MAKING THE IMPOSSIBLE *POSSIBLE*

70

1952 - 2022

FY 2022 ANNUAL REPORT

LAWRENCE LIVERMORE NATIONAL LABORATORY

A PEEK AT THE FUTURE

IGNITION

DECEMBER 5, 2022

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) 2022 marked the 70th anniversary of the Laboratory, a milestone that was celebrated with the theme "Making the impossible possible." This was another exceptional year of innovation, pushing the frontiers of mission-directed science and technology. Notably, continued advances at the National Ignition Facility led to the achievement of fusion ignition and energy gain in an experiment in December 2022 (a peek into FY 2023).

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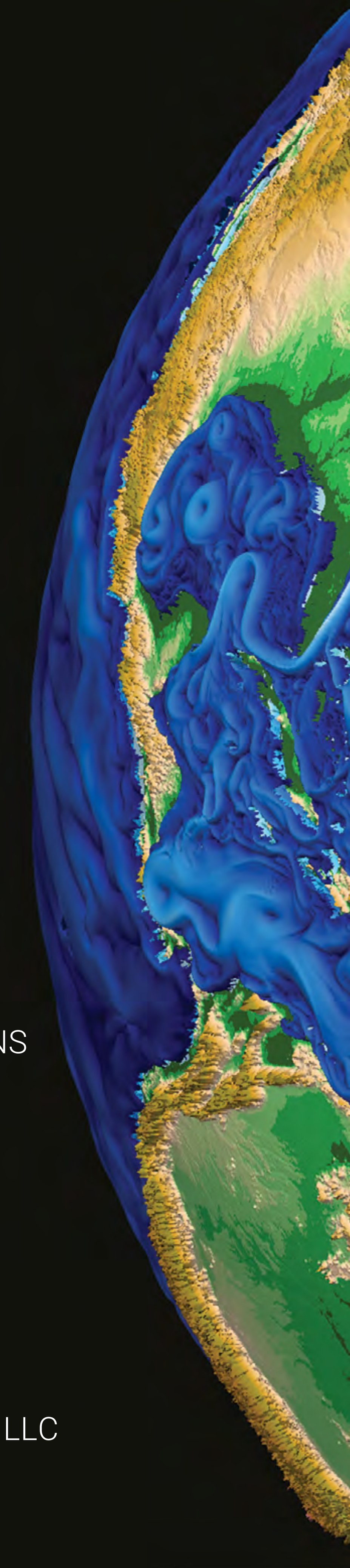
INSIDE FY 2022



SCIENCE & TECHNOLOGY ON A MISSION

Lawrence Livermore National Laboratory had another exceptional year pushing the frontiers of science and technology to strengthen national security in a rapidly changing world

LLNL Director Kimberly Budil speaks at the Department of Energy (DOE) press conference on December 13, 2022, announcing the achievement of fusion ignition at NIF.

In 2022, Lawrence Livermore National Laboratory (LLNL) celebrated the 70th anniversary of its founding as a branch of Ernest O. Lawrence's Radiation Laboratory at the University of California at Berkeley. The theme of this year's celebration—making the impossible possible—carries forward Livermore's founding purpose to be a "new ideas" laboratory and meet pressing needs to advance nuclear weapons science and technology (S&T). One of the early big, new ideas led to the design of the first compact thermonuclear weapons, which were carried on Polaris ballistic missiles. Another "impossible" early big idea was to use a powerful energy source to implode a small pellet of fuel and create fusion energy in a laboratory setting.

After nearly 60 years of pushing the boundaries of laser technology, target fabrication, and design, on December 5, 2022, the impossible was demonstrated to be possible. In an experiment at the National Ignition Facility (NIF), 2.05 megajoules (MJ) of laser energy produced 3.1 MJ of fusion energy. The historic accomplishment of fusion ignition supports key national security goals and is a giant first step forward on the path to using fusion as a carbon-free, abundant source of energy for humankind. This achievement is what the national laboratories were created to do: pursue and persevere on technically ambitious, long-term goals through generations of hard work and breakthrough innovations. The Department of Energy (DOE), its National Nuclear Security Administration (NNSA), the entire inertial confinement fusion (ICF) research community, and the dedicated LLNL scientists and engineers that made the final push in FY 2022 have earned well-deserved congratulations.

LLNL MISSION AND VISION

At our Laboratory, we fearlessly and relentlessly pursue big ideas to solve the most important security challenges facing the nation and the world. LLNL's *FY 2022 Annual Report* illustrates the forward thinking and innovative research we undertake in support of our mission: to enable U.S. security

A panel of NIF scientists answer technical questions about the ignition experiment after the DOE press conference.

and global stability and resilience by empowering multidisciplinary teams to pursue bold and innovative science and technology. For example, LLNL is pioneering cognitive simulation (CogSim), a technique that integrates artificial intelligence with high-performance computing (HPC) and experimental results to accelerate scientific discovery. CogSim has already greatly benefited essential research, such as NIF experiments and vaccine development. We are also making breakthrough advances in additive manufacturing to produce nanoscale precision components with previously unobtainable properties, made from an ever-expanding variety of materials. These and other innovations support projects in our four mission areas.

Nuclear Deterrence continues to be the defining responsibility of our Laboratory. In a rapidly evolving security environment, we must assure the safety, security, and effectiveness of the U.S. nuclear stockpile. Our focus is on transforming the stockpile and the nuclear security enterprise to meet 21st-century national security needs. As our *Annual Report* describes, we are engaged in two programs to modernize stockpile systems: the W80-4 Life-Extension Program, a warhead that will be carried on the all-new Long-Range Standoff missile; and the W87-1 Modification Program, a warhead for the Sentinel ballistic missile being developed by the U.S. Air Force. Through close partnerships with the NNSA laboratories and production sites, we are developing new manufacturing technologies and business processes to improve efficiencies, lower costs, and increase NNSA's agility.

Threat Preparedness and Response is needed to counter severe threats, prevent the use of weapons of mass destruction (WMD), and enhance global security and resilience. We apply advanced capabilities and expertise to support the intelligence community, develop and apply cutting-edge forensic science for incident response, and further nuclear nonproliferation objectives. We are focused on enhancing bioresilience through early biological threat detection and assessment and accelerated design, development, and testing of medical countermeasures. Highlighted in our *Annual Report* is the use of CogSim tools to develop a multipathogen vaccine and advance cancer research.

Climate and Energy Security is one of today's most pressing challenges. LLNL researchers couple expertise in materials science, carbon cycle and subsurface research, and HPC simulation to assess climate impacts on national security and the functioning of critical infrastructure. Our efforts focus on improving models, such as cloud physics, to increase predictability at regional to local spatial scales. LLNL researchers are also developing ways to improve carbon capture methodologies, mitigate the impact of greenhouse gases, and enhance infrastructure resiliency.

Multi-Domain Deterrence seeks to create strategic advantages in an increasingly dangerous multipolar world. Integrated deterrence must meet multifaceted challenges: WMD proliferation, cyber- and space security, directed energy systems, and hypersonic conventional weapons. Livermore is focused on understanding the potential threats, developing advanced defense technologies, and creating computational tools to better model and predict the behavior of complex systems. In addition, U.S. leadership in S&T is important in the face of international competition. LLNL provides expertise and cutting-edge research facilities in many areas central to national security.

TRANSFORMING THE LABORATORY

As we sustain our focus on innovation, Livermore is changing. At the start of the fiscal year, LLNL adopted a hybrid workplace as its "new normal" for operations. As illustrated during the pandemic, a flexible workplace that accommodates telecommuting and enhanced flexibility, consistent with each employee's job responsibilities, supports effective mission delivery. In addition, our physical site has changed with completed construction of the Emergency Operations Center and the Exascale Computing Facility Modernization project, which prepares LLNL for delivery of the El Capitan supercomputer in FY 2023. Many other projects are under way that modernize both Laboratory operations and facilities to meet evolving mission needs.

Outstanding people are the Laboratory's most important resource. We continue to hire exceptional individuals to join our team and are welcoming many new employees to Livermore. Recruiting, training, and retaining our workforce is a top priority. Many employee-focused initiatives were launched in FY 2022, including a Future of Work Task Force that has recommended workplace changes to optimize employee experience and mission success. As we go through generational change, LLNL is building on the heritage established by Livermore's founders. We serve as a "big ideas" laboratory, pursuing multidisciplinary "big science" in the national interest.

SEVENTY YEARS OF INNOVATION

During Employee Engagement Day, staff members toured the supercomputer rooms within the Livermore Computing facility.

The Livermore branch of the University of California Radiation Laboratory at Berkeley opened for operation on September 2, 1952. Co-founders Ernest O. Lawrence and Edward Teller; Livermore's first director, Herbert York; and a remarkable group of young scientists set out to be a "new ideas" laboratory. They were committed to pursuing innovative solutions to the nation's pressing needs to advance nuclear weapons science and technology.

INNOVATION SINCE 1952

"Making the impossible possible" was the theme for the Laboratory's celebration of its 70th birthday. The outstanding efforts by a dedicated workforce have led to many remarkable accomplishments by creative individuals and multidisciplinary teams. Automated computing topped the list of needs identified by the forward-thinking founders, and a UNIVAC 1 computer was ordered even before the official opening of the "Rad Lab." Livermore has provided leadership in high-performance computing for scientific applications ever since. Innovative approaches to nuclear weapons design failed in the Laboratory's first nuclear test in 1953 but led to a strategic breakthrough later in the 1950s that made possible compact thermonuclear weapons for ballistic missiles. Other examples of the Laboratory's technological innovation that have made the impossible possible include rapid flow cytometry needed to pursue the Human Genome Project, adaptive optics for the study of exoplanets from ground-based observatories, extreme ultraviolet lithography technologies that are extending the long life of Moore's Law, and most recently, fusion ignition and burn in a laboratory setting.

Celebrating the 70th year since the founding of LLNL and other notable anniversaries in 2022

Former Laboratory Directors and innovators (from left) John Nuckolls (laser fusion) and John S. Foster Jr. (compact nuclear weapons) converse at the Directors' Symposium.

In September 2022, the nine living Laboratory directors held a panel discussion attended by more than 200 staff members, former employees, community leaders, and other distinguished guests including DOE Under Secretary for Nuclear Security and NNSA Administrator Jill Hruby. The panelists reflected on past successes and discussed the importance of carrying forward the Laboratory's tradition of "making the impossible possible." Celebrating his 100th birthday that month, former director John "Johnny" Foster Jr. spoke of the characteristics that made Laboratory founder Ernest O. Lawrence great—his vision, persuasion skills, and leadership—all qualities LLNL will need to continue as a "big ideas" laboratory.

FIFTIETH ANNIVERSARY OF THE LASER PROGRAM

In July 2022, LLNL's National Ignition Facility & Photon Science (NIF&PS) Principal Directorate celebrated the 50th anniversary of the Laser Program with a series of presentations about past successes, current challenges, and future opportunities. The formation of Y Division in July 1972 consolidated laser research at the Laboratory, which began with the inventions in 1960 of lasers and the concept of inertial confinement fusion. Featured speaker John Emmett, the first Y Division leader and later associate director for Lasers, spoke about the early organizational and technical challenges. Emmett brought in laser experts to join the Laboratory and reached out to industrial partners to continually advance the state of the art. He challenged the audience, "The Laboratory is for big steps, and big risks, and accomplishing big things." NIF&PS presenters discussed breakthrough advances in laser and optics technologies and research activities that contributed to achieving fusion ignition in December.

THREE DECADES OF EXPLOSIVE INNOVATION

In June 2022, LLNL's Energetic Materials Center (EMC) celebrated its 30th anniversary. Since its inception, EMC has brought together a multidisciplinary team of Laboratory researchers who are among the nation's leaders in understanding, synthesizing, formulating, testing, assessing, and modeling energetic materials. An NNSA-recognized center of excellence, EMC combines core scientific expertise, experiments at the High Explosives Applications Facility (HEAF) and Site 300, and high-fidelity modeling and simulations. As the center's director said at the celebratory event, "EMC is ready and agile for whatever comes next."

HEAF

Distinguished speakers at the event—attended by collaborators from partnering institutions, current and former Laboratory employees, and other invited guests—highlighted many past accomplishments and stressed the important contributions EMC is making today and in the future. The center is engaged in its greatest challenge yet in supporting the nation's strategic modernization programs (p. 6) and efforts to accelerate the adoption of new explosive materials and production capabilities within NNSA. EMC scientists also apply their expertise to develop solutions for the Department of Defense's conventional weapons and explore new ways to detect and defeat homemade and improvised explosive devices for homeland security and counterterrorism applications.

CELEBRATING THE SEVENTIETH ANNIVERSARY

"Making the impossible possible" was celebrated on October 11, 2022, with the Laboratory's first-ever Employee Engagement Day. More than 5,000 employees participated in the event, with dozens of the Laboratory's facilities and programs opening their doors for employees to get a close-up look at Livermore's cutting-edge science and technology. In the (presumed) wake of the COVID-19 pandemic, it was the largest gathering of Laboratory staff in years and an excellent opportunity for the many new Livermore employees to discover the breadth of ongoing on-site activities. More than 20 facilities were open for tours—including the NIF, HEAF, and Livermore Computing's largest machine room. Exhibits and demonstrations were presented by more than a dozen other programs and operational support areas.

Activities paused at noontime for a grand BBQ lunch, which included a keynote address by the Laboratory Director and provided opportunities for staff to meet and greet her and other members of the senior management team. Director Budil, who engaged with employees throughout the day, concluded her keynote address, "I hope you've learned something new, I hope you've been somewhere you've never been before, and I hope you've met many new people."

Experimental capabilities to create advanced materials were on display during Employee Engagement Day.

NUCLEAR DETERRENCE

Ensuring a modernized safe, secure, and effective nuclear weapons stockpile

LLNL materials scientists use a hot press to consolidate materials into test components for the W87-1 Modification program.

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 modernize the stockpile and weapons production processes.

ANNUAL STOCKPILE ASSESSMENT

In FY 2022, LLNL completed Cycle 27 of the annual stockpile assessment. The process included a formal comprehensive peer review between LLNL and Los Alamos National Laboratory of each other's weapons 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.

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 (LRSO) missile. The Laboratory is making excellent progress in Phase 6.3 (development engineering) of the W80-4 Life-Extension Program (LEP) and preparing for entry into Phase 6.4 (production engineering). Programmatic activities include executing baseline design reviews, completing multiple high-fidelity engineering tests, activities to improve product producibility, and supporting U.S. Air Force LRSO flight-test activities. 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.

LLNL and SNL are also NNSA's design agencies for a warhead to replace the aging W78. In October 2021, the W87-1 Modification Program moved to Phase 6.2A, during which the Weapon Design and Cost Report (WDCR) is developed. Slated for deployment on the U.S. Air Force's Sentinel ballistic missile (under development) in 2030, the W87-1 will be the first modern warhead that is 100 percent newly manufactured. LLNL successfully completed its portion of the WDCR, yet total program cost issues need to be addressed to support transition to Phase 6.3. Technical activities are focused on maturing weapon design options and modern manufacturing methods.

A Laboratory engineer in the Polymer Enclave uses a highly sensitive measurement system to assess the quality of parts.

ENCLAVES AND PRODUCTION 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. LLNL is pioneering the use of enclaves to accelerate design-to-deployment within NNSA's Nuclear Security Enterprise (NSE). Researchers from the Laboratory and the Kansas City National Security Campus (KCNSC) work side by side at the Polymer Enclave at LLNL using machines, tools, and other production equipment that are equivalent to resources at KCNSC. They are producing development parts needed for the modernization programs and are co-developing with other stakeholders technological advances in additive manufacturing.

The Laboratory is also establishing an Energetic Materials Development Enclave at Site 300 in partnership with the Pantex Plant. This enclave will drive a novel approach to accelerate the adoption of new explosive materials and production capabilities within the NSE. In addition, Livermore and the Y-12 National Security Complex have teamed up to rapidly modernize technology and production methods for crucial weapons components. Utilizing manufacturing space in Oak Ridge, Tennessee, the joint LLNL and Y-12 materials team successfully installed and tested an electron beam cold hearth melter—a machine that can melt and cast various metals including uranium alloys. The team has produced test metal ingots with recycled materials and demonstrated in situ alloying capabilities.

PREPARING FOR EXASCALE

LLNL is fully engaged in preparing for the 2023 arrival of El Capitan, with a peak performance expected to exceed 2 exaflops (quintillion calculations per second). The machine is a major advance in supercomputer size and architecture and will be used by NNSA scientists to run complex, high-fidelity multiphysics simulations that address high-priority issues such as stockpile modernization. Its capabilities will greatly surpass those of 125-petaflop Sierra, NNSA's flagship supercomputer, which is also located at LLNL. Completed in early FY 2022, the $100-million Exascale Computing Facility Modernization project provides the necessary power and cooling for El Capitan (p. 23). Teams of code developers are using three early-access systems—rzVernal, Tioga, and Tenaya—as a "testbed" for assessing and improving the performance of applications. While small compared to El Capitan, these early-access systems rank among the top 200 supercomputers in the world. They include some components that will be used in El Capitan and provide an early test of the larger machine's architectural features.

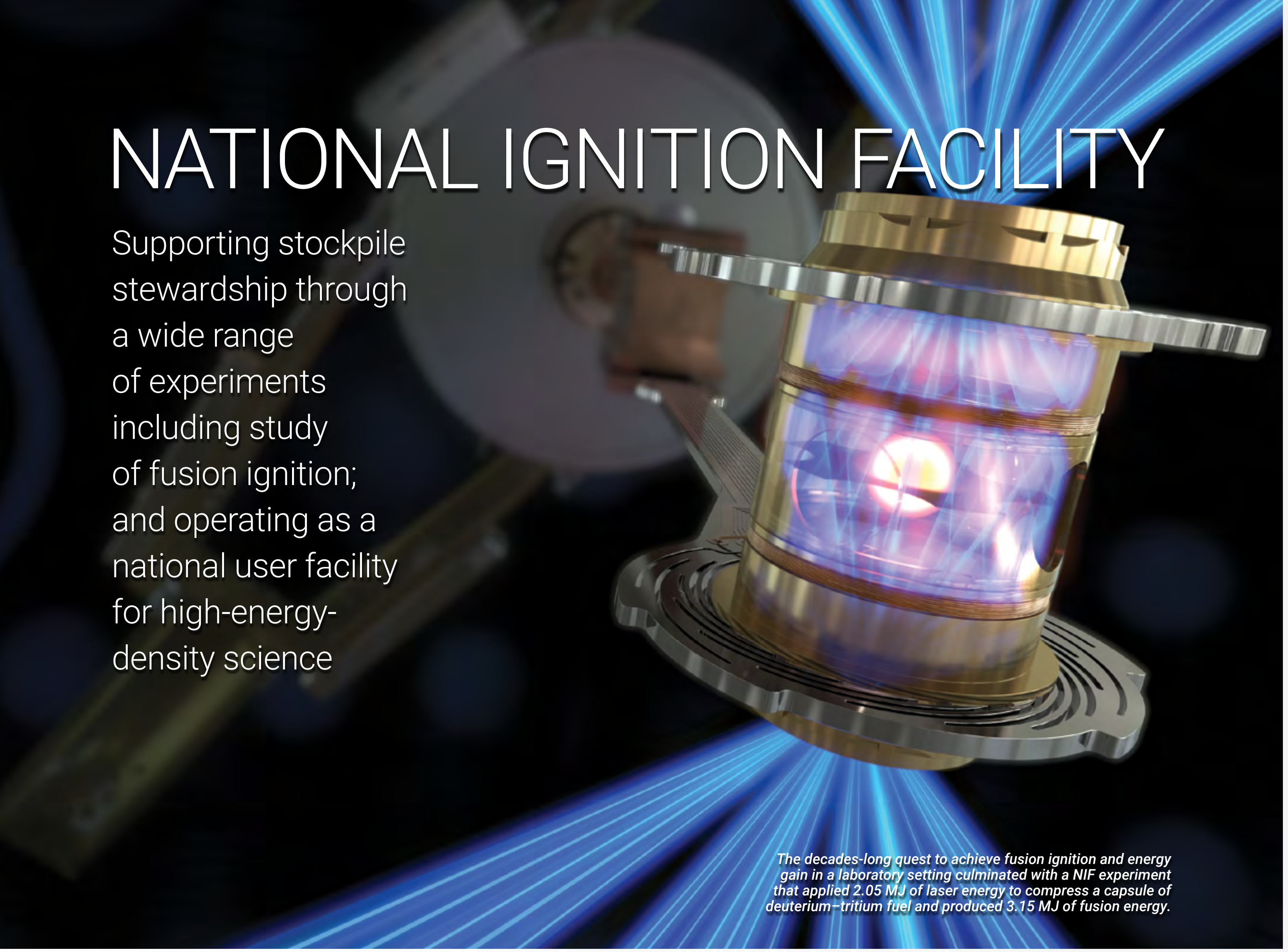
STOCKPILE STEWARDSHIP EXPERIMENTS

Experiments in support of stockpile stewardship ranged from tests to study the chemistry of high-explosive detonations at HEAF to high-energy-density physics tests at NIF (p. 9). In August 2022, LLNL and SNL researchers successfully conducted a high-priority abnormal thermal environment test for the W80-4 LEP at Site 300's Contained Firing Facility. The experiment thermally exposed the test device through a series of safety-relevant events with data captured by an extensive suite of diagnostics. The collaborative Miramar experiment was also performed at Site 300. Miramar was a milestone final preparatory test for the Nimble series of subcritical nuclear tests that will be conducted underground at the Nevada National Security Site. Nimble experiments will play a key role in assessing the safety, security, and effectiveness of the U.S. nuclear stockpile and will provide data that is crucial to certifying that the modernized weapons will perform as expected.

A multi-institutional team prepares to execute Miramar, a key experiment preparing for the Nimble subcritical test series in Nevada.

NATIONAL IGNITION FACILITY

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



The decades-long quest to achieve fusion ignition and energy gain in a laboratory setting culminated with a NIF experiment that applied 2.05 MJ of laser energy to compress a capsule of deuterium–tritium fuel and produced 3.15 MJ of fusion energy.

An historic inertial confinement fusion (ICF) experiment conducted on December 5, 2022, at the NIF achieved ignition and energy gain, delivering 2.05 MJ of energy and producing 3.15 MJ of fusion energy. Fired on September 19, 2022, the final experiment leading to this success produced about 1.2 MJ of fusion energy yield. Both of these experiments applied more laser energy to drive a thicker target as compared to the groundbreaking 1.35-MJ shot in August 2021. The thicker shell design improves hydrodynamic stability and provides more margin to ignite the hot spot. After the September experiment, adjustments to the laser pulse led to a more spherical implosion and successful ignition in December.

Tiny imperfections in the targets' high-density carbon (diamond) capsules had previously stymied efforts to achieve ignition. Four earlier repeat experiments in FY 2022 failed to replicate the 1.35-MJ result achieved in August 2021. However, these shots together with months of analysis provided valuable information to help identify obstacles to success. LLNL researchers and ICF partners held a series of workshops to better understand how inherent variations in laser and target conditions affect performance. What was a bit surprising is the level of perfection that is required from the target. One key to the success of last year's 1.35-MJ experiment was the uniquely high quality of the capsule used in the shot. The LLNL target fabrication team has taken a deeper look into the factors affecting capsule quality and is working with Diamond Materials of Freiberg, Germany, on modifying processes to improve capsule quality. In the near term, the team has revised capsule production processes in a way that should result in fewer defects.

HIGHER LASER ENERGY FOR ICF EXPERIMENTS

For the September 2022 ICF experiment, laser operators began boosting NIF's laser energy to a higher level of operations for ICF experiments. It was the first NIF shot to deliver more than 2 MJ of ultraviolet energy to an ICF target. To support higher-energy shots—and expected higher MJ-fusion yields—the NIF operations team implemented technologies to reduce debris-induced damage. Eighty additional high-quality fused silica debris shields were installed to protect the final optics from debris generated by less-expensive disposable shields. In addition, mechanical debris shielding was installed inside the laser's lower final optics housings. With additional optics improvements and laser upgrades, researchers expect NIF to reach 2.2 MJ of laser energy and 480 trillion watts of peak power in the coming year and potentially as much as 2.6 to 3 MJ later this decade.

TRANSFER LEARNING TO IMPROVE PREDICTABILITY

ICF research is especially benefiting from an important pioneering application of machine learning (ML), called cognitive simulation (CogSim)—the combining of ML and artificial intelligence techniques with high-performance computing simulations and empirical data to dramatically improve predictive analysis. Since 2018, LLNL has been developing, testing, and improving CogSim tools to better predict ICF experimental results. A promising technique, called transfer training of a deep neural network (DNN), teaches the computer the basics of ICF physics with a large number of 1D simulations, further trains the model with more costly 2D simulations, and then "corrects" the model through additional training using prior experimental results.

NIF researchers applied this technique to a series of laser shots conducted at the University of Rochester's Laboratory for Laser Energetics (LLE). Before the experiments, the team's simulations predicted experimental parameters such as the areal density of a shot's plasma cloud, the ion temperature, and the neutron yield, and then applied transfer learning using the experimental data from a portion of the LLE shots to retrain their DNN model. The retrained model more correctly predicted the results of the other LLE shots. CogSim applied to NIF ICF experiments is award-winning research (p. 15). The technique undergoes continual improvement and transfer learning from updated experimental results and is being scaled up for early implementation on El Capitan.

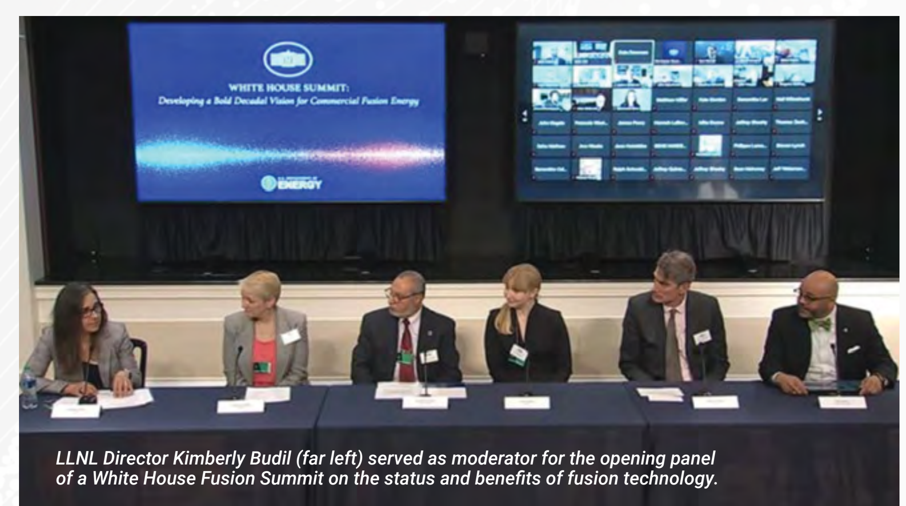
A precision machinist operates one of the new machines installed in a new home that consolidated NIF target fabrication operations.

HED SCIENCE EXPERIMENTS AT NIF

In FY 2022, high-energy-density (HED) science campaigns at NIF supported weapons physics studies, stockpile modernization efforts, and Discovery Science. The study of plutonium (Pu) under HED conditions is an especially important campaign. In 2019, researchers began conducting equation-of-state (EOS) experiments to study crystalline Pu at high pressures. Other Pu experiments have measured changes in the material's phase and its strength under pressure. The EOS shots pose extreme challenges in target fabrication. In FY 2022, the NIF team completed installation of a new Pu target fabrication facility within LLNL's Superblock. The facility now produces Pu targets for stockpile modernization efforts and crucial tri-laboratory studies of Pu aging. Similarly, the three NNSA laboratories are using data from NIF and other experimental facilities to build a fundamental understanding of tantalum's strength. The material is of great interest because it remains in a single solid phase across the full range of conditions examined, while exhibiting complex atomic-scale processes to maintain strength. NIF experiments also probed the first 50 nanoseconds of the chemical reactions in laser-driven high-explosive materials. Discovery Science shots at NIF provided data to determine the melting and structural properties of pure iron up to 10 million atmospheres—three times the pressure in Earth's core and that of super-sized Earth-like planets.

THE INERTIAL FUSION ENERGY INITIATIVE

In FY 2022, the Laboratory launched an Inertial Fusion Energy (IFE) institutional initiative to foster collaborations with academia and U.S. industry to more rapidly advance IFE science and technology for commercializing fusion power. The initiative aims to address the world's long-term need for carbon-free energy. It builds on breakthroughs in fusion in the last several years—especially ignition at NIF—together with the Biden Administration's newly launched 10-year strategy for developing commercial fusion energy. In March 2022, LLNL Director Kimberly Budil was a key participant in the White House Fusion Summit, where the status and benefits of fusion energy technology were discussed.



LLNL Director Kimberly Budil (far left) served as moderator for the opening panel of a White House Fusion Summit on the status and benefits of fusion technology.

GLOBAL SECURITY

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

A nuclear and radiochemistry researcher holds the prototype device for field-deployable nuclear forensics.

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 develop and implement capabilities that 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.

NUCLEAR FORENSICS AT WORK

After a nuclear incident, time is of the essence to determine what radioactive material was used and where it originated. A team at LLNL developed a prototype chemistry-on-a-chip platform for field-deployable nuclear forensics. The assessment tool qualitatively identifies actinides, specifically radioactive elements such as uranium or plutonium, sampled from postdetonation nuclear debris. Using a chemical extractant, the device can separate out elements of interest from only a submilliliter microsample, limiting the exposure risk to operators and allowing for easy, safe analyses that take just 20 to 30 minutes to complete. After separation, the isotopic ratios of the sample are quantified using a combination of nuclear and optical spectrometric techniques. Further work will adapt the tool to effectively measure actinides from more realistic debris samples.

LLNL researchers and collaborators are also studying the formation of uranium oxides in energetic environments, such as conditions following a nuclear event. They discovered that the ambient concentration of oxygen strongly affects the type of compounds formed, while their structural composition is highly dependent on whether the plasma cools from 10,000 °C over microseconds or milliseconds. Hundreds of different types of possible molecules can form. These results will help refine computational models of nuclear explosions and improve predictive capabilities for particle formation and transport. Laboratory scientists also analyzed the massive detonation that occurred in a Beirut port in August 2020. They found that features, such as bodies of water, within the near-source environment can have a large effect on shock and blast waves, seismic motions, and crater formation, as well as cloud rise and fallout effects.

GEOPHYSICAL EVENT MODELING

Researchers at LLNL developed a new computational model that simulates the 3D seismic structure of the upper 400 kilometers of the Earth in the western United States. This work was motivated by the need to improve nuclear explosion monitoring methods by more accurately modeling short-period waveforms. The researchers performed more than 60,000 high-performance computing simulations of 72 earthquakes to update the subsurface model and improve its match with nearly 100,000 recorded seismograms. By more precisely representing the effects of wave propagation through the Earth, the new 3D model can provide improved estimates of seismic-event sources. Another research team used acoustic-gravity waves (AGW) to calculate the size of Tonga's Hunga volcano eruption in January 2022. AGWs propagate along the Earth's surface and are associated with very large atmospheric explosions from volcanic eruptions and nuclear tests. The study found that the Hunga volcano produced an atmospheric explosion the size of which has not been documented in the modern geophysical record and is comparable to that of the 1883 Krakatoa eruption in Indonesia.

COUNTERING BIOLOGICAL THREATS

A team of scientists, led by LLNL, is seeking to develop a multipathogen vaccine that will protect against three bacterial biothreats: tularemia, melioidosis, and plague. Funded by the Defense Threat Reduction Agency, this project builds on LLNL expertise using a nanotechnology—nanolipoprotein particles—as a platform to deliver vaccines against single pathogens. The next step is for the team's disease experts to add antigens that will protect against multiple pathogens simultaneously. A cost-effective, multipathogen vaccine will enable a simplified immunization regime in which warfighters can be fully vaccinated more quickly. Other researchers at the Laboratory are studying an emerging pathogen known as the Rift Valley Fever virus (RVFV). To date, outbreaks have been limited to Africa and the Arabian Peninsula. The team has discovered that RVFV infects special immune cells called mircoglia, which exist only in the brains of humans and other mammals. The researchers also found that the body recruits natural killer cells, which warrant further study, to assist microglia in fighting the infection.

LLNL researchers perform molecular characterization research for the brain's response to a Rift Valley Fever virus infection.

PROTECTING CRITICAL INFRASTRUCTURE

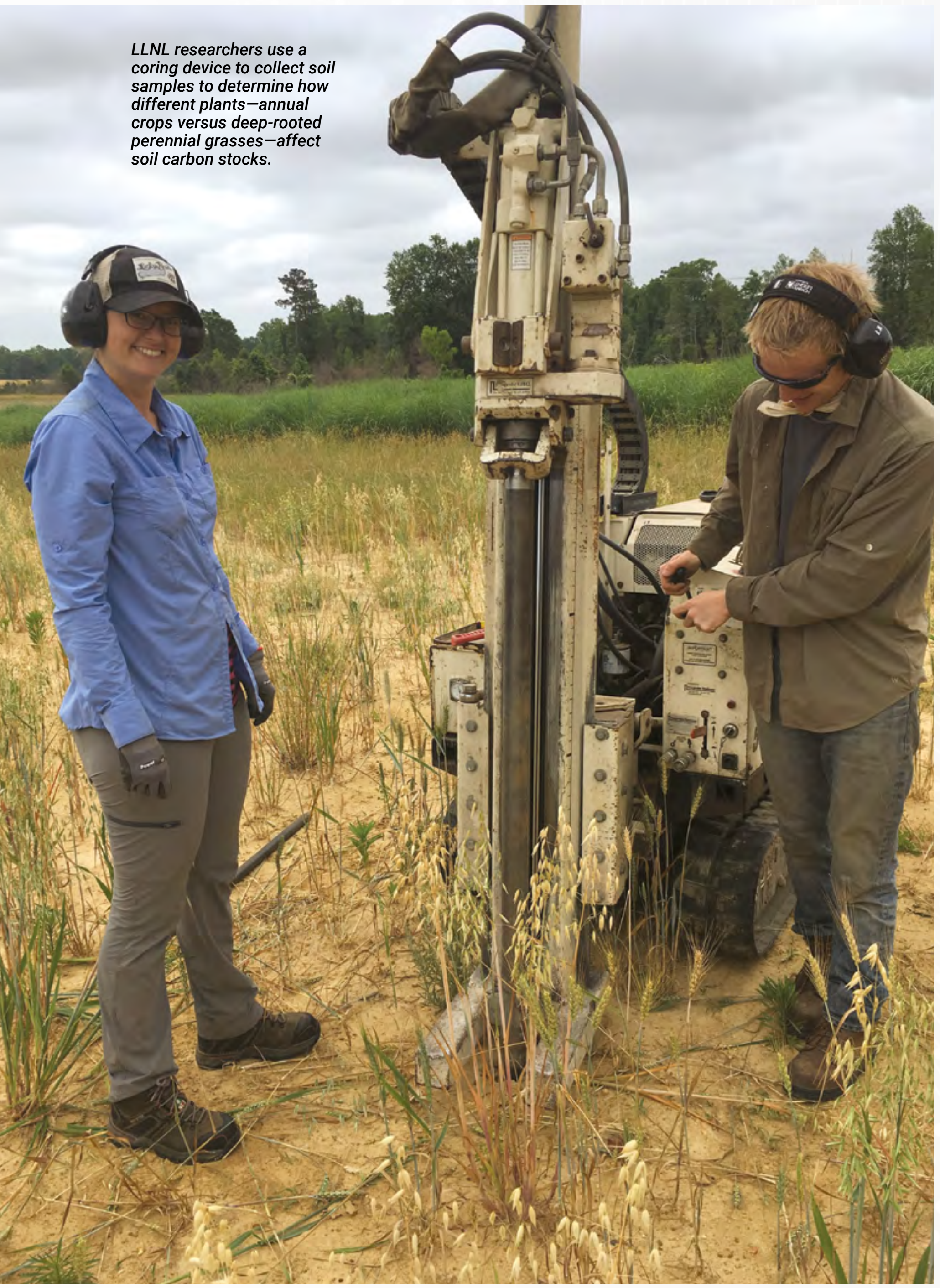
Researchers are combining cyberdefense expertise, network analysis, artificial intelligence, and collaborative-autonomy algorithms to develop a four-layer immune infrastructure framework for protecting the nation's industrial control systems from national security threats. The first layer focuses on understanding the networked system. LLNL developed a portfolio of capabilities that enable cyberdefenders to understand their asset inventory. Such capabilities include Livermore's widely used Network Mapping System, which produces a comprehensive representation of Internet-based computer network environments. For the second layer—keeping adversaries out—Livermore developed cyberdefense scalable tools to perform automatic binary analyses of software updates in search of malicious code. Layer three provides tools for detecting and responding to intrusions by developing intelligent detection capabilities that automatically respond to unknown threats. The team ran a large number of transmission and distribution simulations and applied deep-reinforcement, machine-learning techniques to characterize a healthy system and identify disruptive behavior. For the final layer—operating through compromise—LLNL is developing capabilities to facilitate infrastructure operations despite an attack by using collaborative autonomy to decentralize control of physical systems.

AN "A" GRADE IN ENVIRONMENTAL TEST

For the 12th consecutive year, the Laboratory received an "A" grade in its proficiency test for Organisation for Prohibition of Chemical Weapons (OPCW) certification. For the test, scientists at LLNL's Forensic Science Center had to correctly identify the reportable chemicals and—for the second straight year—perform their collaborative work with added precautions because of the COVID-19 pandemic. LLNL has served as one of two U.S. laboratories certified to test environmental samples for chemical weapons since 2003. The chemical analysis capability exercised in OPCW proficiency tests is foundational to much of the real-world sample analysis and research performed in LLNL's Forensic Science Center.

ENERGY AND ENVIRONMENT

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



LLNL researchers use a coring device to collect soil samples to determine how different plants—annual crops versus deep-rooted perennial grasses—affect soil carbon stocks.

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

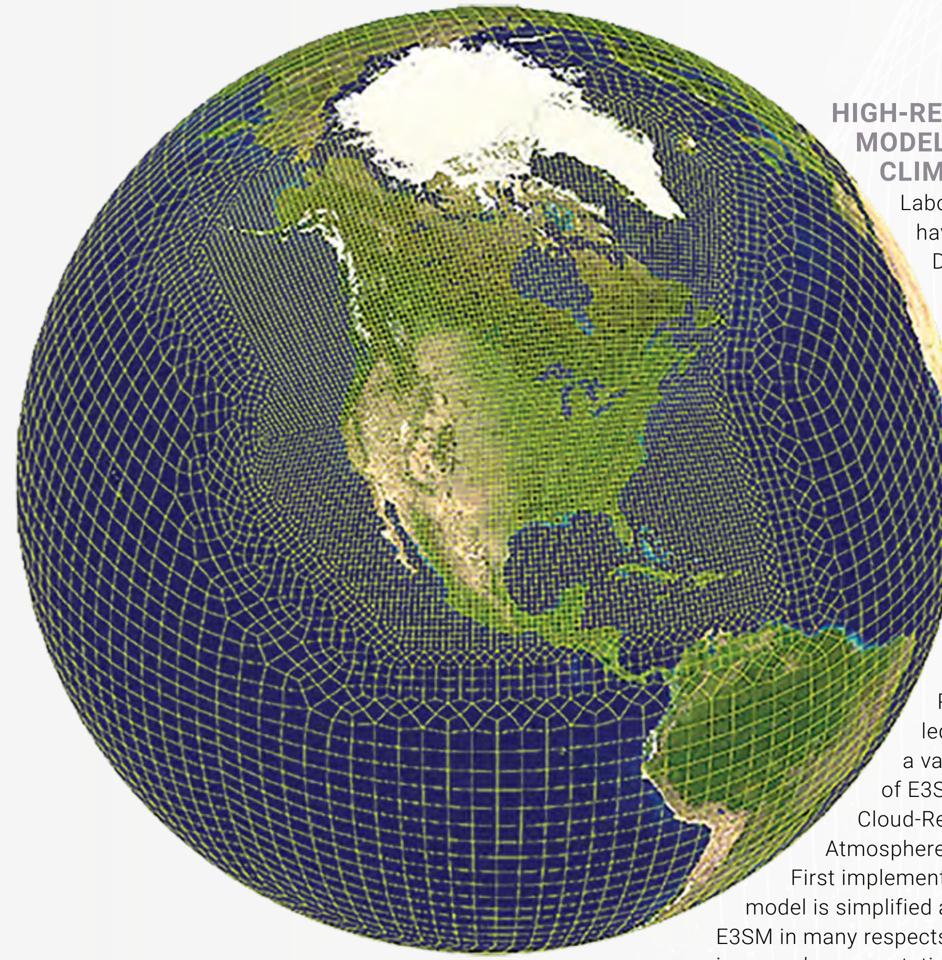
INSIGHT INTO CARBON STORAGE

A Laboratory-led international team produced the first spatially resolved global estimates of mineral-associated carbon and the carbon-storage capacity of soil minerals. Soil is the largest terrestrial reservoir of organic carbon and is central to managing climate change and mitigation. The study found that regions under agricultural management and deeper soil layers contain the largest undersaturation of mineral-associated carbon. The degree of undersaturation can help inform sequestration efficiencies over years to decades. Another team including an LLNL researcher concluded that wildfires and prescribed burns may be an important nature-based climate solution to increase long-term soil organic carbon (SOC) storage. Carbon losses to the atmosphere due to fires are offset by reduced decomposition due to changes in the properties of organic materials in the soil.

In another study, research by LLNL scientists and collaborators found that rock weathering boosts SOC storage by altering soil mineralogy. As primary minerals in rocks weather to form soil, they create reactive, poorly crystalline minerals (PCMs) with less-than-perfectly-ordered structures that bind and store organic carbon. The team linked primary mineral weathering rates to the geographic distribution of PCMs across the United States and found that rock weathering enhances SOC storage at continental scales. However, the influence is limited because PCMs disappear over time as they ripen into more crystalline minerals. Additional active weathering of primary minerals is needed to maintain the amount of PCMs.

THE ROLE OF MICROBES IN THE CARBON CYCLE

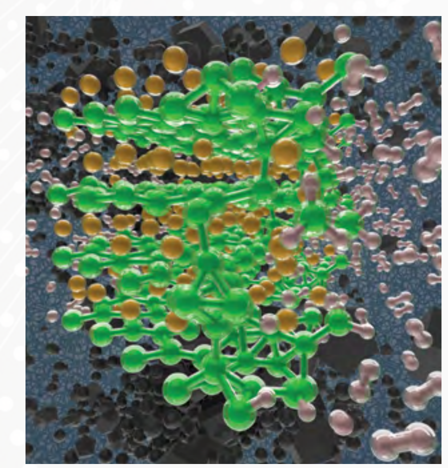
Soil organic matter is the Earth's largest carbon pool. Using new advances in DNA sequencing and isotope tracing, LLNL researchers discovered the importance of both living and dead microorganisms in forming SOC. Dead microorganisms accrete in soil as their cellular remains adhere to the mineral matrix. Their dead biomass can make up as much as 50 percent of the soil organic matter—translating to one of the largest stocks of organic carbon on the planet. Working with collaborators, another team developed a custom microscope using multiphoton nonlinear optics to image microbes in soil and plants at the micrometer scale with greater contrast and resolution. Yet another team created a porous microplate device for studying the exchange of nutrients and metabolites while blocking physical contact between adjacent microalgae cultures. Microscopic algae are responsible for half of the global atmospheric carbon fixed from the atmosphere through photosynthesis. The team found that the algal microscale environment is a complex ecosystem, which allows multiple microbial groups to thrive in different locations within it.



Version 2 of E3SM is capable of modeling at 100-km globally uniform resolution and a 25-km grid over North America.

HIGH-RESOLUTION MODELING OF CLIMATE CHANGE

Laboratory researchers have begun using DOE's first exascale supercomputer to run version 2 of the Energy Exascale Earth System Model (E3SM) at 100-kilometer (km) resolution globally with a 25-km regionally refined grid over North America. Recently, an LLNL-led team created a variant version of E3SM—the Simple Cloud-Resolving E3SM Atmosphere Model (SCREAM). First implementation of this model is simplified and coarser than E3SM in many respects, with focus on improved representation of precipitation. SCREAM was run at 3.25-km resolution, 30 times finer than the typical resolution for climate modeling. The team performed a simulation corresponding to 40 days of Northern Hemisphere wintertime weather. SCREAM reproduced many features of Amazon basin precipitation much more realistically than E3SM and captured the frequency and structure of important weather events, such as cyclones, atmospheric rivers, and cold air outbreaks. The model leaves unresolved some existing climate model biases as compared to observation. The research team continues to refine SCREAM and has identified areas for further improvement.



Simulations reveal the effect of microscale features in solid electrolytes on Li-ion battery performance.

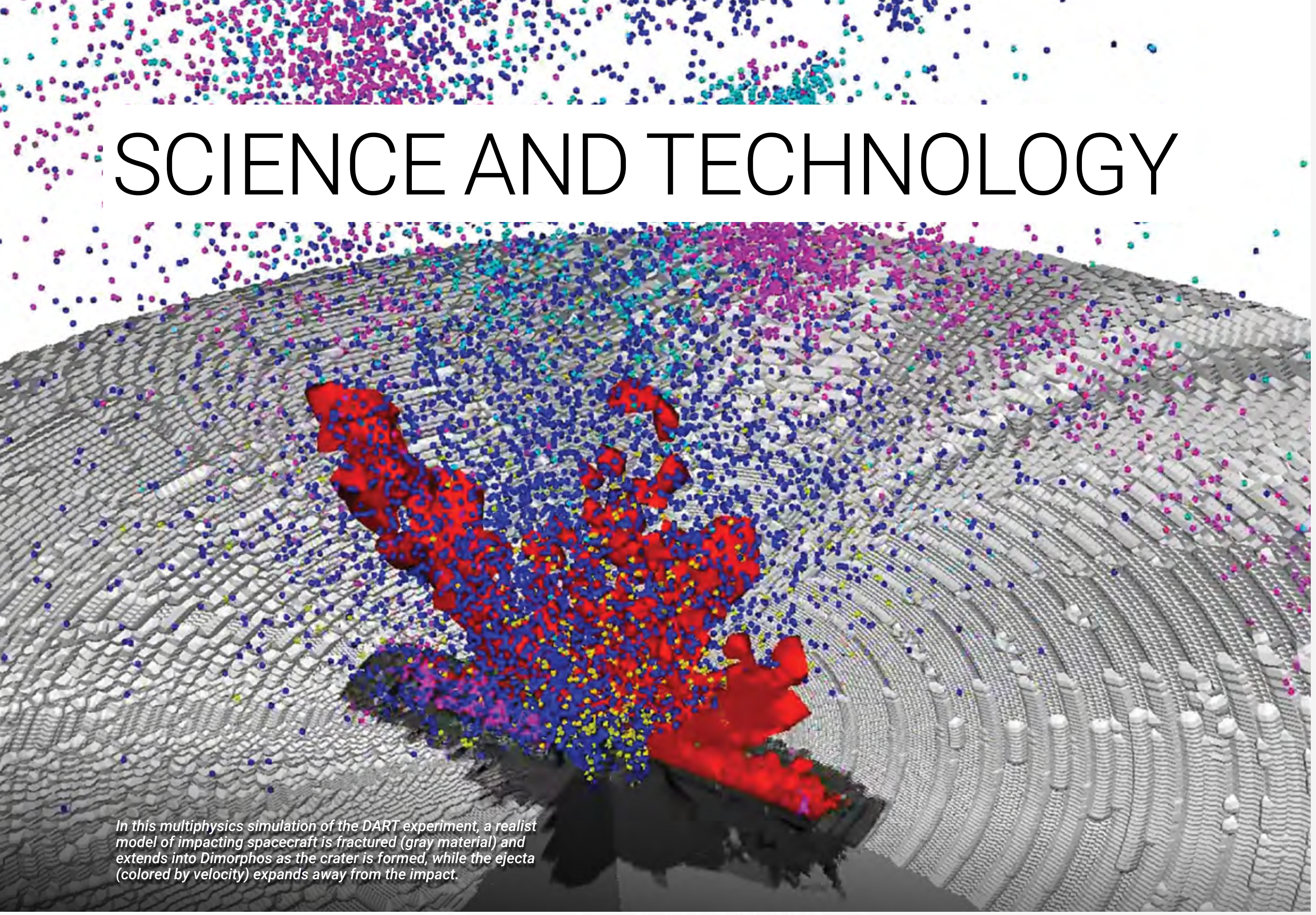
HYDROGEN STORAGE

Solid-state metal hydrides are attractive alternatives to gas-phase hydrogen storage because they provide exceptional energy densities and can reversibly release and uptake hydrogen. However, many high-capacity metal hydrides require extreme hydrogen pressures to regenerate. For example, converting bulk metallic aluminum into alane (aluminum hydride), which has a volumetric hydrogen density twice that of liquid hydrogen, was long thought to be impossible except under more than 6,900 atmospheres of dihydrogen (H_2) pressure. An LLNL–Sandia National Laboratories team found that alane situated within the nanopores of a highly porous framework can be regenerated at tenfold lower H_2 pressure. Borides are also potential hydrogen-storage materials. LLNL researchers showed that metal boride surfaces and their single-layer variants can disorder dynamically from a regular arrangement of atoms at moderate temperatures. Dissociation of H_2 is easier at some of the atomic sites, which in turn is expected to accelerate material activation during hydrogen storage.

IMPROVEMENTS IN LITHIUM-ION BATTERIES

Next generation lithium-ion (Li-ion) batteries will require higher energy and power densities at a lower cost. LLNL is partnering with Ampcera Inc. to develop solvent-free laser powder bed fusion methods to fabricate high-capacity 3D cathode structures that will enable faster charging, higher-energy-density Li-ion batteries. Solventless battery production would have higher throughput and lower energy consumption and cost. Another LLNL collaboration developed a powerful multiscale simulation capability to study the effect of microscale features, such as grain boundaries on ionic transport in solid electrolytes. The multiscale simulations will help overcome technical challenges to the design and development of Li-ion batteries with solid electrolytes, which have numerous intrinsic performance properties and safety advantages over conventional systems.

SCIENCE AND TECHNOLOGY



In this multiphysics simulation of the DART experiment, a realist model of impacting spacecraft is fractured (gray material) and extends into Dimorphos as the crater is formed, while the ejecta (colored by velocity) expands away from the impact.

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.

SUCCESSFUL PLANETARY DEFENSE TEST

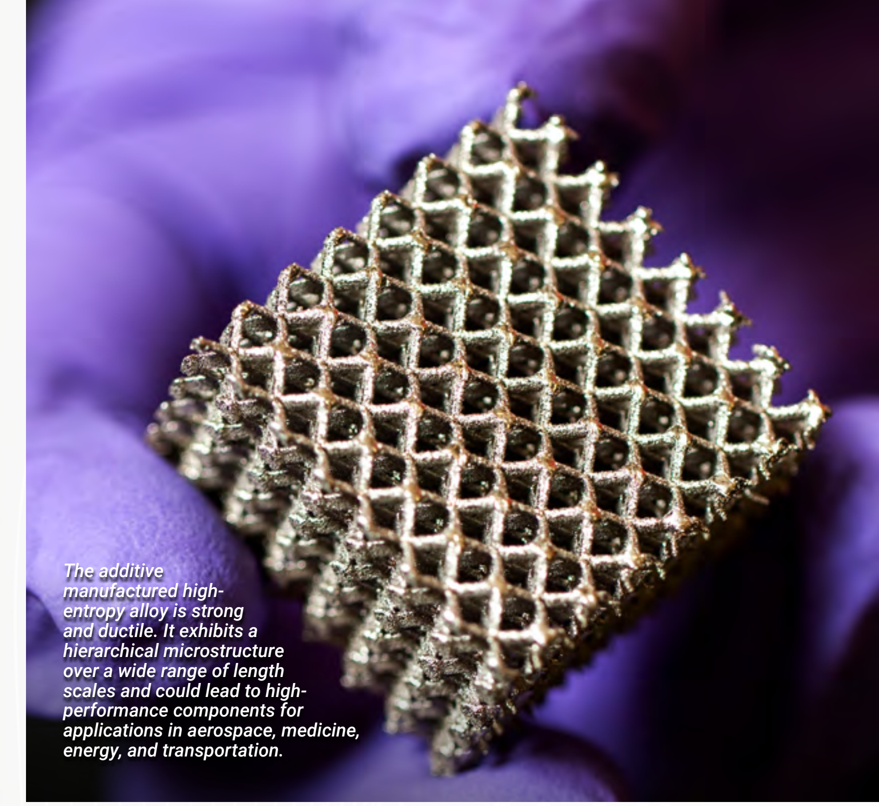
On September 26, 2022, several Laboratory researchers joined other members of the Double Asteroid Redirection Test (DART) team at the Johns Hopkins Applied Physics Laboratory to watch the 600-kilogram DART spacecraft, traveling at 6 kilometers per second, crash into Dimorphos—the small moonlet that orbits the larger Didymos asteroid. Two weeks after the impact, NASA confirmed that the mission successfully deflected Dimorphos and changed its orbital period around the larger asteroid. Livermore scientists have been working as part of the DART team since mission planning began in 2014. They have contributed to developing and applying multiphysics simulations for planetary defense and, in particular, predicting and analyzing the results of the DART demonstration. The LLNL team is applying machine learning to efficiently evaluate the gathered data and pioneering novel ways of ascertaining the structure of the asteroid's rubble, simulating the effect of the impact, and analyzing resulting ejecta.

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

A NEW GENERATION OF METAL ALLOYS

A materials scientist at LLNL, along with researchers at Oak Ridge National Laboratory (ORNL) and several universities, created a new class of flexible super-strong metal parts unattainable through traditional metallurgical processing. Using the laser powder bed fusion (LPBF) method, they 3D-printed eutectic alloys—high-entropy alloys or multi-principal elements alloys—that are composed of two main phases and give exceptional strength and ductility. LPBF involves the selective laser melting of metal powder particles, layer by layer, which fuse together to form a larger 3D structure. The new materials were used to build lattice structures and other engineering components. In addition, using multiscale modeling, researchers at LLNL and ORNL recently demonstrated that microscale simulation approaches, when informed by high-fidelity "top-down" simulations, can effectively predict tailored microstructure formation in metals undergoing laser-based additive manufacturing (AM) processes.

The new alloys exemplify LLNL's state-of-the-art advances in AM of metals and alloys to produce tailor-designed, certifiable, high-precision parts. In addition to creating new materials, Laboratory researchers are exploring the use of surface acoustic waves to characterize surface and sub-surface defects in LPBF metal 3D printing. LLNL researchers also developed real-time diagnostics to distinguish droplet behavior in liquid metal jetting (LMJ) machines that eject tiny molten metal droplets from a nozzle at high speeds to 3D print a part in layers. The compact and non-invasive millimeter-wave diagnostic provides data that can be analyzed to determine whether high-quality drops are being generated and to ensure part quality. Another team is exploring the use of low-frequency, electromagnetic near-field detection to LMJ to capture metal droplet dynamics that, when combined with simulation, provides information on droplet features.



The additive manufactured high-entropy alloy is strong and ductile. It exhibits a hierarchical microstructure over a wide range of length scales and could lead to high-performance components for applications in aerospace, medicine, energy, and transportation.

STUDYING RARE AND TOXIC ELEMENTS

LLNL scientists and collaborators at Oregon State University developed a new method to isolate and study in great detail rare and toxic elements while using very small amounts. Such studies are difficult due to the extreme toxicity of materials, as well as the cost and scarcity of research isotopes. Traditional synthetic methods and chemical studies typically require several milligrams of sample per attempt—for some isotopes, this sample size is equivalent to the world's yearly supply. The groundbreaking method, which involves heavy polyoxometalate ligands, requires 1,000 times less material than prior state-of-the-art approaches. It enables the simple formation, crystallization, handling, and detailed spectroscopic and structural characterization of complexes containing rare isotopes starting from just 1 to 10 micrograms. Using this method, the team found several new single crystal x-ray diffraction structures, including three new compounds of curium. Just 10 curium complexes had been isolated and characterized by single crystal x-ray diffraction since the discovery of the element in 1944.

HONORS FOR HIGH-PERFORMANCE COMPUTING

Awards and honors recognized LLNL's leadership in diverse aspects of high-performance computing (HPC). At the 2022 International Conference for High-Performance Computing, Networking, Storage, and Analysis (SC22), *HPCwire* named LLNL's use of cognitive simulation techniques for inertial confinement fusion research (p. 9) as its Editor's Choice for Best Use of HPC in Energy. Also presented at SC22, the latest TOP500 list of the world's most powerful computer systems includes nine machines at LLNL, led by Sierra, which is ranked #6. Livermore's SUNDIALS open-source software library was announced as the 2023 winner of the prestigious SIAM/ACM Prize in Computational Science and Engineering. The software suite is internationally recognized as a reliable and effective tool for time-integrating equations that model and simulate physical phenomena. Another honor was a Best Paper award at the 15th IEEE Pacific Visualization Symposium. The "Adaptive Multilinear Meshes" method, developed in collaboration with researchers at the University of Utah, provides users with a versatile tool for reducing the size of large scientific datasets to visualize data and extract information.

LLNL cognitive simulation researchers display the HPCwire Editor's Choice award for Best Use of HPC in Energy at the SC22 conference.

DIFFRACTION GRATINGS ENABLE MORE POWERFUL LASERS

LLNL researchers and their collaborators developed new high-energy, low-dispersion (HELD) multi-layer dielectric gratings that provide a factor of 3.4 performance improvement over the existing state-of-the-art technology. Diffraction gratings prevent damage to optics in powerful lasers by stretching a laser pulse and recompressing it after the pulse has been greatly amplified. HELD will be used in L4-ATON, which is designed to deliver up to 10 petawatts (quadrillion watts) of peak power and will be the world's highest power laser system when installed at the ELI Beamlines facility in the Czech Republic. L4-ATON will be able to generate 1.5 kilojoules (kJ) of energy in 150-femtosecond (quadrillionths of a second) pulses at a repetition rate of one shot per minute. Multi-petawatt laser technology opens the door to groundbreaking research in areas such as plasma and high-energy-density physics, astrophysics, laser-driven particle acceleration, enhanced medical diagnostics, industrial processing techniques, and nuclear materials detection. The HELD gratings won a 2022 R&D 100 Award (p. 19).

MACHINE LEARNING SHEDS LIGHT ON CANCER

A Livermore-led team of scientists developed and are applying a highly detailed, machine learning–backed multiscale model for revealing the importance of lipids to the signaling dynamics of RAS, a family of proteins whose mutations are linked to about a third of all cancers. The nearly 120,000 Multiscale Machine-Learned Modeling Infrastructure (MuMMI) simulations performed on LLNL's Sierra supercomputer showed how hundreds of RAS proteins interact with eight kinds of lipids. When combined with experiments performed at Frederick National Laboratory for Cancer Research, the work demonstrated a link between lipid composition and RAS orientation in determining binding probability.

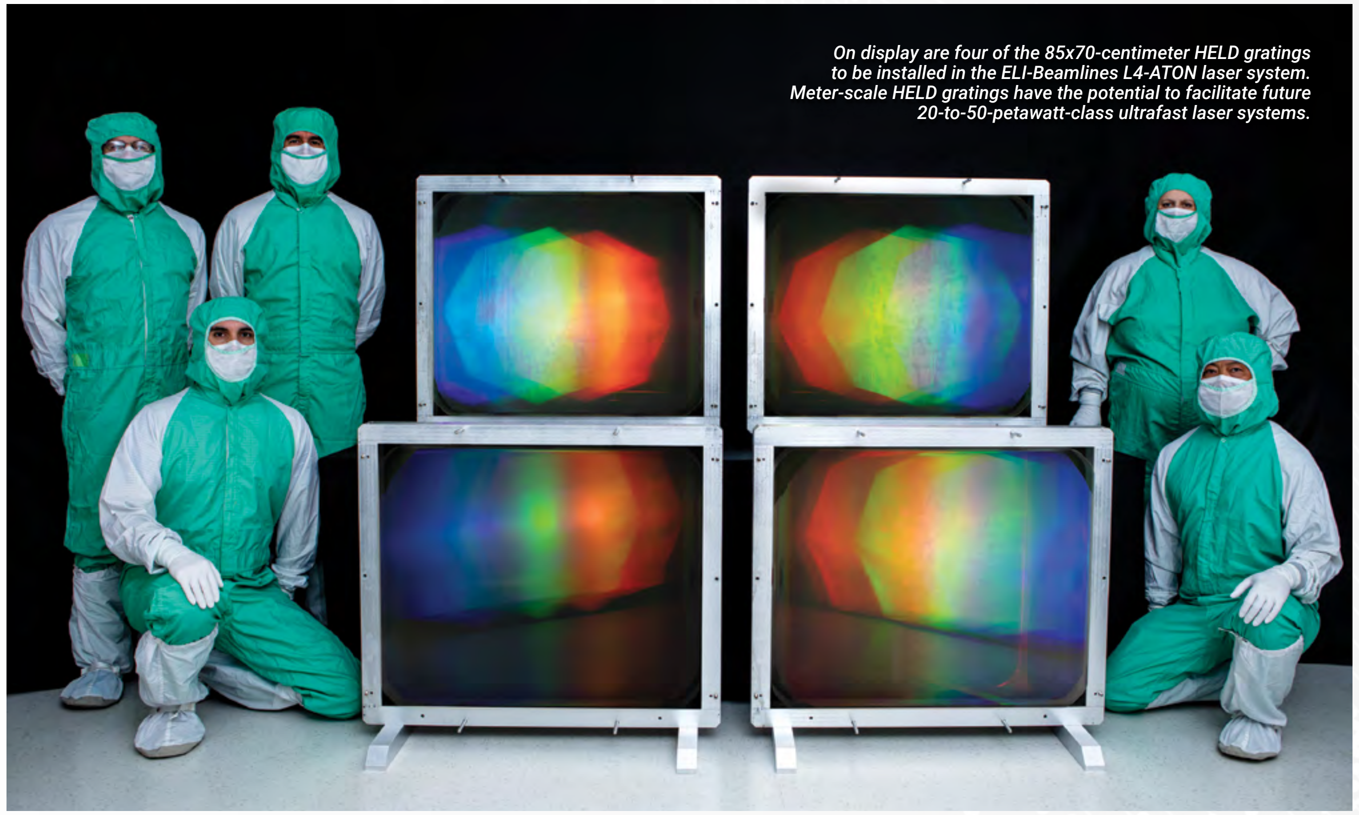
Using the Frontier exascale supercomputer at Oak Ridge National Laboratory, an LLNL team will apply the MuMMI computing framework and artificial intelligence to predict how RAS and RAF proteins interact with each other and with lipids on a realistic cell membrane. The ADMIRRAL (AI-Driven Multiscale Investigation of RAS–RAF Activation Lifecycle) project will provide researchers with a better understanding how the proteins mutate and cause tumors to form.

Researchers from LLNL and University of California (UC) at San Francisco used a logistical regression approach to examine a data set containing nearly a half-million patients who underwent COVID-19 testing at all 17 UC-affiliated hospitals. The data set included nearly 50,000 patients with cancer—more than 17,000 of whom also had tested positive for COVID—and contained information on patient demographics, comorbidities, lab work, cancer types, and various cancer therapies. They found that patients with cancers called myeloproliferative neoplasms and those who had been treated with two medications—venetoclax (to treat leukemia) and methotrexate (an immune suppressant used in chemotherapy)—were more likely to be hospitalized after contracting COVID-19.

SOLAR SYSTEM SCIENTIFIC DISCOVERY

Understanding the history of volatile species, such as water, in the Earth–Moon system is a major objective of planetary science. Interestingly, although much of the Earth's surface is covered with water, overall the planet is relatively dry compared to many other objects in the solar system, and the Moon is even drier. A team of LLNL cosmochemists studied lunar highland rock samples and found only limited ingrowth of strontium–87 from the radioactive decay of volatile rubidium–87. They concluded that the bodies that collided to form the Earth–Moon system had very low levels of volatile species prior to impact. Earth's relatively small proportion of water is then either primarily indigenous or was added by later impacting sources composed of essentially no volatile elements. The study also revealed that the event known as the "Giant Impact" could not have happened prior to 4.45 billion years ago, greatly reducing the time window of the Moon's formation. Both bodies must have come from the inner solar system. In another study of isotopic variations in terrestrial and meteoritic samples, LLNL scientists and collaborators concluded that Earth and Mars formed by collisions of planetary embryos originating from the inner solar system—rather than materials drifting in from the outer solar system.

LLNL and NASA's Goddard Space Flight Center are co-leading Pandora, a small satellite mission to analyze starlight as it passes through the atmosphere of exoplanets. Using a technique called transit spectroscopy, researchers will study about 20 stars with exoplanets and determine atmospheric compositions by observing visible and infrared light as a planet transits in front of its host stars. The challenge is to disentangle the data and determine which variations are due to the exoplanet's atmosphere and which are due to starspots and other stellar phenomena. The Pandora mission, expected to launch in 2024 or early 2025, is part of NASA's Astrophysics Pioneers program.


On display are four of the 85x70-centimeter HELD gratings to be installed in the ELI-Beamlines L4-ATON laser system. Meter-scale HELD gratings have the potential to facilitate future 20-to-50-petawatt-class ultrafast laser systems.

ENGINEERED MATERIALS

LLNL materials scientists are applying additive manufacturing (AM) to make engineered materials with amazing properties. Working with UC Berkeley colleagues, they produced sturdy, complex microstructured glass objects by applying an extension of the team's breakthrough volumetric AM process. Laser light, rather than light-emitting diodes, is used to illuminate a rotating target made of special resin. The intense light produces a 3D object in seconds with a surface smoothness measured in nanometers. The absence of flaws makes the object much less likely to break. Another research team developed a process to transform fully dense, 3D-printed polymeric beams into graphitic carbon hollow tube-in-tube sandwich structures, where, similar to grass stems, the inner and outer tubes are connected through a network of struts. The resulting structure has high stiffness (nearly proportional to density), large surface area, and large deformation recovery. Porous ultralow-density materials have many emerging applications. LLNL scientists also made award-winning advances in direct ink writing (p. 19).

In addition, Laboratory AM researchers pursue research on 4D engineered materials—architected structures that can morph into a particular shape and exhibit new properties when exposed to heat, magnetic or electrical forces, chemical or electrochemical reactions, and mechanical deformations. Examples include shape memory polymers and sentient mechanical logic gates. Potential applications include implantable medical devices, as vehicles for drug delivery, or in autonomous robots.


A polymer engineer studies the curing of nanocomposite silica glass resin subjected to light exposure.

CANCER THERAPIES

LLNL scientists are pursuing wide-ranging efforts to improve cancer treatment, such as studying the biology of tumors to devise more targeted therapies and developing new approaches to study, capture, and purify more effective medical isotopes. Researchers are also investigating a revolutionary technology for cancer treatment and a paradigm shift for predictive oncology. A new radiation treatment concept, called FLASH radiotherapy (FLASH-RT), could be used to deliver a precisely targeted, ultrashort, high dose of therapy radiation that selectively kills cancer cells while minimizing damage to healthy cells. FLASH-RT is based on linear induction accelerator technology developed as part of the Laboratory's Stockpile Stewardship Program. By precisely controlling the magnets in four beamlets placed symmetrically around a patient, a steerable FLASH-RT beam would deliver a nearly instantaneous high dose, which would reduce the patient's time under radiation.

A grand challenge in cancer therapy is to develop "digital twins"—virtual representations of cancer patients using real-time data. A multi-institutional team, including an LLNL contributor, has proposed a framework for Cancer Patient Digital Twin (CPDT) models. Researchers aim to create a multiscale and multimodal data set from individual patients, as well as clinical trials and population studies. These data will be used to train mechanistic and artificial intelligence models for making treatment predictions and advising individualized health care decisions for cancer patients. CPDTs would also provide policymakers with insights into which cancer therapies show most promise, informing investment and resource allocation decisions. However, there are significant hurdles to overcome before such a model becomes a reality.

LLNL Director Kimberley Budil and dignitaries from UC, NNSA and the Livermore Field Office, the City of Livermore, and the Livermore Lab Foundation dedicated the UC Livermore Collaboration Center with a ceremonial ribbon cutting.

PARTNERSHIPS

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

LLNL engages in wide-ranging partnerships with sister laboratories and research institutions, academia, and industry. Many collaborations integrate disparate expertise and capabilities with focus on innovations to meet challenging mission objectives. Others serve to transition science and technology (S&T) breakthroughs into new applications and products.

EXPANDING UNIVERSITY PARTNERSHIPS

Academic collaborations began with the Laboratory's founding as part of the University of California. Ties to the many UC campuses will be further strengthened with the formal opening in FY 2022 of the new University of California Livermore Collaboration Center (UCLCC). The center occupies the newly renovated Hertz Hall complex, which had been established as a branch of the UC Davis Department of Applied Science. UCLCC will serve as a UC multi-campus hub to expand collaborations and partnerships with the Lawrence Livermore, Lawrence Berkeley, and Los Alamos national laboratories. The three buildings in the UCLCC complex include eight general offices, a general lab, a small conference room, and a variety of classrooms that can easily be reconfigured for various uses.

These UC ties and other university collaborations play a vital role in keeping LLNL at the leading edge of innovation in support of its national security mission. The Laboratory's Academic Engagement Office, formerly called University Relations, fosters collaborations and sustains long-term partnerships between LLNL researchers and the academic community, helping to ensure a pipeline of new ideas and people. For example, after three years of growing institution collaboration, the leaders of Case Western Reserve University and LLNL signed a memorandum of understanding in FY 2022 to accelerate their efforts in such areas as energy, materials science, and polymer processing.

THE NEXO EXPERIMENT

LLNL leads for the DOE Office of Science the nEXO project to search for a rare type of nuclear decay called neutrinoless double beta decay (NDBD). It is a large collaborative effort, engaging approximately 200 scientists and technologists from 36 institutions and eight countries, including five DOE national laboratories and more than a dozen U.S. universities. NDBD has not yet been observed and cannot occur according to the known laws of physics because the decay process generates matter without creating antimatter. Detection would be a major discovery and provide key insight into the formation of the universe. nEXO will search for NDBD with a large detector isolated from cosmic rays by being built at a depth of two kilometers in SNOLAB, Canada's deep underground research laboratory, located in a mine in Ontario, Canada. Late in 2022, DOE allocated to LLNL $2.35 million to support nEXO with funding from the Inflation Reduction Act, which aims in part to provide DOE national laboratories with resources to keep the U.S. at the forefront of scientific discovery. The funding will advance nEXO toward the formal definition phase of DOE project development (CD-1).

EXPANDING PARTNERSHIPS IN AI AND LASER S&T

In December 2021, LLNL established an Artificial Intelligence Innovation Incubator (AI3) as a collaborative hub for uniting experts from the Laboratory, industry, and academia to advance AI and machine learning for large-scale scientific and commercial applications. The incubator provides a place where experts with diverse backgrounds and approaches can come together, nurture ideas, and grow projects that push the frontiers of what is possible. As highlighted throughout this *Annual Report*, AI is a "tool of the future" that is already providing breakthrough advances in many mission areas at the Laboratory.

LLNL will be designing and constructing one of the world's most powerful petawatt (quadrillion-watt) lasers for installation of an upgrade to the Matter in Extreme Conditions experimental facility at SLAC National Accelerator Laboratory's Linac Coherent Light Source. The new facility will provide unprecedented high-throughput capability for high-energy-density scientific discovery and national security research. The new laser will advance technologies present in the High-Repetition-Rate Advanced Petawatt Laser System (HAPLS) that Livermore developed for the European Union's Extreme Light Infrastructure Beamlines facility. In FY 2022, agreement was reached for LLNL to upgrade L3-HAPLS performance from 0.5 petawatt peak power to 1 petawatt and triple the repetition rate to 10 Hertz.

A Laboratory materials scientist 3D prints with Energy Ink, a R&D 100 award–winning technology, to create graphene aerogel electrodes that are used in supercapacitors.

INNOVATIVE INDUSTRIAL PARTNERSHIPS

LLNL is benefiting the U.S. economy with innovative technology and methods. In FY 2022, Livermore obtained 109 new patents, asserted 143 new copyrights, and executed 191 new licenses. Licensing income for the year totaled approximately $5.4 million. Among honors, LLNL earned three R&D 100 awards from *R&D World Magazine*. Laboratory laser researchers received an award for high-energy low-dispersion (HELD) diffractive gratings that facilitate future development of ultrahigh-power, ultrafast laser systems (p. 16). Two R&D 100 awards pertain to advances in additive manufacturing: the first for "Tailored Glass Using Direct Ink Writing Technology" and the second for "Energy Inks" that not only enable 3D printing of battery and supercapacitor components but optimize their functional properties. In addition, LLNL and ArcelorMittal, a steel and mining company, received DOE High Performance Computing for Manufacturing program funding to apply to computer vision and machine learning to reduce defects and carbon emissions in steelmaking.

Researchers work at the Matter in Extreme Conditions facility at SLAC, which will be upgraded with an LLNL-designed and built petawatt laser. Credit: Matt Beardsley/SLAC

CENTER FOR GLOBAL SECURITY RESEARCH WORKSHOPS

The Laboratory's Center for Global Security Research (CGSR) partners with the community of national security experts to examine emerging national security challenges in the areas of deterrence, assurance, and strategic stability, as well as global challenges ranging from climate change to biosecurity. The center holds seminars with outside speakers, convenes timely workshops on key security issues, and shares study results through widely distributed publications. In FY 2022, CGSR held 10 workshops on topics ranging from the future of deterrence and multi-domain strategic stability to strategy and statecraft in cybersecurity.

SAFE, SECURE, AND SUSTAINABLE OPERATIONS

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

In response to the COVID-19 pandemic, LLNL Health Services Department administered more than 2,300 vaccines and boosters in FY 2022.

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 and continually improve operations.

RETURN TO NEW NORMAL

At the start of FY 2022, the Laboratory began a deliberate process to "Return to New Normal" (RTNN). The new normal represents an exciting way for LLNL to deliver on its national security mission while providing an enhanced level of flexibility to meet the work–life balance needs of the workforce. It builds on the Laboratory's successful mission delivery and the lessons learned in providing efficient, effective operations since the onset of the COVID-19 pandemic. This hybrid work environment accommodates telecommuting—consistent with employees' work responsibilities. Employees partner with their supervisors, project leaders, and group leaders to develop a telework agreement for approval. These agreements are periodically reviewed to ensure that the arrangements are working well.

RTNN persevered through the Delta and Omicron phases of the COVID-19 pandemic. The Health Services Department (HSD) performed outstandingly in its response to the evolving COVID-19 requirements and automated numerous aspects of the COVID-19 workflow. LLNL's clinic responded to 23 percent more COVID-19 hotline emails and calls than in FY 2021. HSD administered almost double the onsite tests (nearly 5,900) compared to the previous year and provided more than 4,300 at-home tests to employees as part of an assurance testing program. HSD also administered more than 2,300 COVID-19 vaccinations and boosters in FY 2022. The Laboratory lifted its masking requirement for all indoor spaces in March 2022 and continues to operate in accordance with local conditions.

Specialists in LLNL's Project Management Office oversee hundreds of construction projects ongoing at the Laboratory.

WORKER SAFETY AND HEALTH

As exemplified by the Laboratory's actions in response to the COVID-19 pandemic, employee safety and health are paramount. A comparable level of attention to safety applies to all workers on site. The LLNL Project Management Office celebrated 1 million safe hours of work on construction projects between August 2020 and October 2022. The safe hours span nearly 200 projects that included almost 40 general contractors and typically 200 to 300 workers on site daily. Within LLNL, the Worker Safety and Health (WS&H) program assigns integrated safety teams to work in partnership with directorates to help them meet mission deliverables while ensuring employees' safety and ES&H regulatory compliance. For example, WS&H's Biosafety Office supported operations that resulted in zero spills, animal bites, exposures, or physical inventory discrepancies throughout FY 2022. The office also manages biological materials permits for programs.

ENVIRONMENTAL MANAGEMENT

LLNL strives to maintain a safe, secure, and efficient operational environment for its employees and neighboring communities. The *2021 Site Annual Environmental Report* (issued in October 2022) documents compliance with environmental standards and monitoring results. This year, with support from LLNL subject matter experts, NNSA prepared a draft Site-Wide Environmental Impact Statement (SWEIS) for Continued Operation of Lawrence Livermore National Laboratory. The draft SWEIS analyzes the potential environmental impacts of ongoing operations and proposed projects and activities at both the Laboratory's main site and Site 300 for approximately the next 15 years. Among the many activities carried out in FY 2022, LLNL environmental specialists completed field inspections to verify compliance, improve the risk posture related to greenhouse gases (GHG), and help to set up strategic infrastructure initiatives to reduce GHG releases.

ATTENDING TO INFRASTRUCTURE NEEDS

Modern infrastructure is important to attracting and retaining LLNL's world-class staff and continuing mission success. In addition to aggressive ongoing and recently completed new construction (p. 23), the Laboratory is demolishing outdated facilities, refurbishing facilities where cost effective, and attending to a maintenance backlog. In FY 2022, demolition of Building 175, which supported LLNL's former Uranium Atomic Vapor Laser Isotope Separation Program, was completed and the pool-type reactor in Building 280 was safely removed to prepare for facility demolition. Both projects were challenging due to the facilities' level of contamination and are important to providing buildable space for new improved structures within LLNL's one-square-mile area.

To cost-effectively reduce the maintenance backlog, the Laboratory is developing improved management tools to prioritize work. Moreover, LLNL is providing leadership within NNSA in developing and applying data-intensive "science-based" tools to enhance infrastructure management. Assessment of risks based on current and predicted future condition, together with prioritization and timely scheduling of investments, enables more cost-effective modernization of NNSA's aging infrastructure.

SUPPORT OF NUCLEAR CRITICALITY SAFETY

Nuclear criticality safety staff provided outstanding operational support at LLNL's Superblock and the Radioactive and Hazardous Waste Material facility. They also engaged in activities at the Nevada National Nuclear Security Site, such as performing criticality safety evaluations for Nimble and other upcoming subcritical experiments (p. 7). In FY 2022, nuclear criticality safety personnel were called upon as expert instructors to teach two hands-on training courses to qualify as a nuclear criticality safety engineer at DOE sites. Division personnel were also invited to be guest lecturers at the Nuclear Data Summer School held at UC Davis, as part of the Nuclear Science and Security Consortium, a university–national laboratories collaboration funded by DOE.

SUPPLY CHAIN MANAGEMENT

In FY 2022, LLNL's purchasing system successfully completed a Procurement Evaluation and Re-engineering Team (PERT) review, which is conducted by DOE every six years. Livermore was recognized for employing procurement best practices. In support of mission delivery, the Laboratory crossed the $1 billion threshold in annual procurements—including custom laser diodes, field effect transistors, components for high-performance computers, construction of new office and laboratory buildings, fire department services, and furniture services. Those expenditures included $420 million to small businesses, which had a beneficial impact on the local community.

MANAGING FOR THE FUTURE

FY 2022 was a year of building for future mission successes through new initiatives, attention to workforce needs, and expanding partnerships.

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

STRATEGIC LEADERSHIP

Under the leadership of Laboratory Director Kimberly Budil, LLNL is providing NNSA with technical leadership in many facets of its national security mission and efforts to modernize the NNSA complex. Livermore is engaged in two nuclear warhead development programs (p. 6) and is working with other NNSA sites to develop technologies and procedures that will accelerate the weapon design-to-production process. These efforts are benefiting from major advances in high-performance computing and machine learning, additive manufacturing, and experimental capabilities to certify weapons performance and advance fusion research. LLNL was also strongly engaged in NNSA's strategic planning efforts in FY 2022, fully supporting NNSA's strategic vision to innovate, collaborate, and deliver.

In planning activities, LLNL's senior management team (SMT) developed aspirational goals and objectives in Mission and Programs, Workforce, Operations, and Science and Technology. Special attention is directed at four mission focus areas: Stockpile and Enterprise Transformation, Integrated Deterrence and Technology Competition, Climate Impacts and Resilience, and Bio Resilience. As a complementary planning activity, the GuideStar study team, comprised of 19 mid-career Laboratory leaders, deliberated about the challenges LLNL will face over the next 25 years. These planning efforts reinforced the importance of attracting and retaining a talented workforce to meet national security priorities and sustain LLNL's tradition of innovation and scientific excellence.

DIRECTOR'S OFFICE CHANGES

In September 2022, Carolyn Zerkle joined the Laboratory as LLNL Deputy Director and Vice President of Lawrence Livermore National Security, LLC (LLNS). As deputy director, Zerkle participates in the day-to-day management of LLNL—providing executive-level guidance and direction within the SMT and interfacing with the NNSA Livermore Field Office, the LLNS Board of Governors, and the Laboratory's many partners. She brings a wealth of career experience managing major construction projects and operations at Los Alamos National Laboratory. Departing deputy director Linda Bauer provided outstanding service to the Laboratory in her nearly three years of service. She worked closely with Director Budil to implement the ever-evolving protocols necessary to carry out research and operations in the hybrid workplace that resulted from the COVID-19 pandemic.

Other Director's Office changes include a new acting Chief of Staff and the creation of three new positions: a Senior Director, Strategic Communications; a Senior Director, Office of Government and External Affairs; and a Director for Strategy and Planning.

LLNL Director Kimberly Budil and NNSA Administrator Jill Hruby listen as U.S. Secretary of Energy Jennifer M. Granholm speaks at the DOE press conference announcing fusion ignition.

Carolyn Zerkle joined the Laboratory as Deputy Director in September 2022.

SUPPORTING A CHANGING WORKFORCE

An outstanding workforce is Livermore's principal strength. Recruiting, training, and retaining exceptional talent is a top priority at a time of rapid change in our workforce. Management attention to engaging Laboratory employees contributed to LLNL receiving a Glassdoor Employee's Choice Award for the fourth straight year. Many initiatives are under way, with some early successes in improving employee benefits. A Future of Work Task Force is looking at redefining LLNL's workplace to optimize mission success and the employee experience. In addition, a performance management team is redesigning the performance management process to provide a clear pathway for contribution and growth that helps employees understand the value of their work and enhances mission delivery. A compensation task force is working closely with NNSA to better align the compensation system with current practices to enhance recruiting and retention. Future plans include revisiting job structures and implementing the Future of Work Task Force recommendations.

COMPLETION OF MAJOR INFRASTRUCTURE PROJECTS

In June 2022, DOE Under Secretary for Nuclear Security and NNSA Administrator Jill Hruby and other dignitaries came to the Laboratory to dedicate the completion of two important construction projects: the $100-million Exascale Computing Facility Modernization (ECFM) project and the 20,550-square-foot Emergency Operations Center (EOC). Both projects were completed ahead of schedule and under budget. ECFM provides the infrastructure needed to support El Capitan (p. 7) and its successor later in the decade. The upgrade can supply up to 85 megawatts—enough for about 75,000 modest-sized houses—to power LLNL's supercomputers and triple the amount of cooling.

The EOC consolidates the Laboratory's emergency response functions and provides 24/7 operations. Transitioning emergency response capabilities, which involved hundreds of tasks, was completed successfully with no major operability issues. An NNSA NA-50 pilot project, EOC construction successfully demonstrated the streamlining of commercial-like Line-Item projects in the $20–$50 million cost range. Many significant construction projects now in progress—including new facilities to support stockpile modernization—will further contribute to the Laboratory's ability to carry out its important national security missions.

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 2022 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 Laboratory research. The Board chartered functional management reviews (FMRs) on an as-needed basis. Eight FMRs were completed in FY 2022 in topical areas including Records Digitization, Packaging and Transportation, Water Needs, Work Planning and Control, and Industrial Gas. Recommendations provided by Board committees, ERCs, and FMRs have led to substantive responsive actions.

Members of the Laboratory's Exascale Computing Facility Modernization team, which kept construction on schedule and finished under budget, are pictured atop the new cooling towers.

COMMUNITY CONNECTIONS

Partnering with our neighbors through science education and charitable giving

Children gather around Livermorium Plaza's focal point and rotate the floating-on-a-fountain-of-water, five-foot-diameter granite sphere that represents the nucleus of a livermorium atom.

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. This year LLNL staff and LLNS donated more than $3.6 million to local nonprofits, while hundreds of employees donated their time to local service agencies. In FY 2022, more events and programs were held in-person as COVID restrictions were lifted.

CITY CONNECTIONS

In June 2022, representatives from the City of Livermore, NNSA, and LLNL joined other community members to dedicate Livermorium Plaza in downtown Livermore. The park honors the Laboratory's contributions to the discovery of element 116—livermorium—and boasts a five-foot-diameter, 18,000-pound floating granite sphere fountain that represents the atom's nucleus. The sphere is inscribed with facts about the element's discovery. Signs within the plaza provide additional scientific information for visitors.

The Laboratory also collaborated with the City of Livermore to advance local climate actions and build community-wide resilience to climate change impacts.

REACHING TEACHERS AND STUDENTS

LLNL debuted an all-new Virtual Tour Map, providing an interactive experience for visitors to learn about the Laboratory and its missions by navigating the site online. In addition, nearly 400 high-school students attended virtual 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 NIF scientist took the Laser Road Show to fifth-grade classes in the Livermore Valley Joint Unified School District (LVJUSD), engaging nearly 900 students in demonstrations and hands-on activities about special properties of light.

Hands-on projects offer a learning experience about the Laboratory's research and provides SAGE program participants opportunities to gain technical skills.

THE LABORATORY GOES TO SCHOOL

Throughout FY 2022, LLNL worked directly with Livermore-area schools to continue promoting science education and technical skills for students. The Laboratory hosts the Girls Who Code program, an after-school coding program for LVJUSD's middle- and high-school students. New in 2022, the Laboratory expanded the program to include nearly 100 students from the Tracy Unified School District. MathCounts continues to draw Livermore middle-school students to help improve their math and problem-solving skills. In February 2022, the Science on Saturdays' virtual series theme was "Energy and the Environment." Accomplished LLNL scientists and researchers spoke to more than 500 middle- and high-school students about the Laboratory's efforts in energy research and climate change.

A SUMMER OF SCIENCE

During the summer, the Laboratory provided exciting opportunities for budding scientists to learn more about STEM disciplines and contribute to ongoing research projects. More than 800 college undergraduate and graduate students completed LLNL summer internships through virtual interactions with mentors and various web-based learning activities. In July, nearly a dozen middle-school students were introduced to robotics during the 8th Grade Tech Workshop and given programming instruction in Python and Blockly. The Biotech Summer Experience in July brought 22 local high-school students together for two weeks of immersion in biotechnology and bioinformatics. Students took a deep dive into the DNA of duckweed, a promising potential source of biofuel.

Science Accelerating Girls Engagement (SAGE) in STEM was a new program for summer 2022. LLNL hosted 20 girls for a weeklong camp to learn about the science and technology research and careers at LLNL and in the national laboratory system. The Laboratory continued to offer the Teacher Research Academy (TRA) program virtually, hosting six workshops for middle- and high-school teachers and adding a new Climate Science TRA to the offerings.

DATA SCIENCE EVENTS AND CHALLENGES

The Laboratory's fifth Women in Data Science (WiDS) regional event took place in March, in conjunction with the worldwide event at Stanford University. The program for this one-day virtual conference included a livestream of the Stanford conference as well as workshops, mentoring sessions, and networking opportunities. This year's Livermore event was kicked off by a fireside chat with Kimberly Budil, LLNL's first woman director. The Laboratory's event was one of more than 200 WiDS events organized in 60-plus countries held in conjunction with a conference featuring prominent women data scientists from around the world.

Students from UC Merced worked with LLNL mentors to identify drug compounds that could be used to treat COVID-19 during a two-week Data Science Challenge. Two dozen students, including recent graduates, undergraduates, and Ph.D. candidates in computer science, engineering, mathematics, and biology, formed into teams led by the doctoral students. Each team worked with a Laboratory computer scientist on real-world drug discovery problems, using machine learning and other advanced tools to find small molecule inhibitors of SARS-Cov-2, the virus that causes COVID-19.

HOME CAMPAIGN AND COMMUNITY GIFTS

Laboratory employees and LLNS raised more than $3.6 million in the 2022 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 2022 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, and focus on literacy, STEM education, and cultural arts. Other recipients focus their charitable efforts toward children, families, senior citizens, and individuals in need of assistance.

WORKFORCE RECOGNITION

Acknowledging exceptional performance, service, and expertise

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.

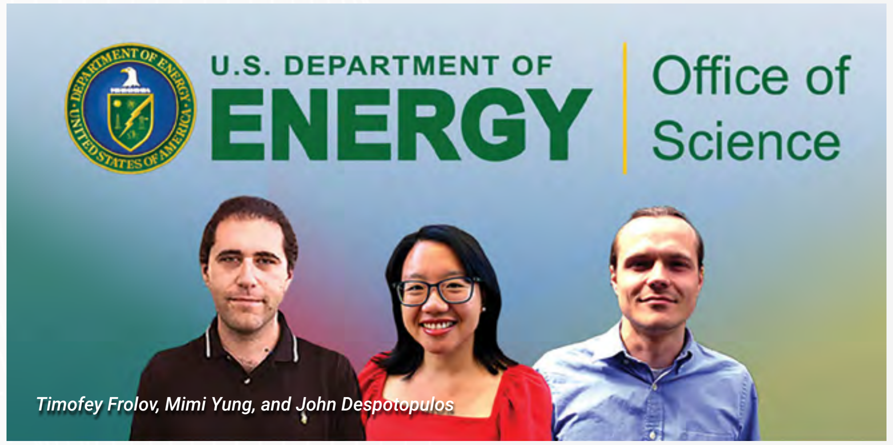
DOE AND NNSA AWARDS

Two scientists are recipients of the prestigious 2021 E.O. Lawrence Award that recognizes mid-career U.S. scientists and engineers for exceptional scientific, technical, and engineering achievements related to the broad missions of DOE and its programs. **Jennifer Pett-Ridge** was recognized for her research in biological and environmental sciences for pioneering work in quantitative microbial ecology and leadership in developing and applying isotopic tools to discover and

Sofia Quaglioni and Jennifer Pett-Ridge

quantify how the changing climate shapes the roles of microorganisms and plants in environmental biogeochemical cycles. **Sofia Quaglioni** was cited for her work in nuclear physics, specifically for seminal contributions unifying the theory of structure and reactions of light nuclei, providing predictive capability critical for understanding inertial fusion and nuclear astrophysics, as well as pioneering applications of quantum device simulations for nuclear dynamics.

Three scientists are recipients of the DOE Office of Science Early Career



Timofey Frolov, Mimi Yung, and John Despotopulos

Research Program award. **Mimi Yung**, **John Despotopulos**, and **Timofey Frolov**, are among 83 awardees receiving the recognition. Typical awards for DOE national laboratory staff are $500,000 per year in research support for five years.

DOE Project Leadership Institute (PLI) selected **Lara Leininger** and **Al Churby** as 2022 cohort participants. Members of the PLI cohort have demonstrated their expertise as technical, business systems, or project leaders, with significant experience and responsibility for project or organization performance and resources.

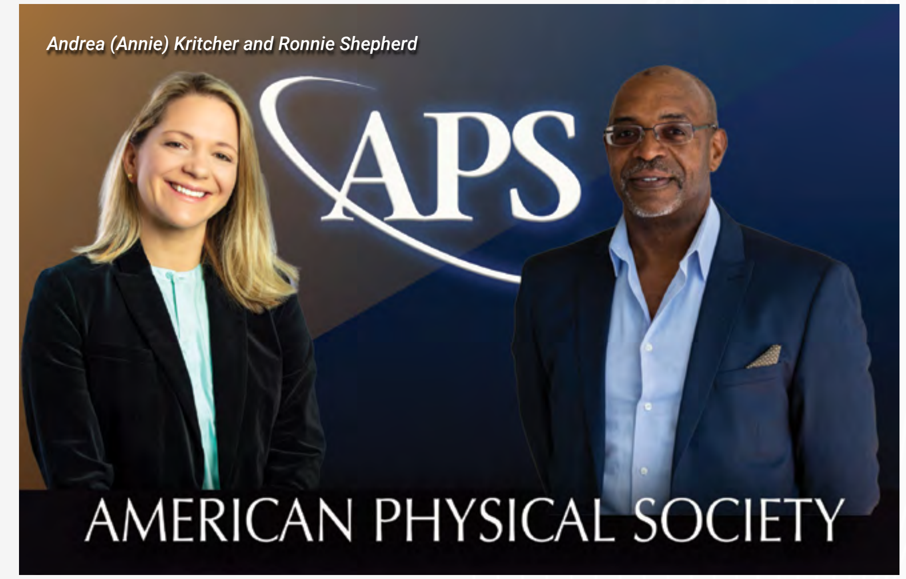
Nine project teams and one individual were recognized with **NNSA Defense Programs Awards of Excellence** for significant achievements in quality, productivity, cost savings, safety, or creativity in support of NNSA's nuclear weapons program.

Computer scientist **Kathryn Mohror** and materials scientist **T. Yong Han** are among 33 individuals from all 17 DOE national laboratories selected as 2022 fellows by the Oppenheimer Science and Energy Leadership Program (OSELP). Established in 2017, OSELP is a distinguished fellowship program that brings together exceptional leaders to explore the complexities, challenges, and opportunities facing the national laboratory system and DOE.

LLNL and NNSA officials presented members of the **Expand Electrical Distribution System (EEDS) project team** with the Secretary of Energy's Achievement Award for Project Management. Among the highest honors a DOE employee or contractor can receive, the award recognized the 50-plus-member EEDS team for finishing the massive electrical system upgrade at LLNL four months ahead of schedule and more than $1 million under budget.

PROFESSIONAL SOCIETY FELLOWS

Physicists **Andrea (Annie) Kritcher** and **Ronnie Shepherd** were selected by the American Physical Society (APS) Division of Plasma Physics as fellows. Annie Kritcher was chosen for leadership in hohlraum design physics leading to the creation of the first laboratory burning and igniting fusion plasma. Ronnie Shepherd was selected for contributions



Andrea (Annie) Kritcher and Ronnie Shepherd

to understanding dense energetic plasmas through experiments at short-pulse lasers and for the development of time-resolved diagnostics for the measurements.

The American Society for Precision Engineering has announced Laboratory research engineer **Robert Panas** as the organization's new president-elect.

Christopher Stolz has been elected as a fellow of SPIE, the international society for optics and photonics.

Richard Klein has been selected as a 2022 fellow of the American Astronomical Society for scientific achievements on radiatively driven stellar winds and star formation theory.

SCIENCE AND TECHNOLOGY AWARDS

The Fusion Energy Division of the American Nuclear Society presented the 2021 Edward Teller award to **Omar Hurricane** for his "visionary scientific insights and leadership of National Ignition Facility experiments resulting in the achievement of fuel gain, an alpha-heating-dominated plasma, and a burning plasma."

The Fusion Power Associates (FPA) Board of Directors has selected physicist **Debbie Callahan** as a recipient of its 2022 Leadership Award. The FPA Board recognized her decades of leadership and outstanding contributions to the design of hohlraum targets for implosion experiments at NIF and to the mentoring of younger scientists.

The Society for Industrial and Applied Mathematics (SIAM) announced computational mathematician **Rob Falgout** as the recipient of the 2022 SIAM Activity Group on Supercomputing Career Prize for his broad and distinguished contributions to the field of algorithms research and development for parallel scientific and engineering computing.

A suite developed by a Laboratory team to simplify evaluation of approximation techniques for scientific applications has won the first-ever Best Reproducibility Advancement Award at the 2021 International Conference for High Performance Computing, Networking, Storage, and Analysis (SC21). Recognized were scientists **Konstantinos Parasyris**, **Giorgis Georgakoudis**, **Harshitha Menon**, **James Diffenderfer**, **Ignacio Laguna**, **Daniel Osei-Kuffuor**, and **Markus Schordan**.

SPECIAL HONORS

The principal associate director for Global Security, **Huban Gowadia**, was inducted into the state of Alabama's Engineering Hall of Fame.

The University of California President's 2022 Lindau Nobel Laureate Meetings Fellows Program selected three postdoctoral appointees, **Magi Mettry**, **Johanna Schwartz**, and **Dane Sterbentz**, to attend the 71^{st} annual Lindau Nobel Laureate meeting in Germany. The Lindau Nobel Laureate meeting is an international scientific forum that provides a unique opportunity for about 600 students and postdocs from around the world to meet with 30 to 40 Nobel laureates.

Brooke Buddemeier has been named to the National Council on Radiation Protection and Measurements' board of directors.

Tony Baylis was honored by the American Indian Science and Engineering Society as the 2021 recipient of their Government Partner Service Award.

Kathy Brown, who volunteers with the Civil Air Patrol, received a certificate of recognition and a ribbon with a silver star for her lifesaving role in rescuing an injured woman..


In September 2022, John S. Foster Jr. celebrated his 100^{th} birthday. Happy Birthday, Johnny!

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

LLNS is a limited liability company managed by Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and Amentum Environment & Energy, Inc. Battelle Memorial Institute also participates in LLNS as a teaming subcontractor. Cutting-edge science is enhanced through the expertise of the University of California and its 10 campuses and LLNS' affiliation with the Texas A&M University system.

The Laboratory's Central Cafeteria (foreground), an office building (left), and the main Livermore Computing facility surround Lake Haussmann.

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SANDIA VP EMERITUS MIRIAM JOHN HONORED WITH FOSTER MEDAL

Members of the national security community honored Miriam "Mim" John as she was presented the John S. Foster Jr. Medal in September 2022. Sandia National Laboratories (SNL) Vice President Emeritus John was recognized for her decades of service, including leadership of SNL's California Division and her expertise in a vast range of national-security related fields, such as nuclear weapons, nonproliferation, and chemical and biological defense. She is the seventh recipient of the Foster Medal.

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NIF and Photon Science

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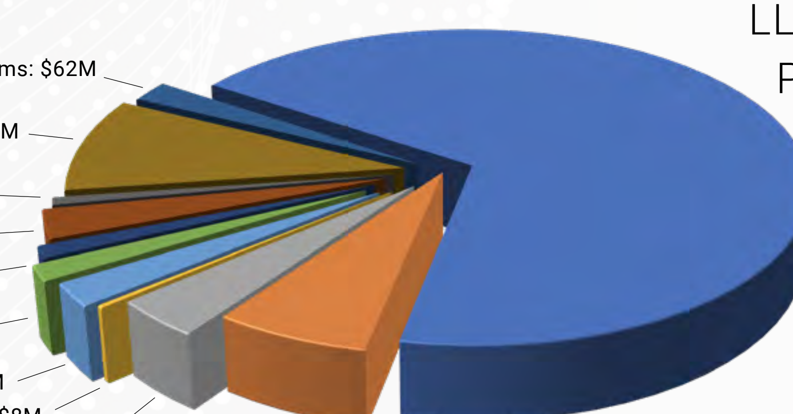
Human Resources
Project Management Office
Security Organization
Environment, Safety, and Health
Infrastructure and Operations
Office of the Chief Financial Officer

LLNL FY 2022 PORTFOLIO: $2.926 BILLION (ACTUAL FUNDS)



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