secretary's Exceptional Service Award to Goldstein, and Acting NNSA Administrator Charles Verdon presented him with the Administrator's Distinguished Service Gold Award.

Former deputy director of the Laboratory's Center for Global Security Research **Mona Dreicer** received the NNSA Administrator's Distinguished Service Gold Award for her many accomplishments during a long, distinguished career in arms control and nuclear nonproliferation.

Mona Dreicer

LLNL staff were presented with 10 DOE Secretary's Achievement awards, which are given to teams that have made outstanding accomplishments. The honored teams (some multilaboratory) engaged in COVID-19 response, high-performance computing, nuclear nonproliferation and emergency response, workforce recruiting and security, and carbon neutrality projects.

Physicist **Andrea Schmidt** and research scientist **Xue Zheng** are among 83 scientists nationwide who were recipients of the DOE Office of Science Early Career Research Program award. Under the program, Laboratory scientists typically receive $500,000 in research funding per year for five years.

LLNL engineer **Bill Pitz** earned a Lifetime Distinguished Achievement Award from DOE's Vehicle Technologies Office for his significant contributions to the field of chemical kinetics applied to fuel combustion in engines. Pitz was also selected as a Society of Automotive Engineers fellow in 2021.

FEDERAL SERVICE AWARDS

LLNL's **Nils Carlson** received an exceptional service award from the Office of the Director of National Intelligence (ODNI). He was recognized for his work as the National Intelligence Manager for Space and Technical Intelligence while on assignment with ODNI. Carlson's advice and fostering of collaborative efforts were instrumental in achieving breakthrough intelligence insights.

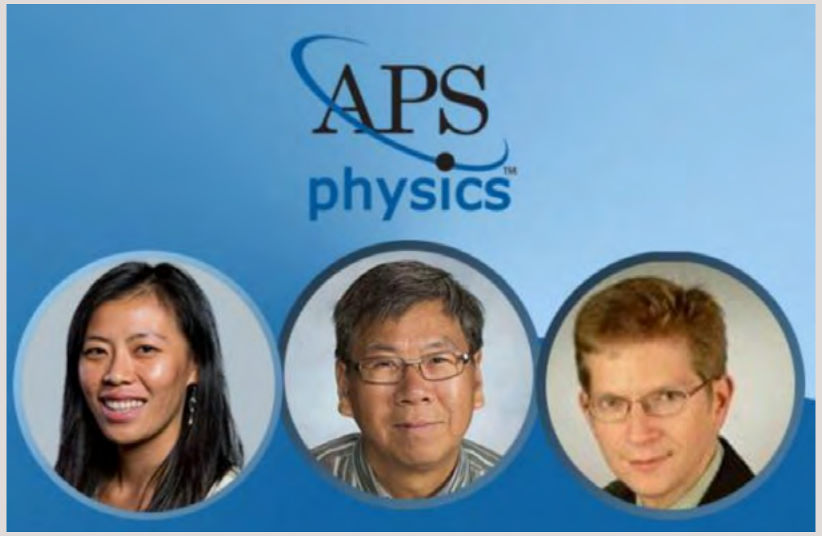
Nils Carlson

LLNL's **Charles Ball** and **Debbie Ball** each received the Office of the Secretary of Defense (OSD) Medal for Exceptional Public Service. While on assignment with OSD, Charles Ball served as the deputy assistant secretary of defense for Threat Reduction and Arms Control; Debbie Ball was a senior policy advisor in the Office of the Deputy Assistant Secretary of Defense for Nuclear and Missile and Defense Policy.

Physicist **Christopher Cross** received the Meritorious Civilian Service Award from the Department of the Army for his service as a member of the Army Science Board. The honor is the second highest award granted by the Secretary of the Army or a major Army commander to civilian personnel.

PROFESSIONAL SOCIETY FELLOWS

Three scientists have been selected as 2021 fellows of the American Physical Society (see the box).



Three LLNL scientists have been selected as 2021 fellows of the American Physical Society: **Tammy Ma**, **Xueqiao Xu**, and **Tilo Doeppner**. The new fellows have physics expertise in areas ranging from intense laser–matter interactions and inertial fusion energy science to leading the development of edge simulation models and codes to pioneering new regimes of warm dense matter experimental science.

The Institute of Electrical and Electronics Engineers (IEEE) elevated Livermore Computing's chief technology officer **Bronis R. de Supinski** to the rank of fellow, recognizing his leadership in the design and use of large-scale computing systems. *HPCwire* also chose de Supinski as one of its "People to Watch" in 2021.

Computational mathematician **Robert Falgout** was selected as a fellow of the Society for Industrial and Applied Mathematics (SIAM) for his work on multilevel solvers and his service to the community.

The Association for Women in Mathematics (AWM) named LLNL computational scientist **Carol Woodward** as a fellow. The award highlights her efforts to encourage more women to pursue careers in mathematics and her leadership in AWM and SIAM activities.

SCIENCE AND TECHNOLOGY AWARDS

The American Meteorological Society selected atmospheric scientist **Mark Zelinka** to receive the Henry G. Houghton Award for early-career achievements, including "innovative advances in understanding the critical involvement of clouds" in climate interactions.

Physicist **Tammy Ma** received the 2021 Excellence in Fusion Engineering Award from Fusion Power Associates for "the impressive and influential body of scientific work she has completed during her relatively short career to date."

Experimentalist **Peter Celliers** was recently elected vice-chair of the American Physical Society Topical Group on Shock Compression of Condensed Matter. This one-year responsibility is the first of a four-year executive committee assignment.

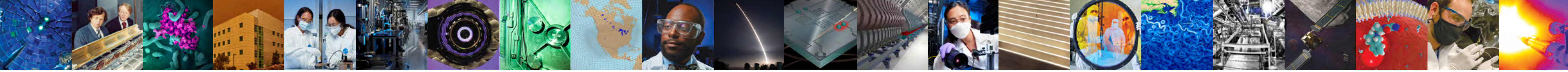
LLNL computational engineering postdoctoral researchers **Felipe Leno da Silva** and **Ruben Glatt** were invited to virtually attend the international Heidelberg Laureate Forum to meet and interact with laureates of the major prizes in mathematics and computer science.

The Krell Institute, a nonprofit organization serving the scientific and educational communities, awarded computational scientist **Jeff Hittinger** with its 2021 James Corones Award in Leadership, Community Building and Communication, which recognizes mid-career scientists for their research and mentoring accomplishments.

LLNL postdoctoral fellows **Oluwatomi (Tomi) Akindele**, **Matthew Edwards** and **Wei Jia Ong** were selected by the University of California Office of the President to attend the 70th annual Lindau Nobel Laureate meeting in Germany to interact with 30 to 40 Nobel laureates and 600 other students and postdocs from around the world.

Laboratory retiree and consultant **Craig Tarver** was honored with the American Physical Society's 2021 George E. Duvall Shock Compression Science Award for "theoretical advancement of the understanding of shock-driven reactions and detonation in condensed phase explosives."

Computer scientist **Rushil Anirudh** co-authored a paper that received the Best Paper Honorable Mention award at the 2021 IEEE Winter Conference on Applications of Computer Vision. The award was given based on the work's potential impact to the field.



LAWRENCE LIVERMORE NATIONAL SECURITY, LLC

Overseeing management and operation of the Laboratory for the U.S. Department of Energy and the National Nuclear Security Administration

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ORGANIZATION AND LLNS BOARD MEMBERS IN FY 2021

BOARD OF GOVERNORS

BOARD OF GOVERNORS COMMITTEES

Business, Operations, and Security
Ethics and Audit
Mission
Nominations and Compensation
Science and Technology

LLNS PRESIDENT AND LABORATORY DIRECTOR

Kimberly S. Budil

SCIENCE AND TECHNOLOGY

Computing
Engineering
Physical and Life Sciences

MISSIONS AND PROGRAMS

Global Security
Weapons and Complex Integration
NIF and Photon Science

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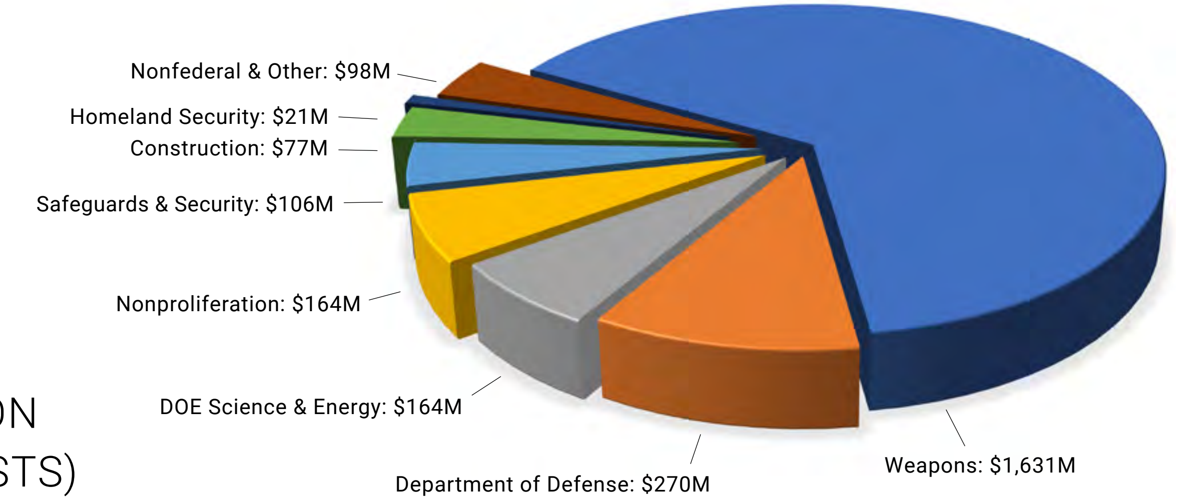
New York University

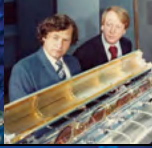
RICHARD MIES
Member of the Mission Committee
Admiral, U.S. Navy (Retired);
Former Commander in Chief,
U.S. Strategic Command

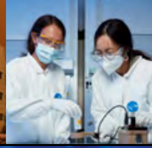
LLNL DIRECTOR EMERITUS GEORGE MILLER HONORED WITH FOSTER MEDAL

Former colleagues and national security leaders paid tribute to George Miller as he was presented the John S. Foster Jr. Medal in November 2021. Director Emeritus Miller was recognized for his exceptional leadership in nuclear weapons science and technology (S&T), the establishment and early successes of the Stockpile Stewardship Program, and the construction of the National Ignition Facility. Miller's leadership continued with his service as a trusted senior advisor on national security S&T. He is the sixth recipient of the John S. Foster Jr. Medal.

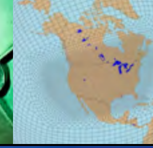
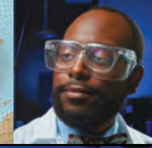
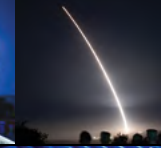
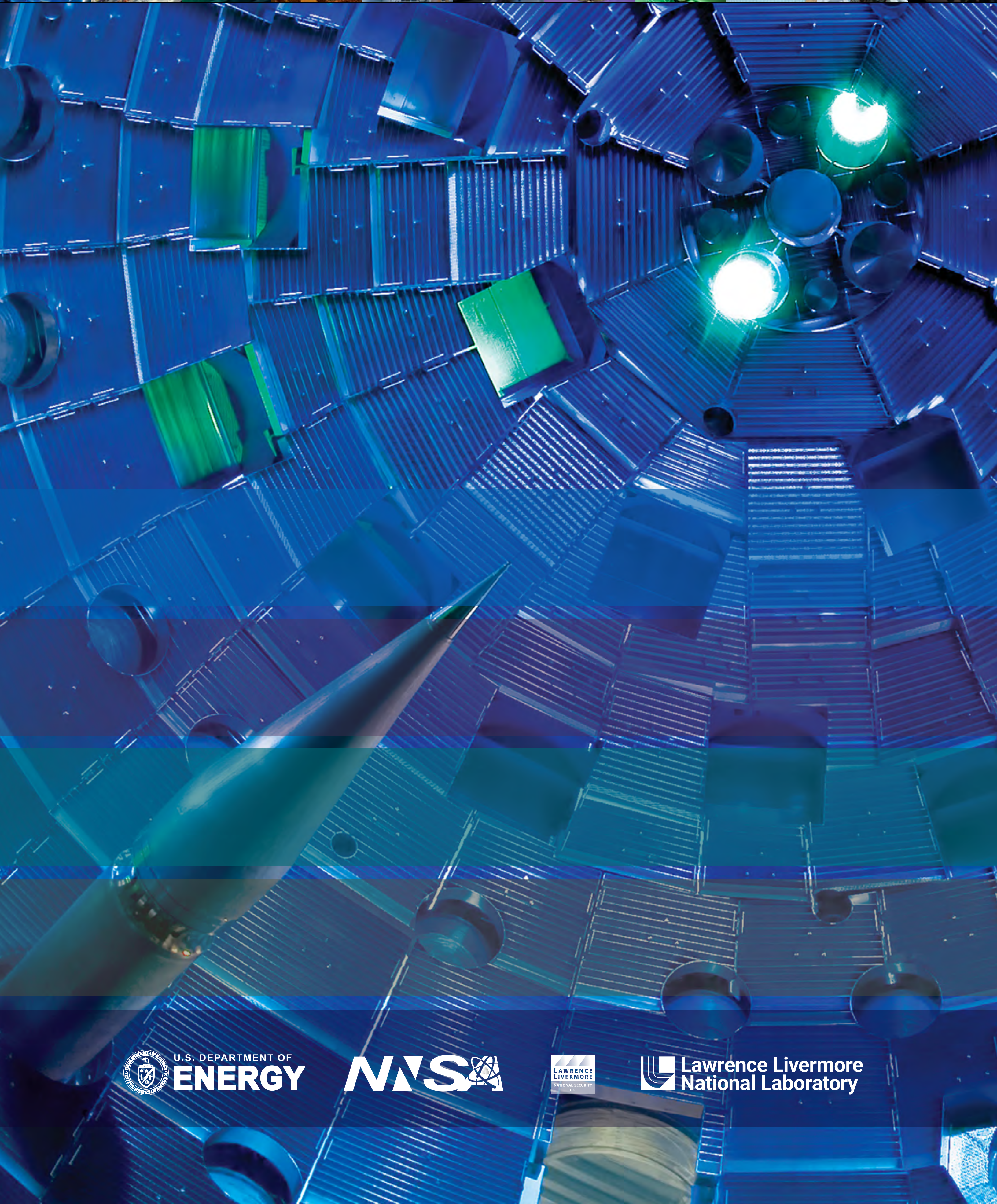
LLNL FY 2021 PORTFOLIO: $2.532 BILLION (ACTUAL COSTS)





U.S. DEPARTMENT OF ENERGY

NNSA

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