LAWRENCE LIVERMORE NATIONAL LABORATORY

2022
Technology Transfer Report

INNOVATION IN ACTION

OVERCOMING CHALLENGES

through Resiliency and Rebirth

Since the industrial revolution, American businesses have adapted their operations to weather a range of disruptions. Global upheavals such as two world wars; conflicts in Korea, Vietnam, Iraq, and Afghanistan; and the stock market swings of 1929, 1974, 1987, and 2000 impacted consumer consumption. Health-related outbreaks such as typhoid, polio, HIV, and COVID-19 also left a mark in all business sectors. Positive disruptions impact the way business is conducted too. Advances in technology, the internet, and industry shape the way our nation applies its business acumen.

As we navigate our way through COVID-19, we stand on a new playing field trying to identify ways to execute business plans and determine how or if the pre-COVID rules apply today. The challenges are certainly different than they were three years ago. How we shop, how we interact, and how younger generations view work/life balance are all in flux. How do we adapt to this paradigm shift?

LLNL's Innovation and Partnerships Office (IPO) is not immune to such disruptions. We are asking the same questions and examining how we should conduct business going forward. With change comes renewed focus and opportunities to embrace. We view the present time as an exciting opportunity to re-assess our goals, our culture, our methods, and our tools. We are examining how we travel, how we communicate, how we tell the LLNL technology story, and how we introduce the Lab's cutting-edge technologies to potential industry partners.

Since the mid-1980s, IPO has served as a focal point for LLNL engagement with industry. Whether by technology commercialization, encouraging entrepreneurship, or via Laboratory business development activities, our mission is to help grow the economy by advancing the development and commercialization of LLNL's scientific discoveries. Our experience has revealed two constants. Disruptions are opportunities to be seized, and the introduction of new technologies has and will continue to drive our society, fuel our American economy, and improve our quality of life.

Our mission has not changed, only its execution has . . . and we welcome it.

—Elsie Quaite-Randall
Acting Director, Innovation & Partnerships Office

IPO
INNOVATION & PARTNERSHIPS OFFICE
COMMERCIALIZING LLNL TECHNOLOGY
Industrial Partnerships • HPCIC • Regional & Strategic Partnerships

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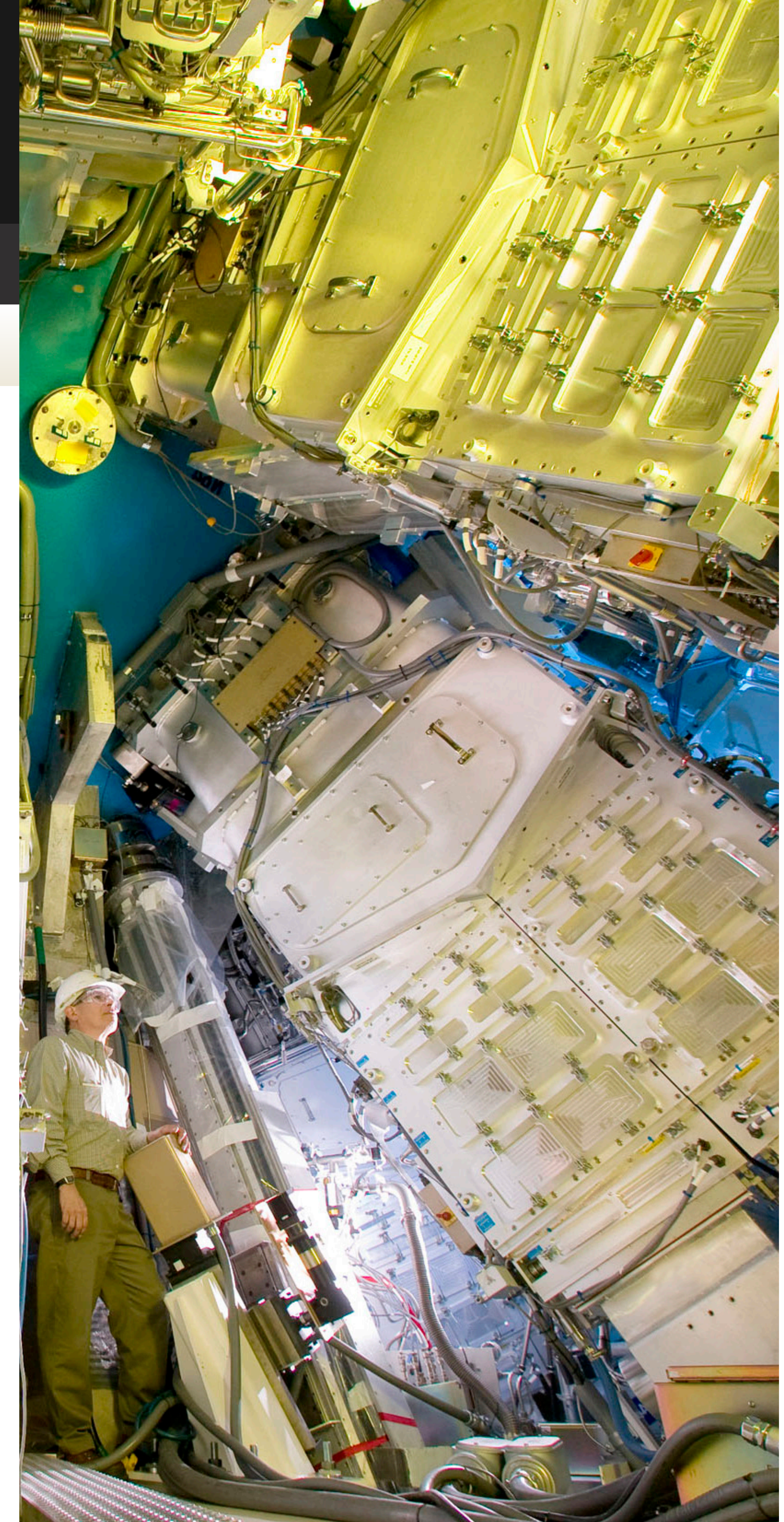

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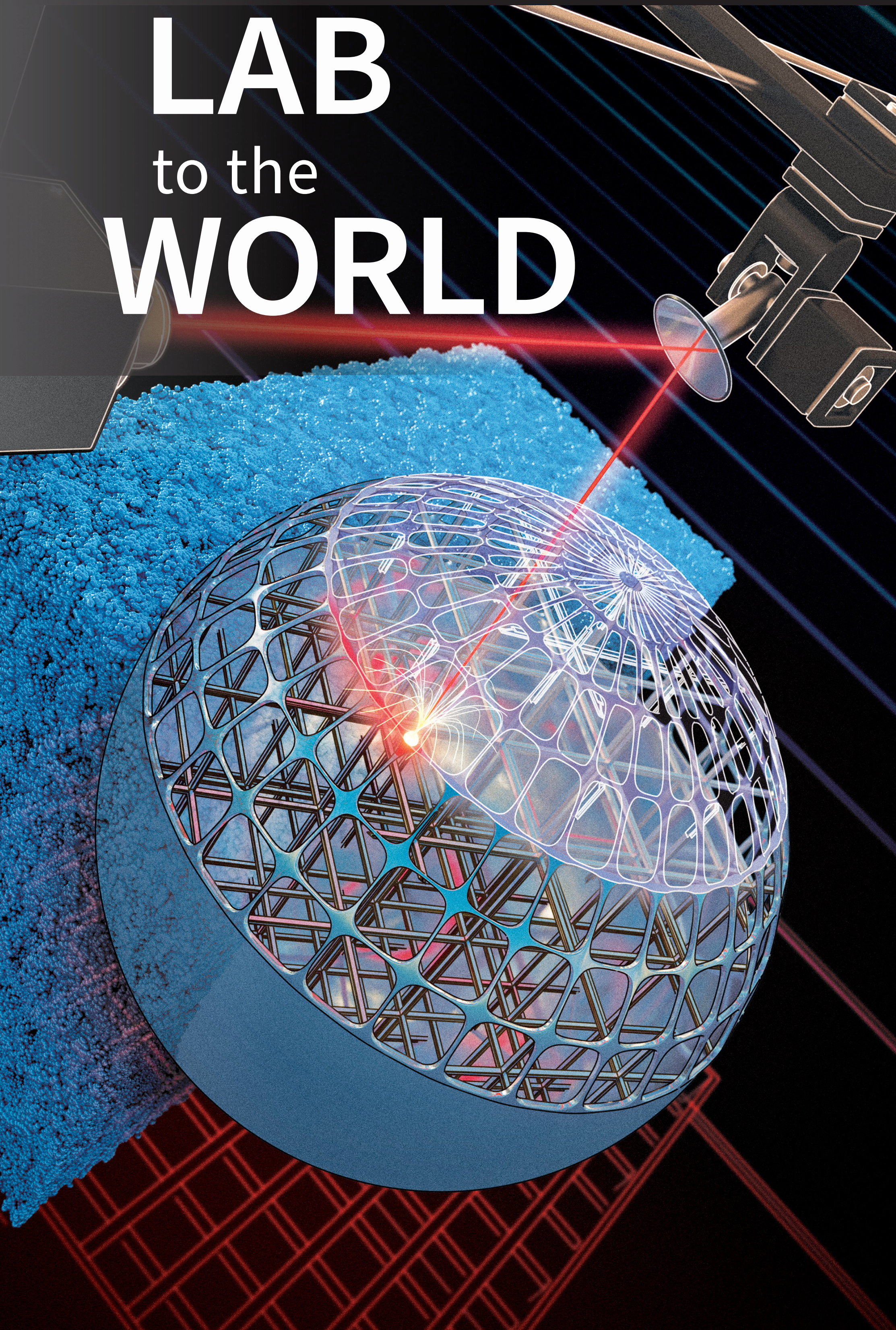
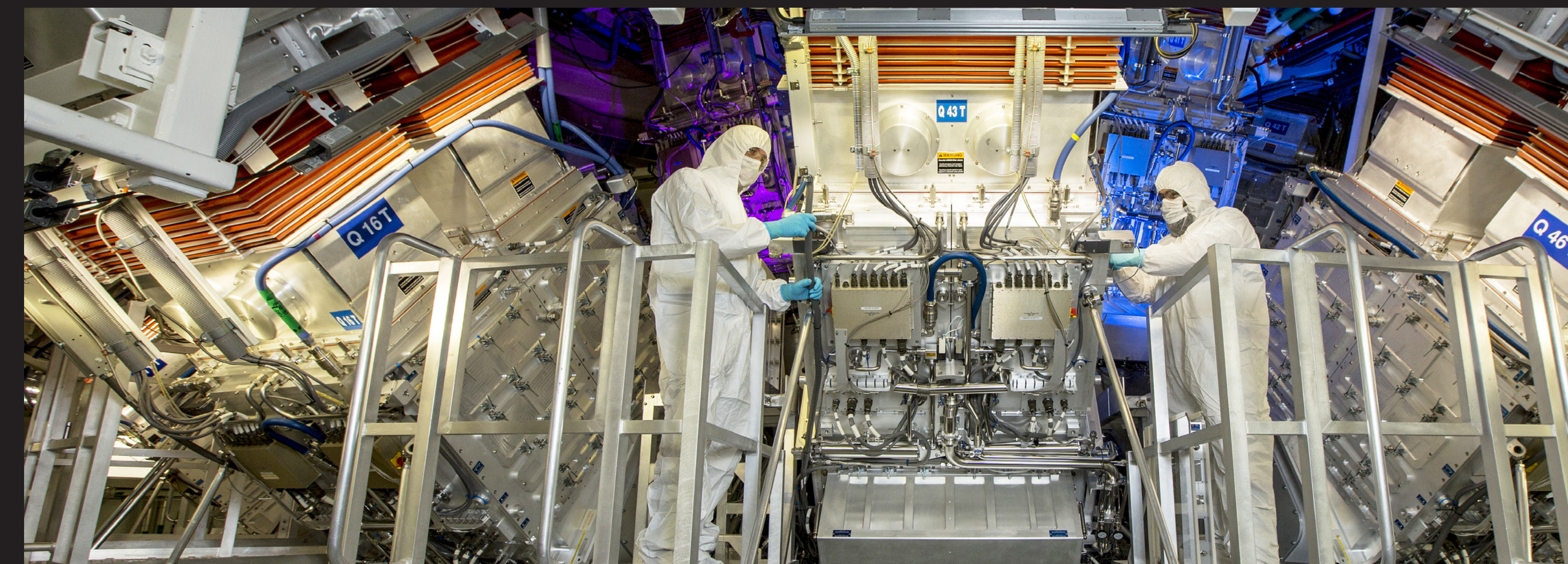


An artistic representation of selective laser melting of a stainless steel cage. Residual stress is an important issue that requires in-depth understanding and careful control during selective laser melting processes. *Image credit: Ryan Chen*

EXECUTIVE SUMMARY



AS THE LABORATORY CELEBRATES ITS **70TH BIRTHDAY,** IT CONTINUES TO LEVERAGE MULTI-DISCIPLINARY EXPERTISE TO ADDRESS NATIONAL SECURITY CHALLENGES.

Lawrence Livermore National Laboratory's Innovation and Partnerships Office (LLNL IPO) transfers LLNL-developed technologies to government and industry to meet national security and societal needs. Many successes highlighted here are in advanced manufacturing; for example, "energy inks" for energy-related products; solvent-free laser powder bed fusion for lithium batteries; and tailored glass by direct ink writing for engineering properties. Also highlighted are high-energy, low-dispersion diffraction gratings to facilitate 100 petawatt-class laser systems; and microencapsulated carbon sorbents to lessen CO_2 in the atmosphere.

Partnerships accelerate innovation. For example, artificial intelligence (AI) experts in the AI Innovation Incubator are advancing commercial applications; LLNL and Amazon Web Services are establishing open-source software components that run at high performance computing (HPC) centers and on cloud resources; and LLNL with University of California Berkeley are creating micro-computed axial lithography to cure 3D objects. Five universities and industry partner Western Rare Earths are joining LLNL to develop a separation and purification process for rare earth metals, and LLNL and ArcelorMittal are coupling computer vision and machine learning with HPC to reduce defects in steel manufacturing. Partnerships are also looking toward space. LLNL and NASA Ames Research Center will integrate a LLNL monolithic optical telescope on NASA's Pathfinder Technology Demonstrator spacecraft, and LLNL and Space Tango will develop LLNL's volumetric additive manufacturing 3D printing technology to produce artificial cartilage tissue in space.

Entrepreneurship programs include Energy I-Corps, the National Labs Entrepreneurship Academy, and the National Lab Accelerator; and collaborative facilities such as the Advanced Manufacturing Laboratory, the High Performance Computing Innovation Center, and the University of California Livermore Collaboration Center, help DOE missions. Many investments also result in awards. For example, DOE's Technology Transfer Working Group awarded two IPO staff members with "Best in Class" awards; R&D World Magazine announced three awards for LLNL; and three researchers were inducted into LLNL's Entrepreneurs' Hall of Fame. As LLNL anticipates the challenges of the future, the IPO will continue its work to deliver Lab technologies to commercial applications that meet the nation's needs.

TECHNOLOGIES TRANSFORM OUR WORLD

LLNL DEVELOPS INNOVATIVE TECHNOLOGIES THAT TRANSITION INTO NEW APPLICATIONS FOR GOVERNMENT AND INDUSTRY

LLNL researchers advance the technological state of the art to accelerate cost-effective development of advanced materials and manufacturing processes. The technologies improve national energy security, transform manufacturing by producing materials and components with new structural, chemical, thermal, and electrical properties, enable high-energy research, and contribute to economic growth. Below are examples of LLNL technologies that are highlighted in this report.

- Three “Energy Inks” will revolutionize the production of energy sector-related products that can be produced through the additive manufacturing process of direct ink writing. Industry will be able to use these next-generation materials to create customizable components for a wide range of products.
- High-energy, low-dispersion multilayer dielectric diffraction gratings that are capable of delivering 3.4 times more total energy than current state-of-the-art technology will allow scientists access to new realms of high-energy research.
- A new class of CO_2 sorbent materials—microencapsulated carbon sorbents —combines the advantages of liquid solvents with the advantages of solid sorbents to lessen the amount of CO_2 added to the atmosphere.
- Tailored Glass by Direct Ink Writing is an additive manufacturing process that enables a free-form glass production method capable of yielding monoliths and intricate lattices while enabling precision design and engineering of optical and material properties.

MICRO ENCAPSULATED CARBON SORBENTS

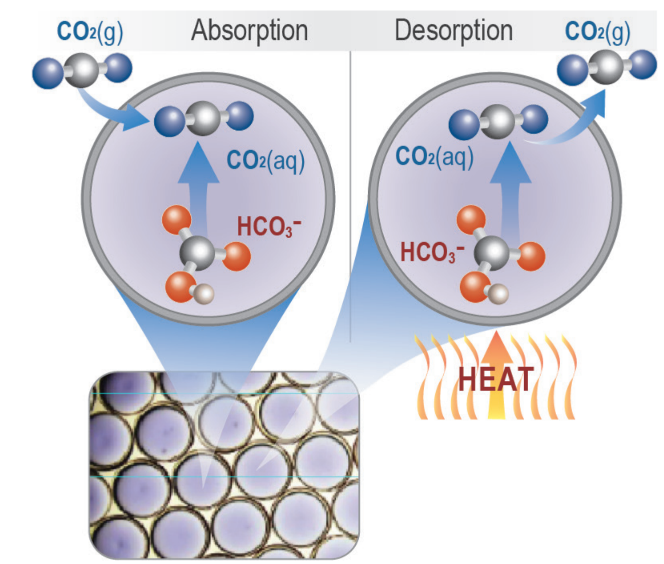
A REVERSIBLE, HIGH-CAPACITY CARBON CAPTURE AND STORAGE SOLUTION

CHALLENGE:

Since 1880, the earth's climate has warmed by about 1.8°F (1°C) on average due to excess carbon dioxide (CO_2) and other greenhouse gases in the atmosphere. Most experts agree there is a need to limit warming to no more than 2.7°–3.6°F (1.5°–2°C) if we are to avoid catastrophic impacts such as frequent and severe storms; extreme heat; wildfires; severe droughts; flooding; a rise in sea level; species extinction; impacts to human health, food, water supply, and economic growth; and increased global conflict over resources. The most established technique for capturing CO_2 brings flue gas in contact with an aqueous amine solution, typically monoethanolamine (MEA), which reacts with CO_2 to form carbamates. While MEA has a fast absorption rate and high CO_2 carrying capacity, it also possesses several drawbacks that prohibit widespread use. MEA is highly corrosive, yields toxic degradation products, and requires significant energy to remove CO_2 during sorbent regeneration.

SOLUTION:

LLNL has developed a new class of CO_2 sorbent materials—microencapsulated carbon sorbents (MECS)—that combines the advantages of liquid solvents such as high capacity, high selectivity, and water tolerance with the advantages of solid sorbents, such as high surface area and low volatility. During absorption, CO_2 diffuses through the thin, highly permeable capsule shells, then dissolves and reacts in the liquid sorbent core to form the desired product(s). During regeneration, the reaction is reversed upon heating to yield high-purity CO_2, which can be compressed for storage or utilization. The LLNL MECS technology overcomes a central challenge in membrane-based gas separations, where permeability and selectivity are often competing parameters, since microcapsule permeability and sorbent selectivity can be independently optimized.



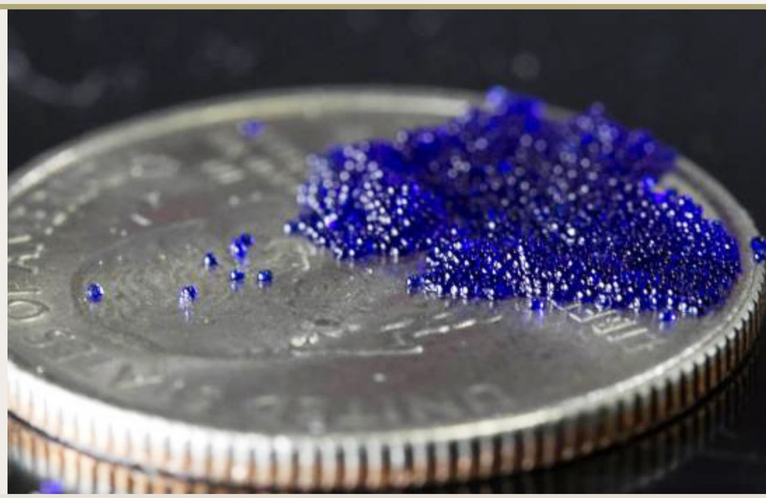
Schematic illustration of the encapsulated liquid carbon capture process in which CO_2(g) diffuses through a highly permeable silicone shell and is absorbed by a liquid carbonate core. The polymer microcapsules are then heated to release absorbed CO_2 for subsequent collection.

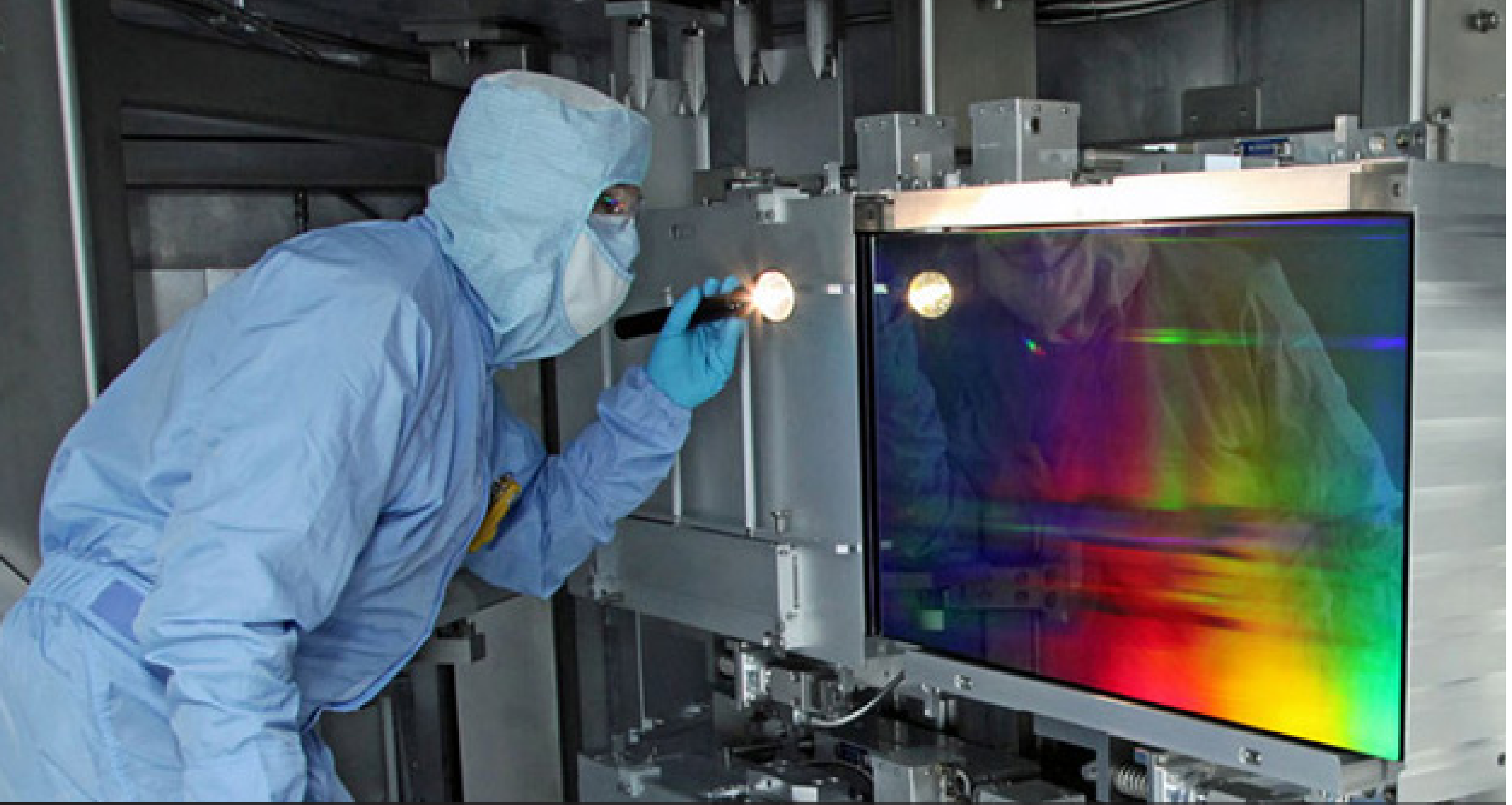
COLLABORATION:

The new federal climate bill will spur investments in green energy and shrink U.S. carbon emissions, opening up new collaboration opportunities for commercialization of MECS and other innovative carbon capture, storage, and utilization technologies as part of a climate mitigation strategy.

IMPACT:

MECS could make a big impact by capturing CO_2 released from large-scale sources such as power plants and industrial sites. Emissions from large-scale U.S. sources account for more than 50 percent of total CO_2 emissions. In fact, 2.8 billion tons of CO_2 per year are generated by power plants alone. Reducing these emissions by capturing them at the point of generation is one way to lessen the amount of CO_2 added to the atmosphere.





HIGH-ENERGY LOW-DISPERSION MULTILAYER DIELECTRIC GRATINGS

NOVEL MULTILAYER DIELECTRIC DESIGN DELIVERS 3.4 TIMES MORE TOTAL ENERGY THAN CURRENT STATE OF-THE-ART TECHNOLOGY

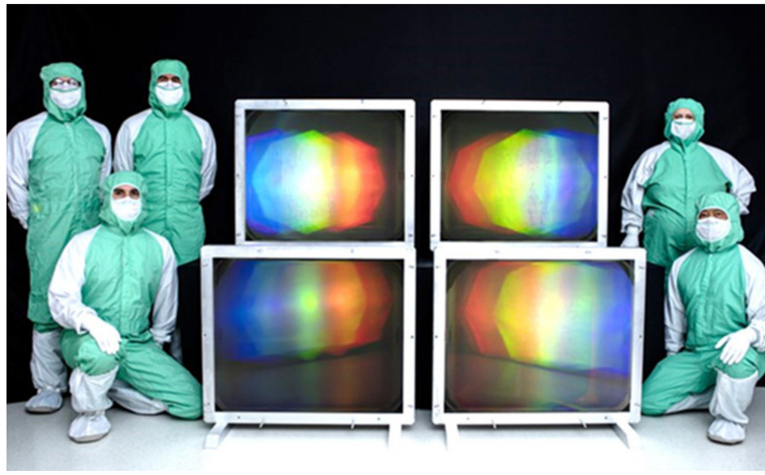
CHALLENGE:

High-powered lasers are used to study the origins of the universe, fusion energy, the interiors of planets, and more. However, today's laser system optics are unable to withstand direct and repeated high-energy pulses. High-energy lasers employing a process known as chirped pulse amplification (CPA) make use of diffraction gratings that compress beam pulses into increasingly energy-dense states. These gratings are susceptible to damage from redirecting beam pulses now capable of carrying petawatt (PW) loads. Multilayer dielectric (MLD) gratings are used in CPA systems due to their high laser-induced damage thresholds. MLD gratings are composed of a base substrate upon which layers of dielectric mirrors with varying refractive indices are stacked and topped with a layer of ion-etched photoresist that is fine-tuned to the desired diffraction specifications. The design of the MLD diffraction gratings is of high importance to enlarge their spectral tolerance. However, new laser systems will have higher peak power and will require optics with even higher damage thresholds and larger diffraction gratings.

SOLUTION:

In collaboration with Spectra Physics–Newport, National Energetics, and ELI Beamlines, LLNL has developed high-energy, low-dispersion (HELD) MLD diffraction gratings that are capable of delivering 3.4 times more total energy than current state-of-the-art technology. The HELD gratings comprise a novel design of MLD pulse compression gratings that enables a new class of high-energy, 10 PW ultrafast laser systems for extremely high and unprecedented peak power. The meter-scale HELD gratings also have the potential to facilitate future 100 PW-class ultrafast laser systems.

Prior to the HELD grating technology, the Texas Petawatt Laser held the record for the highest energy output 100 femtosecond (fs) ultrafast laser system—1 PW of power, 0.14 kilojoules (kJ) in 140 fs pulses. The HELD grating design achieves 1.6 times lower dispersion, thereby lowering the requisite angle of incidence. This lower angle of incidence equates to a resulting projected angle that is 3.4 times smaller than when using conventional gratings. With a smaller projected angle, the system achieves over a beam 6.4 times larger beam aperture compared to previous standards.



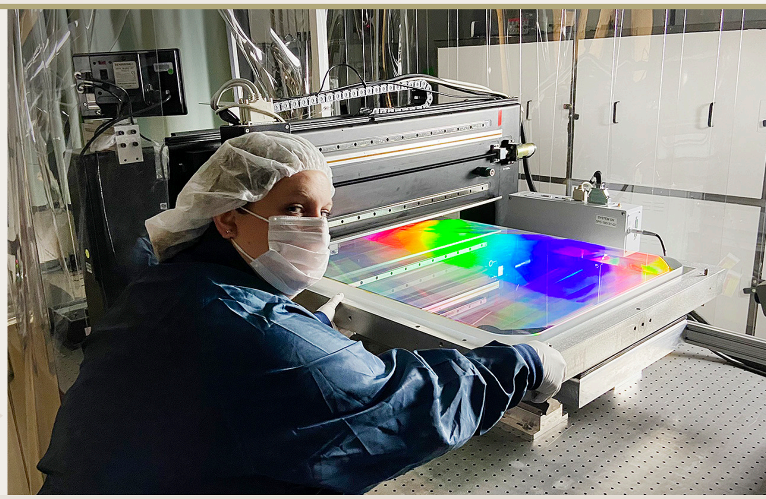
Members of LLNL's Diffractive Optics Group with four of the 85x70-centimeter HELD gratings to be installed in the ELI-Beamlines L4-ATON laser system. Meter-scale HELD gratings have the potential to facilitate future 20-to-50-petawatt-class ultrafast laser systems.

COLLABORATION:

The gratings, scaled to meter size, will be incorporated into the ELI Beamlines L4-ATON laser system, capable of generating an unprecedented 10 PW of power, 1.5 kJ in 150 fs pulses. A 10 PW laser pulse when focused on a diffraction-limited spot with a full-width half-max of 1 micron would result in an intensity of 10^{24} W/cm^2.

IMPACT:

Combining higher-energy lasers with HELD gratings will afford researchers access to new realms of high-energy research benefiting advances in cosmology, medical diagnostics, industrial processing techniques, laser-driven particle acceleration, and national security capabilities.



Mechanical technologist Candis Jackson performs atomic force microscopy of a High Energy Low-Dispersion grating to characterize the grating profiles.

ENERGY INKS

“ENERGY INKS” ACHIEVING SPECIFICALLY DESIGNED FUNCTIONAL PROPERTIES WILL REVOLUTIONIZE THE PRODUCTION OF ENERGY SECTOR-RELATED PRODUCTS

CHALLENGE:

Direct ink writing (DIW) is a popular additive manufacturing method that robotically extrudes continuous polymers or “ink” filaments through a micronozzle to form a 3D object layer-by-layer on a three-axis motion stage. Additive manufacturers have generally used inks to 3D print prototype models of components that are too complex and expensive to create using traditional manufacturing techniques. Although 3D-printing offers control and reproducibility to efficiently create models, the inks often do not contain the properties to create functioning components. This is especially true in the energy sector...until now.

SOLUTION:

LLNL seized that challenge and created three “Energy Inks” that achieve specifically designed functional properties while maintaining the required ink viscosity conditions needed for 3D printing. These inks will revolutionize the production of energy sector-related products that can be produced through the additive manufacturing process of DIW. Researchers adapted DIW technology to precisely deposit graphene oxide inks in a pre-defined tool path to form 3D structures. When characterized for compression and capacitance performance, researchers observed that the printed architectures exhibited better performance than conventionally manufactured counterparts. LLNL has created three Energy Inks using different materials to achieve different performance characteristics.

The Graphene Oxide ink is well suited for battery, supercapacitor, electrocatalysis energy storage applications. This 3D-printable graphene-based ink promises fast charge rates, increased cycle-life, and improved gravimetric capacitance. In a collaboration with University of California, Santa Cruz, LLNL researchers 3D-printed a graphene aerogel electrode and demonstrated a simultaneous increase in both energy and power densities due to improved electrolyte infiltration and ion diffusion.

The 3D Printable Yttria Stabilized Zirconia ink is a ceramic feedstock ink that remains chemically and mechanically robust in extreme temperatures and high pH environments. These porous ceramics are ideal for use in sensors, filtration, catalysis, and thermal insulation due to high surface area and tunable porosity.

The Printable Ultra-High Temperature B4C Ink is a boron carbide-based, lightweight, super-hard, ultra-high-temperature ceramic material. It can be used to construct complex shapes, and its properties make this ink ideal for components subjected to extreme temperatures and high-wear environments, such as nuclear reactors, or for light-weight body armor.

COLLABORATION:

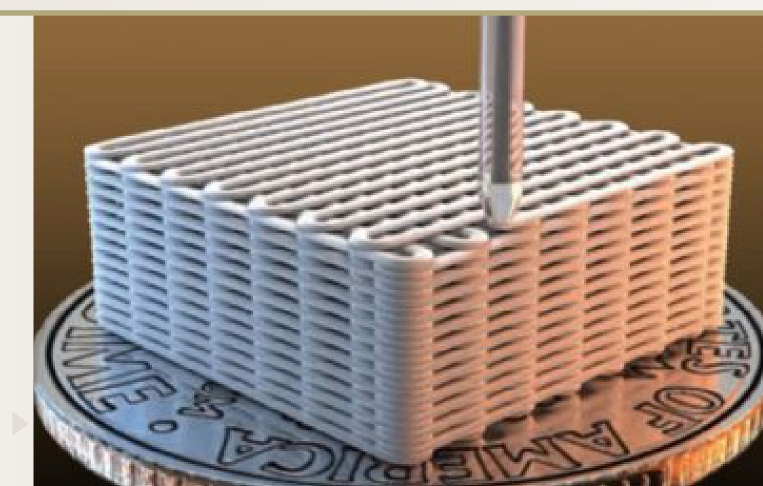
In 2021, LLNL and global chemical and materials supplier MilliporeSigma introduced the Energy Inks to users for applications in consumer electronics, transportation, and medical devices. LLNL and MilliporeSigma make these Energy Inks available to researchers worldwide to pursue their own projects.

Lawrence Livermore National Lab created a thixotropic ink based on boron carbide (B_4C) nanoparticles. It is suitable for various direct ink write printing technologies. The ink offers a stable dispersion of B_4C, high viscosity, good printability, and long shelf life. Sintered patterns provide excellent thermal stability and hardness. The ink is suitable for applications such as heat exchanges, high wear components, components in extreme temperature environments, etc.

IMPACT:

Industry will be able to use these next-generation materials to create customizable components such as lithium-Ion batteries, supercapacitors, sensors, filtration devices, hydrogen fuel cells, heat exchangers, and more. Devices once thought to be too complex and expensive for commercial markets can now be printed faster and will be less expensive and will operate with improved performance.

LLNL’s precision, direct ink writing process can print complex architectures used in energy storage devices and other energy-related devices.



TAILORED GLASS USING DIRECT INK WRITING

ENABLING PRECISION DESIGN AND ENGINEERING OF OPTICAL AND MATERIAL PROPERTIES

CHALLENGE:

Glass is typically produced from melting silica powders and subsequent shaping by molding techniques or by subtractive manufacturing methods. These traditional glass-shaping methods produce articles of a uniform composition in a limited range of achievable structures and may leave the glass susceptible to aberrations that negatively impact its structural integrity. Designers have long desired a means by which to tune the material properties—color, density, refractive index—within glass components.

SOLUTION:

LLNL researchers have developed an additive manufacturing method that extrudes glass "inks" capable of forming a continuous concentration grading when deposited with the physical precision of 3D printing. Known as Tailored Glass by Direct Ink Writing (TGDIW), the result is a free-form glass production method capable of yielding monoliths and intricate lattices while enabling precision design and engineering of optical and material properties.

Direct ink writing (DIW) is an extrusion-based additive manufacturing process that provides high levels of design freedom and precision. Just as commercial 3D printing uses polymers, DIW works by robotically depositing viscous "inks" through a micronozzle over a computer-defined path in order to build an object from the ground up. In TGDIW, the inks form glass. Glass is a unique and difficult material in the context of 3D printing, since it is conventionally produced via a process of melting and fusing silica powders.

LLNL's TGDIW process prints silica-based optics and glass components with customizable forms and spatially varying material properties. Flow of multiple glass-forming inks is finely controlled to achieve the desired structure and optical properties. Subsequent heat treatment renders a dense, transparent glass product. Unlike traditional processes used for developing new silica-based products that are costly and require specialized equipment to withstand very high temperatures, TGDIW eliminates the need for excessive industrial equipment.

TGDIW offers a high-level design freedom and resilient construction over a broad range of applications. Designs successfully produced so far include gradient refractive index optics, specially shaped liquid-tight containers, and microfluidic channels.

COLLABORATION:

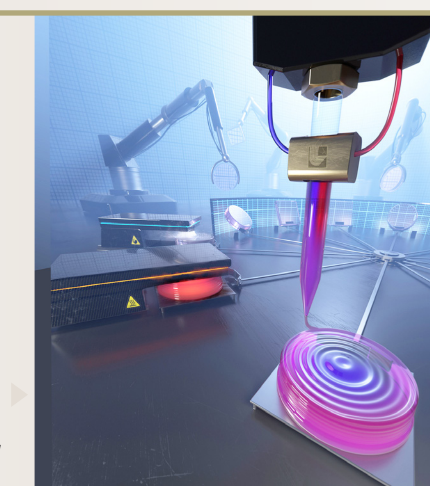
LLNL's industry partners recognize the technology's promise. Swarovski has identified the technology's potential for creating products ranging from jewelry to interior lighting that require high refractive indices and optical dispersion. Optimax Systems, Inc., has recognized the unique process for the potential production of lightweight, robust mirrors to operate within laser systems. Several other corporations and institutions in the fields of laser and optical systems, aerospace, and national security and defense, have also expressed similar interest for this application.

Image by Adam Lau/Berkeley Engineering

A microscopic object 3D printed in silica glass using volumetric additive manufacturing.

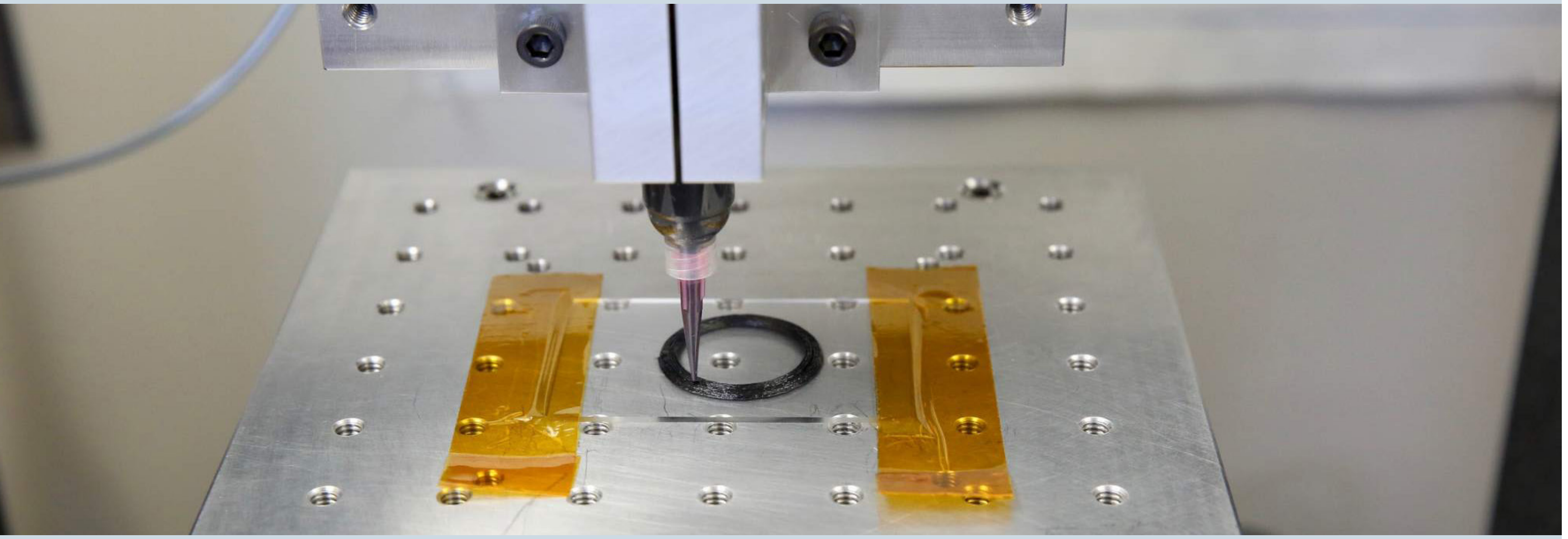
IMPACT:

There are significant cost benefits when manufacturing low-volume glass items. Each new structure or new design can be produced using the same equipment rather than requiring expensive custom molds for each new design. The technology may reduce or eliminate the need for expensive finishing or joining processes. Costs for power consumption and specialized work safety requirements could be reduced by working at lower temperatures rather than those used for melting glass. For some applications, it would also eliminate waste material resulting from precision subtractive manufacturing methods.



Artistic rendering of future automated production process for custom gradient-index, showing multi-material 3D printing of a tailored composition optic preform, conversion to glass via heat treatment, polishing and inspection of the final optics with refractive index gradients.

ADVANCED MANUFACTURING



A vibrant manufacturing base serves as the underpinning for virtually every aspect of a healthy society. Creating, improving, expanding, or modernizing new methods within the manufacturing sector significantly impacts our economy, national security, and quality of life.

Since its inception, LLNL has leveraged its core capabilities to improve multiple facets of manufacturing, particularly when the capabilities intersect with the Laboratory's national security mission. Advances in additive manufacturing (AM) are creating materials with previously unimaginable properties and are providing more cost-effective production processes within the nuclear weapons complex and U.S. industry. LLNL contributes to the manufacturing evolution through its research and development to improve industrial processes, create new materials, and commercialize other manufacturing technologies. The Laboratory also collaborates with industry and universities to tackle challenges that reflect shared interests.

Industry has generally focused its AM efforts in the areas of aerospace, automotive, medical, and product development. Significantly reducing the time and cost of creating prototypes from 3D CAD files, and creating complex geometries with unique properties, such as lightweight materials that are stronger than steel, batteries that charge faster and last longer, or biological tissue, have tremendous potential for commercial applications.

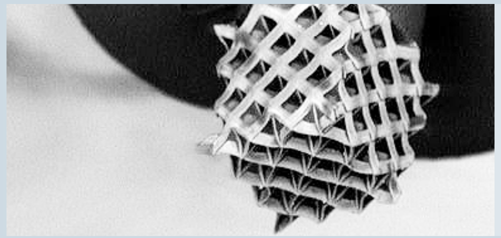
Chris Spadaccini, LLNL's Materials Engineering Division Leader notes there are some differences on how LLNL and industry approach AM. "The Laboratory has a national security focus. It conducts more fundamental science and more material and process research. As a result, LLNL's technologies fall into the early stage TRL1 to TRL3 categories. LLNL also incorporates more high-performance computer modeling and simulation into its AM research. This computing power is more robust than what industry can leverage on its own," said Spadaccini. "Industry is generally focused on using more mature AM technologies for defined applications. Though, there are some AM companies that will focus on early-stage technologies if they believe there is a market or customer."

These divergent approaches spark collaborative synergies between LLNL and industry, benefiting both parties. The Laboratory matures its early-stage technologies with the input from commercial companies, and those companies leverage the breadth of LLNL tools and expertise to transition early-stage technologies into viable commercial applications.

To further encourage external collaborations, LLNL created a 14,000 square foot Advanced Manufacturing Laboratory (AML) that offers five technology tracks, each focusing on a particular manufacturing area that is relevant to a partner's needs and interests.

- In the Design track, partners leverage the Laboratory's design optimization capabilities and high-performance computing (HPC) resources to improve complex, multifunctional designs for their products.
- The Materials track applies Livermore's expertise in developing new manufacturing materials, such as metallic particles, nanomaterials, glass, and liquid photo resins.
- The Process track develops new manufacturing processes for a range of materials and length scales from custom direct-ink writing extrusion to laser diode-based systems that can produce objects faster and at reduced cost.
- The Application track offers partners the opportunity to develop materials for a range of specific applications, such as 3D-printed graphene aerogel for batteries and supercapacitors; ultra-lightweight, strong, stiff materials; and new materials and structures for CO_2 capture.
- The Qualification and Certification track pairs in situ diagnostics, targeted experiments, data mining, and uncertainty quantification with LLNL's HPC process modeling and simulation to accelerate component certification. This approach optimizes the heating, melting, cooling, and solidification processes associated with metal AM. Similar methods are applied to a number of other emerging AM technologies.

A partnership with San Jose-based Artveoli is applying LLNL's carbon capture microcapsule technology to a wall-mounted, algae-containing device capable of converting CO_2 into pure oxygen in indoor environments. A second project is co-developing a volumetric 3D printing process called computed axial lithography. It uses laser-generated 3D images that are flashed into a spinning container of photosensitive resin to produce parts in a fraction of the time required by traditional layer-by-layer 3D printing. A project with GE Global Research is improving the quality and consistency of metal 3D-printed parts using the Lab's "Intelligent Feed Forward" approach.



"LLNL has one of the leading metal additive groups in the country."

—Former GE Global Research's Technology Director of Additive Research, Brent Brunell

Leveraging the Laboratory's computing power provides large quantities of data on AM materials, design, and process. The AML is already forming new external partnerships involving this area of AM. A longer-term goal is to merge machine learning, in situ diagnostics, and digital twin technology, to ensure component qualification and to be able to make design changes during the build cycle.

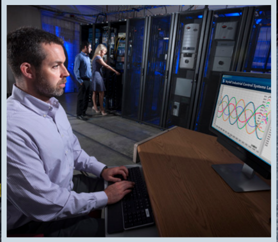
Genaro Mempin is IPO's business development executive responsible for the commercialization of LLNL's advanced manufacturing technologies. Prior to joining LLNL in 2004, Genaro served as an industrial engineer and R&D Operations Manager at Intel Corporation. He was attracted to the broad spectrum of technologies and industries associated with the national laboratories.

Genaro meets the needs of LLNL and its partners. His successes have been built on the principle that striking a deal, whether it is a cooperative research and development agreement (CRADA), licensing agreement, or other collaboration, must work for both parties.

Since 2004, Genaro has evaluated and managed 1,341 record of inventions, of which 516 patents and 57 copyrights were filed, and he negotiated 111 options/licenses and 72 CRADAs. One noteworthy success includes structuring a collaboration agreement between General Electric and LLNL to improve the quality of parts produced with GE's metal additive manufacturing machines. He also managed a number of collaborations with Volumetric Biotechnologies Inc., to develop new bio-materials and bio-printing processes.

Genaro is a Certified Licensing Professional™, a member of the Licensing Executives Society, and he developed LLNL's commercial equity policy for licensing for agreements. He received his B.S. in industrial engineering and operations research from the University of the Philippines, and his M.S. in engineering-economic systems from Stanford.

To learn more about LLNL's advanced manufacturing capabilities:
contact Genaro at mempin1@llnl.gov



PARTNERSHIPS BOOST ECONOMIC DEVELOPMENT

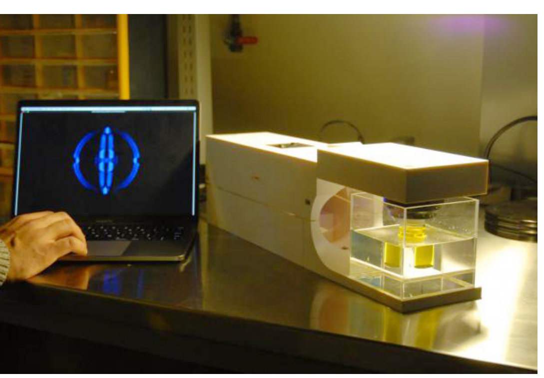
COLLABORATIONS **LEVERAGE THE TALENT** OF MULTIDISCIPLINARY TEAMS TO **SOLVE CHALLENGING** MISSION **PROBLEMS**

Laboratory researchers value strong partnerships with government agencies, academia, and industry to integrate complementary strengths of the whole team. Below are some of LLNL's collaborations highlighted in this report.

- A partnership with Ampcera Inc. will develop solvent-free laser powder bed fusion to generate 3D structures for faster charging and higher-energy-density lithium-ion batteries.
- A memorandum of understanding (MOU) between LLNL, Google, IBM, and NVIDIA, will use the artificial intelligence (AI) Innovation Incubator to accelerate AI for applied science.
- A MOU between LLNL and Amazon Web Services will establish a common stack of open-source software components that can run at large HPC centers and on cloud resources.
- A collaboration between LLNL and UC Berkeley will develop micro-computed axial lithography to cure 3D objects faster and at higher resolution.
- A Non-reimbursable Space Act Agreement between LLNL and NASA Ames Research Center will integrate a LLNL monolithic optical telescope on a "6U" small satellite bus as part of the NASA Pathfinder Technology Demonstrator series of spacecraft.
- The High Performance Computing Innovation Center along with other global supercomputing centers are standing up the International Association of Supercomputing Centers to develop best practices, find solutions for common challenges, and foster collaboration among the partners and users.
- The High-Performance Computing for Energy Innovation (HPCEI) program recently awarded eight projects in the HPC4Mfg portfolio. In one project, LLNL is partnering with ArcelorMittal to couple computer vision and machine learning methods with HPC resources to accelerate analysis of steelmaking.
- NASA is funding LLNL and space life sciences company Space Tango to develop LLNL's volumetric additive manufacturing 3D printing technology to produce artificial cartilage tissue in space.
- The Defense Advanced Research Projects Agency awarded $4 million to LLNL and its partners, Penn State, Columbia University, Tufts University, University of Kentucky, Purdue University, and industry partner Western Rare Earths to develop separation and purification processes of rare earth elements.

TECHNOLOGY IMPACTS

NASA FUNDS LLNL TO DEMONSTRATE "REPLICATOR" 3D PRINTER



The National Aeronautics and Space Administration (NASA) has awarded LLNL and Kentucky-based space life sciences company Space Tango with funding to develop LLNL's revolutionary volumetric additive manufacturing (VAM) 3D printing technology to produce artificial cartilage tissue in space.

The funding will allow LLNL and Space Tango to mature prototypes of the "replicator" technology — an ultrafast 3D printer co-developed by LLNL and the University of California, Berkeley — for bioprinting in microgravity on the ISS. The VAM printers are expected to operate with little to no crew intervention. NASA plans to enable manufacturing "In Space for Earth" on the International Space Station, to develop new and promising technologies for advanced materials and products for use on Earth and create a robust economy in low-Earth orbit.

The VAM technology takes computed tomography images of 3D objects from multiple angles and projects them into a photosensitive resin. The resin cures at points where the accumulated, absorbed light energy exceeds the gel thresholds, and when the remaining liquid resin is drained, it produces 3D objects within seconds or minutes, much faster than traditional layer-by-layer 3D printing techniques.

LLNL's partner, Space Tango, has years of experience in developing automated microgravity experiments in the pursuit of manufacturing health and technology solutions in space. The partnership highlights the promise of the VAM technology and connects LLNL with the commercial spaceflight industry.

USING MICROORGANISMS TO SEPARATE AND PURIFY RARE-EARTH ELEMENTS

Rare-earth elements (REEs) are essential for U.S. competitiveness in a high-tech economy because they are used in many devices important to the clean-energy industry and national security, including computer components, wind turbines, hybrid/electric vehicles, LCD screens, and tunable microwave resonators. In the defense sector, they are used for lasers, precision-guided weapons, magnets for motors, and other devices. Although the U.S. has adequate domestic REE resources, its supply chain is vulnerable due to dependence on foreign entities for separation and purification of these elements.

The team will leverage advances in microbial and biomolecular engineering to develop a scalable, bio-based separation and purification strategy using naturally occurring and engineered proteins and bacteria. The project will leverage the diversity, specificity, and customizability of environmental microbiology, synthetic biology, and protein engineering to enable new biomining methods for the separation, purification, and conversion of REEs into manufacturing-ready forms with high commercialization potential.

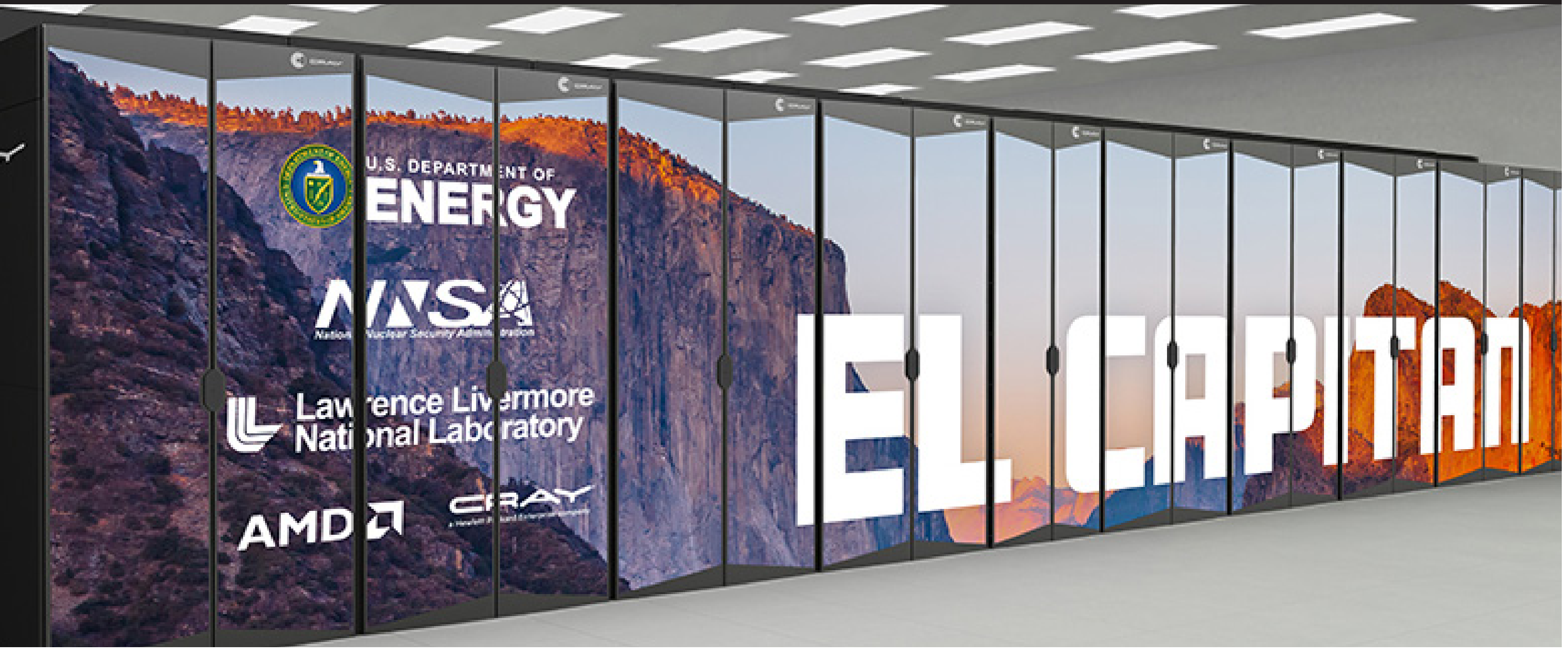
Defense Advanced Research Projects Agency (DARPA) has awarded an initial $4 million in funding to LLNL and its partners, Penn State, Columbia University, Tufts University, University of Kentucky, Purdue University, and industry partner Western Rare Earths to increase the yield from under-developed domestic sources.

NEW LASER-BASED VOLUMETRIC ADDITIVE MANUFACTURING PROCESS CAN PRINT GLASS IN SECONDS

Traditional glassmaking techniques can be slow and costly, and 3D-printing glass often results in rough textures, making them unsuitable for creating smooth optics. Computed Axial Lithography (CAL) had been previously developed by LLNL and UC Berkeley. CAL works by computing projections from different angles through a digital model of an object, optimizing the projections computationally and then delivering them into a rotating volume of photosensitive resin using a digital light projector. The projected light patterns form and harden the object inside the resin while the vat of resin spins. The fully formed object materializes far faster than traditional layer-by-layer 3D printing techniques.

As part of an effort to produce layer-less optics that can be built in seconds or minutes, LLNL and UC Berkeley have improved on the CAL process and created micro-CAL. This new process uses a laser instead of an LED light source, and nanocomposite glass resin developed by the German company Glassomer and the University of Freiburg. The laser produces a higher dose of light and cures 3D objects faster and at higher resolution. When combined with the nanocomposite resins, researchers have produced sturdy, complex, microstructure glass objects with a surface roughness of just six nanometers with features down to a minimum of 50 microns.

COLLABORATIVE EXPLORATIONS



LLNL ESTABLISHES INCUBATOR TO ADVANCE ARTIFICIAL INTELLIGENCE

LLNL has established the AI Innovation Incubator (AI3), a collaborative hub aimed at uniting experts in artificial intelligence (AI) from LLNL, industry, and academia to advance AI for large-scale scientific and commercial applications. With a recently signed memorandum of understanding, the Laboratory, Google, IBM, and NVIDIA, will use the incubator to facilitate discussions and form future collaborations around hardware, software, tools, and utilities to accelerate AI for applied science.

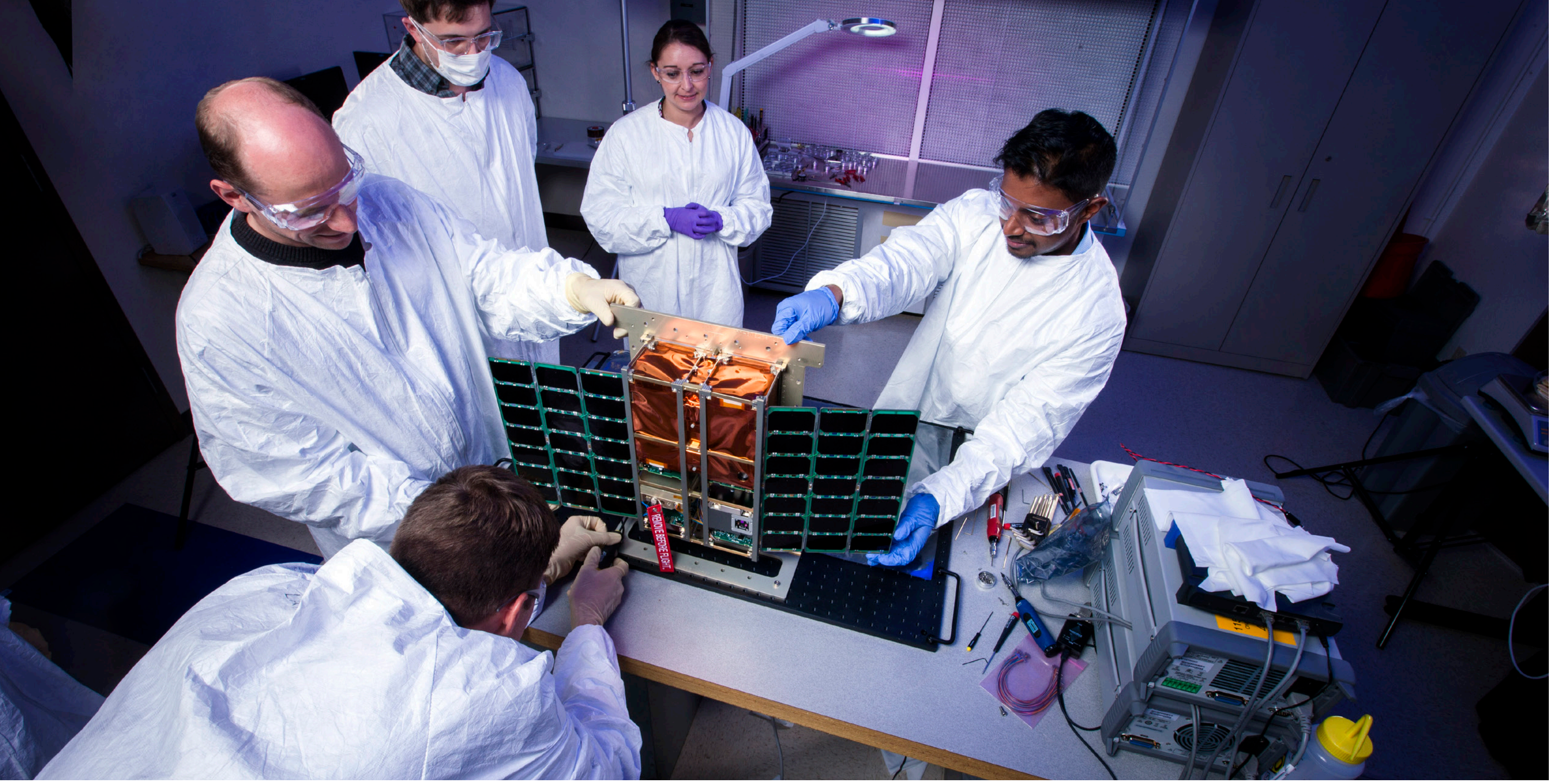
Several other existing projects will also fall under the AI3 umbrella, including continued work with Hewlett Packard Enterprises and Advanced Micro Devices Inc. to demonstrate the power of AI and high-performance computing on the future exascale system El Capitan. This project focuses on innovative, AI-driven cognitive simulation and design optimization methods at unprecedented scales to devise novel approaches to inertial confinement fusion experiments at the National Ignition Facility.

Other ongoing projects with AI accelerator/computing companies SambaNova Systems and Cerebras Systems, and precision motion company Aerotech Inc., will be further developed through AI3. Additional companies, universities, and leaders in the AI space are encouraged to consider joining AI3, where early research areas are expected to include advanced material design, 3D printing, predictive biology, energy systems, "self-driving" lasers, and fusion energy research.

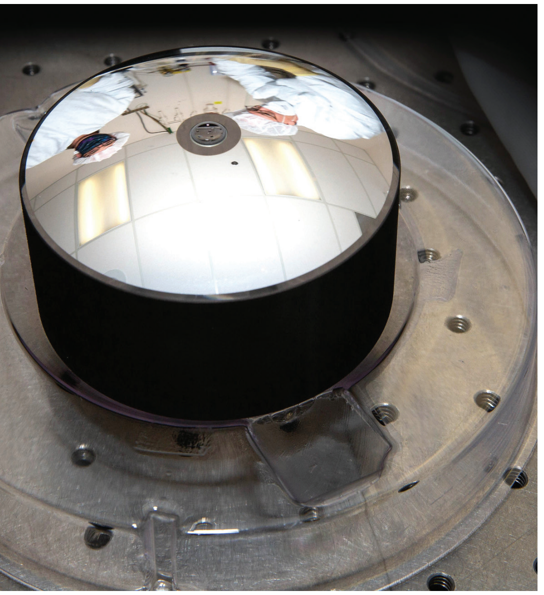
LLNL, AMAZON COLLABORATE TO STANDARDIZE SOFTWARE STACK FOR HIGH PERFORMANCE COMPUTING

LLNL and Amazon Web Services (AWS) have signed a memorandum of understanding to define the role of leadership-class high performance computing (HPC) in a future where cloud HPC is ubiquitous. With a growing cloud HPC market, LLNL and AWS will explore software and hardware solutions spanning cloud and on-premises HPC environments. The goal is to establish a common stack of open-source software components that can run equally well at both large HPC centers and on cloud resources.

LLNL and AWS also have an existing open-source collaboration involving Spack—a software package LLNL developed for HPC machines. Building off that collaboration, LLNL and AWS will look to better understand how HPC centers can best utilize cloud resources to support HPC and will explore models for cloud-bursting, data staging, and data migration for deploying both on-site and in the cloud. This work addresses growing requests from customers to provide cloud capabilities that can support workloads running at the world's largest HPC centers, including those that integrate AI and complex simulation capabilities.



SPACE ACT AGREEMENT TO INTEGRATE LLNL OPTICAL PAYLOAD WITH NASA CUBESAT



In June 2022, IPO worked with the NASA Ames Research Center in Silicon Valley to jointly sign a Non-reimbursable Space Act Agreement for a collaboration that will integrate a LLNL monolithic optical telescope on a “6U” small satellite bus as part of the NASA Pathfinder Technology Demonstrator (PTD) series of spacecraft. Each of the planned PTD missions consists of a 6-unit, or 6U, CubeSat weighing approximately 14 kg (30 pounds) and comparable in size to two stacked cereal boxes.

NASA’s PTD series of missions will test the operation of a variety of novel CubeSat technologies in low-Earth orbit. These tests involve a new propulsion system, communication system, and solar array to increase the performance of these small and effective spacecraft. LLNL is working with the NASA Space Technology Mission Directorate’s Small Spacecraft Technology program hosted at Ames Research Center, and the Terran Orbital Corporation, to install the monolithic optics payload on the fourth PTD mission in the series, PTD-R, which will be launched nominally in 2023 or early 2024. LLNL’s monolithic telescopes are extremely well suited to the unique capabilities offered by small satellites.

The optics will demonstrate the rapid integration and launch of a compact, high-resolution telescope on a 6U cubesat with the ability to study phenomena in both ultraviolet (UV) and visible/short wavelength infrared (SWIR) bands. The PTD-R mission will advance multiple technologies, including the first flight demonstration on UV and SWIR monolithic telescopes, the first flight demonstration of a UV-optimized complementary metal-oxide-semiconductor sensor, and the first flight demonstration of a small-pixel InGaAs sensor. The agreement with NASA leverages LLNL’s previous CRADA with Tyvak, now known as Terran Orbital. The established relationship and teams’ familiarity with the payload design and spacecraft bus allows the payload to be rapidly integrated with PTD-R.

3D PRINTED LITHIUM-ION BATTERIES

LLNL will be partnering with Ampcera Inc. to develop solvent-free laser powder bed fusion (L-PBF) additive manufacturing technologies for the fabrication of 3D-structured lithium battery cathodes. The partnership will accelerate the development and commercialization of the ultra-fast and low-cost L-PBF additive manufacturing technology for high-performance lithium battery manufacturing. L-PBF was originally developed for 3D printing of metal parts. Now it will be used to thermally bind the cathode powder mixtures onto the aluminum current collector to generate unique 3D structures for faster charging and higher-energy-density batteries for next generation lithium-ion batteries. The process allows for thick, high-capacity 3D cathode structures to be processed, enabling lithium-ion batteries to reach the fast-charging goal of 80% charge in 15 minutes or less. Current battery manufacturing, based on slurry casting and coating, is struggling to improve these key metrics. By eliminating the solvent, ultrafast laser processing allows large-scale battery manufacturing with higher production throughput and lower energy consumption and cost.

HIGH PERFORMANCE COMPUTING INNOVATION CENTER

The High Performance Computing Innovation Center (HPCIC) provides industry and academia with an accessible point of entry at LLNL to engage with the Lab on leading-edge projects aligned with the Lab’s mission and HPC capabilities. In turn, these activities enhance the HPC skills of the Lab workforce. Each year, HPCIC fosters many collaborative engagements and events. These activities help companies and universities increase their capabilities of utilizing HPC to accelerate innovation and competitiveness.

The HPCIC creates and manages strategic partnerships to boost the Lab’s workforce and capabilities in all aspects of computational science and technology. The RAND Corporation, the University of California, the National Center for Supercomputing Analysis, and the UK Science and Technologies Facilities Council are all strategic partners that add value to the Lab’s mission through broadened capabilities working together. The HPCIC also hosts workshops, seminars, and industry events.

In FY22, the HPCIC reached out to other global supercomputing centers to stand up the International Association of Supercomputing Centers (IASC). LLNL and co-founders Science and Technology Facilities Council (STFC) Hartree Centre, the National Center for Supercomputing Applications (NCSA), and Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities (LRZ), envision the IASC as a conduit for determining computing center management best practices, studying solutions for major common challenges and fostering communication and collaboration among the centers, partners, and users. The IASC creation was announced by the four founding centers at ISC 2022 in Hamburg, followed by the signing of an MOU establishing the intent to move forward robustly with global participation as IASC is fully realized.

COMMERCIAL PARTNERSHIPS

HPC4 ENERGY INNOVATION

The High-Performance Computing for Energy Innovation (HPC4EI) program comprises two programs—HPC4Manufacturing (HPC4Mfg) and HPC4Materials (HPC4Mtls)—that leverage the national laboratories' world-class computational resources with industry to advance the national energy agenda. Companies submit concept papers to the program, and if accepted, a laboratory scientist is assigned to help the company develop a full proposal. The HPC4EI program selects winning proposals by how well the technology advances the state of the art, the technical feasibility of the team, the project's impact on industry, and its need for HPC systems.

In FY22, the HPC4EI concluded its spring solicitation, awarding eight projects in December 2021 for the HPC4Mfg portfolio. The projects will use the national laboratories' supercomputers to optimize processes and end-use projects across the manufacturing sector, from increasing the energy efficiency of steelmaking to reducing the weight of vehicle components to save fuel and reduce emissions. The program also released a fall solicitation which received 41 responses focused on topic areas for the HPC4Mfg and HPC4Mtls programs. In July 2022, DOE awarded $3 million in funding for 10 projects to address topics such as reduction of carbon emissions and improvements to carbon conversion applications. HPC4EI spring 2022 is in the final stages of the review process; award announcements are expected in November 2022. Preparations to release a solicitation in the fall are underway.

HPC4MFG PROGRAM

The HPC4Mfg program enhances the adoption and advancement of HPC by addressing manufacturing challenges such as optimizing production processes, enhancing product quality, and speeding up design and testing cycles while decreasing energy consumption and greenhouse gas emissions. LLNL leads the program and is joined by Lawrence Berkeley and Oak Ridge national laboratories (LBNL, ORNL). Eight additional national laboratories participate as executors of selected projects. HPC4Mfg offers a low-risk path for U.S. manufacturing companies interested in adopting HPC technology to advance clean energy technologies and increase energy efficiency. DOE labs in the HPC4Mfg program include LLNL, LBNL, ORNL, Sandia National Laboratories, Argonne National Laboratory (ANL), National Renewable Energy Laboratory, National Energy Technology Laboratory (NETL), Idaho National Laboratory, Los Alamos National Laboratory (LANL), Pacific Northwest National Laboratory (PNNL), and Ames National Laboratory. DOE's Advanced Manufacturing Office is the primary sponsor of the HPC4Mfg program. LLNL partnered with ArcelorMittal in an awarded HPC4Mfg project to couple machine learning methods with HPC resources to reduce defects from inclusions in steel manufacturing.

HPC4MTLS PROGRAM

The HPC4Mtls program brings together industry partners and DOE laboratory scientists to work on short-term, collaborative projects and focuses on applying HPC to challenges associated with materials in energy technologies, including reduced material costs or improved carbon capture for power plants or clean hydrogen. LLNL leads the program and is joined by ORNL, NETL, LANL, PNNL, and ANL. HPC4Mtls offers a low-risk path for U.S. manufacturing companies interested in adopting the application of HPC, modeling, simulation, and data analysis to address key challenges in developing, modifying, and/or qualifying new or modified materials. The HPC4Mts program is funded by the Office of Fossil Energy and Carbon Management.

NEWLY FUNDED PROJECT TARGETS MORE ENERGY-EFFICIENT STEELMAKING

LLNL has partnered with steel and mining company ArcelorMittal to couple computer vision and machine learning methods with HPC resources to reduce defects from inclusions (oxide, sulfide, or nitride particles) in steel manufacturing. This is one of eight new projects receiving DOE funding through the High Performance Computing for Manufacturing (HPC4Mfg) program.

The technology will be used to accelerate analysis of steelmaking—usually performed through automated scanning electron microscopy on samples taken from liquid steel—to enable near-real-time process control and save energy by avoiding rejection of products due to poor quality.

HPC4Mfg is managed by LLNL for the DOE Office of Energy Efficiency and Renewable Energy's Advanced Manufacturing Office.

DOE labs involved in the HPC4Mtls program include:

Lawrence Livermore National Laboratory

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Los Alamos NATIONAL LABORATORY

The iron and steel industry consumes an estimated:

6% of the energy used by the U.S. manufacturing sector.

This technology could reduce the amount by:

1–2% and lessen CO_2 emissions by about **1.5 million tons** per year.

INVESTMENTS SPARK INNOVATION

INSTITUTIONAL **INVESTMENTS FOSTER COLLABORATIVE** ENVIRONMENTS THAT **SPUR INNOVATION**

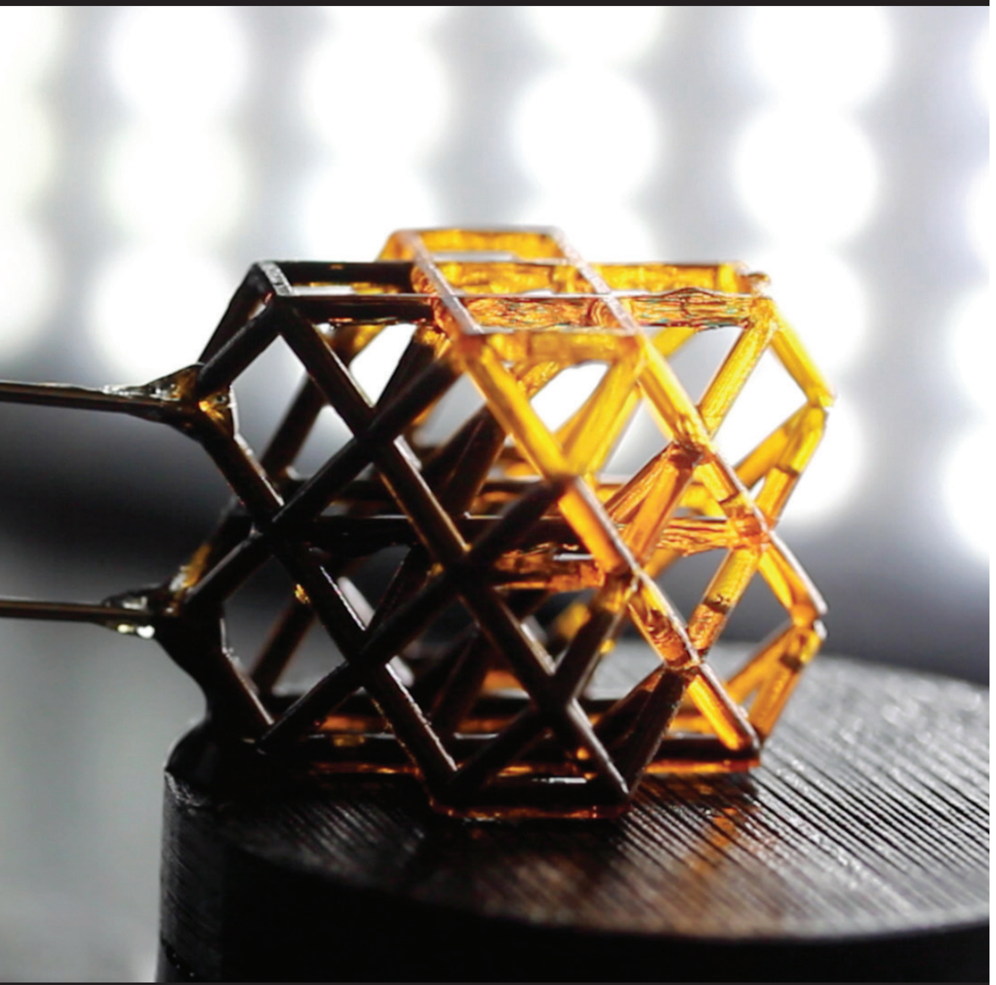
LLNL investments in programs and researchers support business concepts around market needs and technologies that meet national security challenges. Below are some of the past year's investment highlights.

- Energy I-Corps is helping two researchers develop a market pathway for the team's bioreactor.
- I-GATE's Daybreak Labs is opening a new 7,000 square foot facility near LLNL.
- The Livermore Valley Open Campus continues to expand capabilities to foster collaboration.
- Collaborations in the Advanced Manufacturing Laboratory will develop new recyclable polymers; develop 3D printers that allow for magnetic alignment within stereo-lithographically printed photopolymers; build a volumetric additive manufacturing system; build an integrated testing/analysis capability for hydrogen-materials interactions; increase the energy efficiency of CO_2 electrolyzers; and advance lung bioprinting work.
- Forty-seven scientists and engineers participated in the National Labs Entrepreneurship Academy in November 2021, and five researchers worked with business mentors to develop business models in the National Lab Accelerator in 2021.
- Renovation of the Hertz Hall Center, renamed the University of California Livermore Collaboration Center, will expand its work to help DOE missions.

Investments also resulted in many awards. For example:

- DOE's Technology Transfer Working Group awarded IPO Business Development Executive Annemarie Meike the Innovative Lab Technology Transfer award, and Digital Assets Coordinator Mary Holden-Sanchez the "Best in Class" licensing award.
- Three researchers were inducted into LLNL's Entrepreneurs' Hall of Fame: physical chemist Tony Ruggiero for advances in ultrahigh bandwidth laser communications; laser physicist Mary Spaeth, an innovator in tunable dye lasers; and materials scientist Natalia Zaitseva, for rapid growth technology for potassium dihydrogen phosphate and potassium dideuterium phosphate crystals for NIF.
- *R&D World Magazine* announced three awards for LLNL: Tailored Glass by Direct Ink Writing; High-Energy Low-Dispersion Gratings; and 3D Printed Energy Inks.

FOSTERING COLLABORATION



The AML houses some of the most sophisticated and capable equipment in the field of advanced manufacturing.

LIVERMORE VALLEY OpenCampus

LIVERMORE VALLEY OPEN CAMPUS

The Livermore Valley Open Campus (LVOC) makes it easier for renowned laboratories to help solve the world's pressing problems. Engineered to foster collaboration among LLNL, Sandia National Laboratories, private industry, and academic institutions, LVOC's 110-acre campus houses hybrid meeting spaces, laboratory facilities, and drop-in workspaces to promote innovation through discovery, knowledge sharing, and technology maturation. Based on the ever-growing activity in the open campus, the Laboratory continues to expand on-site capabilities while developing a long-term plan for replacing outdated structures and amenities.

Available meeting spaces are 80% occupied as in-person meetings and events with external parties ramp up to support a wide range of user needs in biology, manufacturing, science education, public affairs, and employee engagement groups. Increased numbers of unclassified, hybrid meeting spaces with A/V and VTC capabilities, higher-capacity

LLNL invites high school teachers to bring their class for a virtual visit to one of the Lab's premier facilities. The Scientist in the Classroom program connects LLNL scientists and engineers with students in their virtual classroom.

conference rooms, and refreshed support spaces will help LVOC better support current needs and help develop new scientific capabilities. Planning continues for new interdisciplinary research facilities to fill gaps in scientific infrastructure and enhance delivery on important mission challenges.

In addition to providing collaborative research and meeting space for LLNL employees and external partners, LVOC retains a focus on scholastic outreach. LVOC houses LLNL's flagship educational facility, the Discovery Center. To provide the general public and K-12 audiences with an up-to-date glimpse of the groundbreaking innovations at LLNL, work is underway to present a rebranded, refreshed Discovery Center in the next fiscal year. LVOC also includes a newly renovated Collaboration Center operated by the University of California campus system, which enhances the environment for university engagement and targeted training, internship, and recruiting opportunities.

ADVANCED MANUFACTURING LABORATORY

The Advanced Manufacturing Laboratory (AML) is a 14,000-square-foot facility that brings together science and engineering expertise, leading-edge technology, academic partners, and industry experience under one roof, to develop new materials and technologies that push the boundaries of manufacturing. The facility, located on the LVOC, enables industry partners to collaborate more freely and without the additional security requirements needed to access the rest of the Laboratory.

The AML houses some of the most sophisticated and capable equipment in the field of advanced manufacturing, including equipment for direct ink writing, powder bed fusion, electrophoretic deposition, projection microstereolithography, and laser-based processes such as two-photon lithography and selective laser melting. New technologies developed at the AML can be used to advance LLNL's national security missions, while industry partners can leverage technologies to create products and services for commercial markets.

In 2022, the AML established new partners and matured collaborations with its existing partners. LLNL's AML Advisory Panel has approved new collaborations with the following partners:

1. **FLO Materials –** This partnership is developing and testing new recyclable polymers. Unlike traditionally recycled polymers that use recycled materials with inferior/unpredictable properties, these new recyclable polymers can achieve 100% recovery of their mechanical and aesthetic properties after recycling. This greatly incentivizes their use and re-use.
2. **Fortify –** The Fortify 3D printers allow for magnetic alignment within stereo-lithographically printed photopolymers. The goal of this partnership is to further the development of both the printing hardware/software and the high-viscosity, highly filled, and higher-performing polymers.
3. **Facebook Reality Labs –** Under this partnership, a cryo-capable, laser-based volumetric additive manufacturing (VAM) system will be built. When adding cryo- and laser-based capabilities to the basic VAM technology, the resolution of the VAM system as well as the selection of available materials that can be printed with it will be greatly increased.
4. **Hydrogen Materials Mini Lab –** This partnership will develop an integrated testing/analysis capability for hydrogen-materials interactions. Installation of this capability in the open campus establishes this lab as the third testing center in the DOE complex for hydrogen storage. Co-locating this with advanced manufacturing capabilities will allow for rapid development and testing feedback for new materials for hydrogen storage, production, and utilization. It is expected that this will enable additional relationships through future/pending CRADA partnerships.
5. **Siemens –** This partnership aims to increase the energy efficiency and scale of CO_2 electrolyzers using advanced manufacturing and computation design. This is part of a DOE Advanced Manufacturing Office-funded project in partnership with TotalEnergies—an existing AML collaborator.
6. **VolumetricBio/3D Systems –** Under the previous partnership with VolumetricBio, LLNL supported the design/build of a large-area PμSL (Projection Micro Stereo-Lithography) printer called Tessel, which has 2.7μm resolution over 115 mm diameter build area, with high-speed scanning. VolumetricBio was acquired by 3D Systems in October 2021, and the collaboration is expected to continue with lung bioprinting work that is underway at LLNL.
7. **Space Tango –** This is a partnership funded under NASA's In Space Production Applications (InSPA) Program. The goal of this partnership is to demonstrate the benefits and feasibility of using the VAM system in space for 3D bioprinting tissues and organs. 3D bioprinting with cell-loaded materials is a critical requirement for high-quality transplantable tissues, and microgravity is an essential enabler, as the soft materials used for the tissues will not be subject to slumping/distortion in gravity.

UC INVESTS AND EXPANDS COLLABORATION OPPORTUNITIES IN THE LIVERMORE VALLEY OPEN CAMPUS

The **Hertz Hall Complex** (HHC) is a set of three University of California (UC)-owned buildings located on the eastern edge of LLNL and within the 220-acre Livermore Valley Open Campus (LVOC). LVOC is located outside the security fences, providing a more accessible venue for national laboratories, academic and industrial collaborations, as well as educational and outreach programs. Construction of the first building on the HHC site was completed in the mid-1970s; the third building was completed in 2003.

The HHC was originally managed and operated by UC Davis, and it housed the UC Davis Department of Applied Science (DAS) until the department was closed in 2011 for budgetary reasons. DAS was a cooperative academic program established in 1963 by UC Davis and LLNL that served as a vehicle for LLNL senior staff to teach, and for younger LLNL staff members to complete their doctorate degrees in disciplines relevant to the Laboratory's mission. More than 400 students received their graduate degrees in highly specialized scientific and engineering fields from UC Davis, and many went on to become leaders within the national security complex. The HHC played a pivotal role in forging a decades-long, impactful partnership between UC Davis and LLNL in research collaborations, workforce pipeline, workforce development, and educational programs.

In 2018, operations and maintenance of the HHC were transferred from UC Davis to the UC National Laboratories (UCNL) Office within the UC Office of the President (UCOP), and an effort was launched to reinvest in the complex and broaden its reach beyond LLNL and UC Davis. In 2022, the recapitalization and renovation effort of the complex was completed and was renamed the University of California Livermore Collaboration Center (UCLCC).

The rejuvenated complex has numerous conference rooms and classrooms of various sizes, laboratory spaces, offices, a courtyard, and advanced A/V technologies throughout the buildings, for a maximum capacity of approximately 525. Those facilities will expand partnerships and drive innovations in multiple focus areas, including advancing research and innovation to further science technology and engineering (ST&E) core competencies; developing workforce education and training programs to expand job skills and cultivate knowledge in ST&E and operations; developing recruitment programs to attract new talent; and developing an outreach program to reach the broader community. A ribbon cutting for the UCLCC is scheduled for September 26, 2022.

UNIVERSITY OF CALIFORNIA
Livermore Collaboration Center

The University of California Livermore Collaboration Center will be made available as a system-wide asset to enhance DOE and UC missions, and it leverages the full capabilities and strengths of UC's

10 CAMPUSES
3 NATIONAL LABS
5 MEDICAL CENTERS

and a network of agriculture and national resource centers.

ENGAGING ENTREPRENEURS

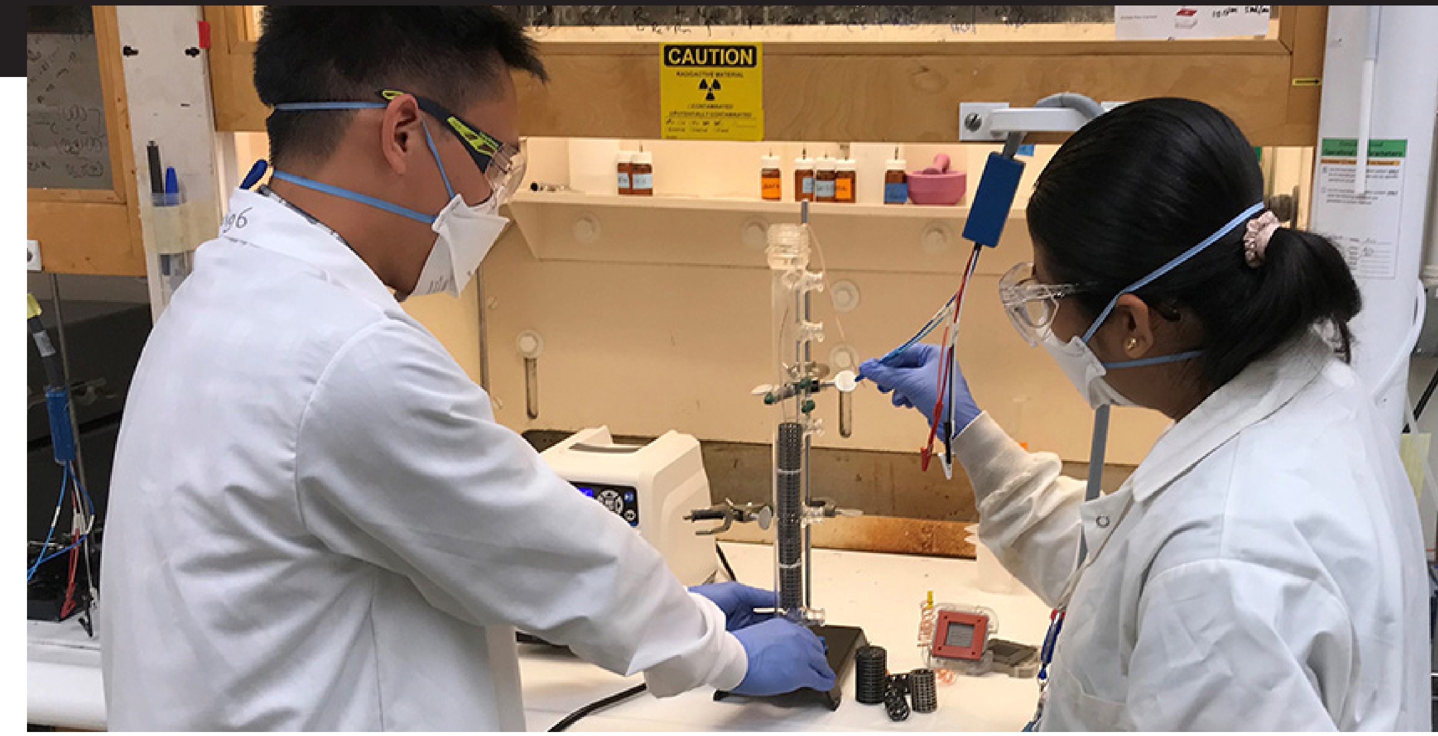
National Labs Entrepreneurship Academy, a partnership of LLNL, Sandia National Laboratories/ California and UC Davis that is designed to help drive innovation at the labs.

NATIONAL LABS ENTREPRENEURSHIP ACADEMY

The National Labs Entrepreneurship Academy is a three-day classroom-based opportunity featuring a curriculum developed and taught by professors in the UC Davis Graduate School of Management. Instructors focus on technology value proposition development.

Forty-seven researchers participated in the Academy in November 2021, bringing the total trained to more than 350 since 2015. Due to continued COVID-19 impacts, the 2021 curriculum was modified for a four-day virtual learning delivery.

Since 2015, LLNL's IPO has partnered with the UC Davis Institute for Innovation and Entrepreneurship to host eight academies teaching scientists and engineers the fundamentals of entrepreneurial business. The course teaches the researchers the value proposition of technology and communication skills for working with funding sponsors. It integrates scientific research, industry relevance, and social benefit. Participants explore technology commercialization, intellectual property, business development techniques, and how to build networks.



Simon Pang (left) and Buddhinie Jayathilake assemble and prepare a prototype bubble column electrobioreactor to test additively manufactured three-dimensional electrodes. Under their project, excess renewable electricity from wind and solar sources would be stored in chemical bonds as renewable natural gas.

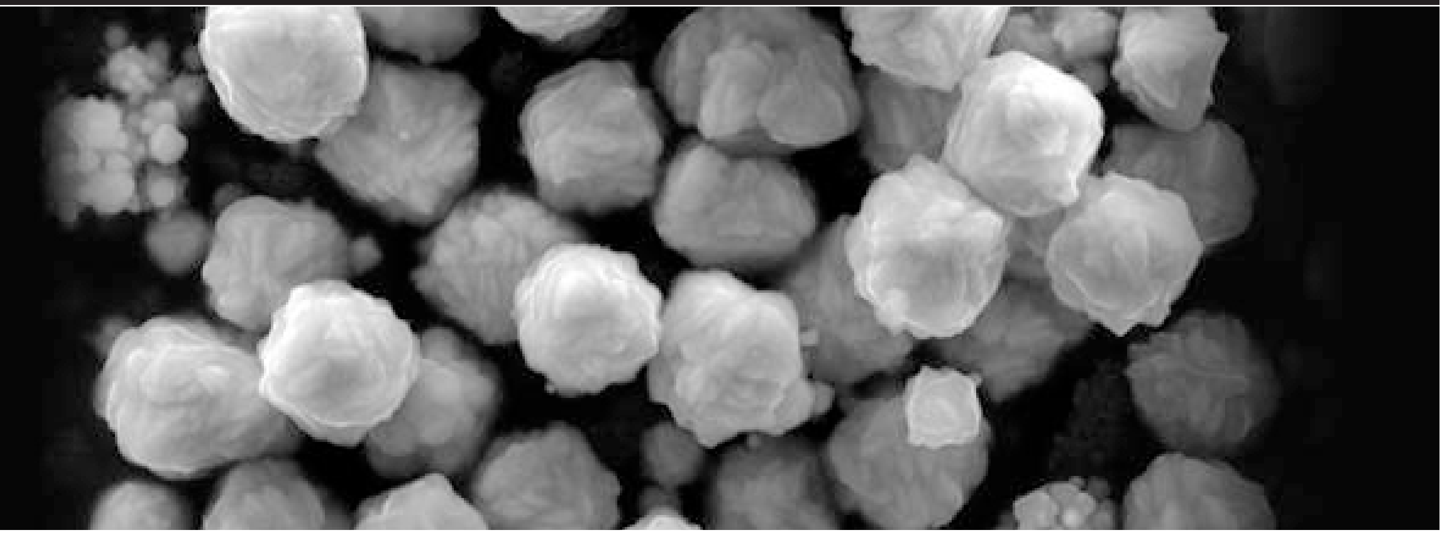
ENERGY I-CORPS

The "Bioreactor" team of LLNL materials scientists Samantha Ruelas and Fang Qian was chosen and funded to participate in DOE's Energy I-Corps program Cohort 14. Scientist participants, side-by-side with industry mentors, go through an intensive two-month training in which the researchers define technology value propositions, validate the propositions through customer discovery interviews, and develop viable market pathways for the commercialization of the technologies. Researchers return to LLNL with a framework for industry engagement to guide future research and inform a culture of market awareness.

Eight LLNL teams have participated in Energy I-Corps since 2015. Team Bioreactor participated in spring 2022, learning about markets that are ripe to employ their additively manufactured, solid-state bioreactor for upgrading biogas. "Our goal is to decrease the amount of methane in our environment with our bioreactor technology. This will help ease the greenhouse gas emissions in our environment currently creating climate change," said Ruelas. "The Lab focuses a lot on cutting-edge technology…we thought [Energy I-Corps] would be a great opportunity to help us commercialize our technology."

"We will continue to optimize our technology to directly address the concerns of customers. After the Energy I-Corps program, we have become more confident that our technology will make a real-world impact in the not-too-distant future," said Qian.

ENERGY I-CORPS U.S. Department Of Energy



A scanning electron microscope image of synthetic pyrite particles that were used to kill antibiotic resistant bacteria.

NATIONAL LAB ACCELERATOR

The LLNL-hosted National Lab Accelerator is a DOE Office of Technology Transitions-funded program. The 6–9 month individualized training and business mentoring program focuses on business model development and communication. With a stronger understanding in business, researchers are able to better communicate a value proposition with businesspeople. The knowledge also increases the likelihood of moving technologies developed at the national laboratories into the hands of those who can create value. Their work culminates in a pitch competition, which is an opportunity for the business community to learn firsthand about the diverse science and technology at the DOE national labs. Judges comprise Bay Area and Silicon Valley investors.

The 2021 Accelerator program saw five LLNL researchers working with business mentors to develop business models and pitches applying LLNL technologies to a market need. Each went on to compete in the LLNL pitch event for the opportunity to represent LLNL in the DOE-wide pitch event. Keith Morrison was the LLNL winner with his pitch, “Advanced Synthetic Mineral: Building mineral-based cures to combat antibiotic resistance.” Keith’s competition included Viacheslav Li presenting, “Intelligent detection of nuclear threats”; Andrew Hoff presenting, “Mini-tubular ceramics for diesel particulate filters”; Michael Barrow presenting “MedECC: Efficient inpatient telemedicine platform”; and Raymond Mariella Jr. presenting “RLSID: Remote Laser Inspection and Decontamination of Nuclear and Chemical Hazards – how to decontaminate a concrete surface.”

On September 29, 2021, IPO hosted a virtual National Lab Accelerator Pitch Event. Eleven national labs were represented. Investors and entrepreneurs evaluated the commercial potential of innovations for transfer to the private sector. In addition to LLNL, other participating national labs included BNL, LANL, SNL, LBNL, PNNL, INL, ANL, NREL, PPPL, and NETL. The competition resulted in a first-place tie. The winners were: SNL’s Brooke Harmon for her presentation, “Platform for Discovery, Design, and Engineering of Antibody Therapeutics for Emerging Viruses”; and BNL’s Chang-Yong Nam, for her presentation, “VIPP: Vapor-Infiltration Photoresist Process Technology for Next-Generation Semiconductor Manufacturing by Extreme Lithography.”

George Farquar, who led a Lab team that invented DNATrax, demonstrates how the technology can be used to identify the original source of tainted food.

I-GATE/DAYBREAK LABS

i-GATE manages a life sciences and deep tech incubator called Daybreak Labs, which in September 2022 will open a new 7,000 square foot facility less than two miles from LLNL. Daybreak Labs’ new incubation facility offers an extensive list of biological research and development equipment as well as prototyping capabilities to help early-stage life sciences and deep tech startups grow. i-GATE’s incubation programs have supported a number of high-tech startups that are commercializing technologies originally developed at LLNL.

One example of a successful i-GATE alumni company is SafeTraces, an LLNL licensee of DNATrax technology. SafeTraces has obtained $20M in funding, including $3M in FDA, NIH, and NSF grants. Investors include UL, Bunge, Spero Ventures (Omidyar Network fund), and S2G Ventures. The company has grown its business, created 23 jobs in the San Francisco Bay Area, and filed for six patents, creating significant intellectual property.

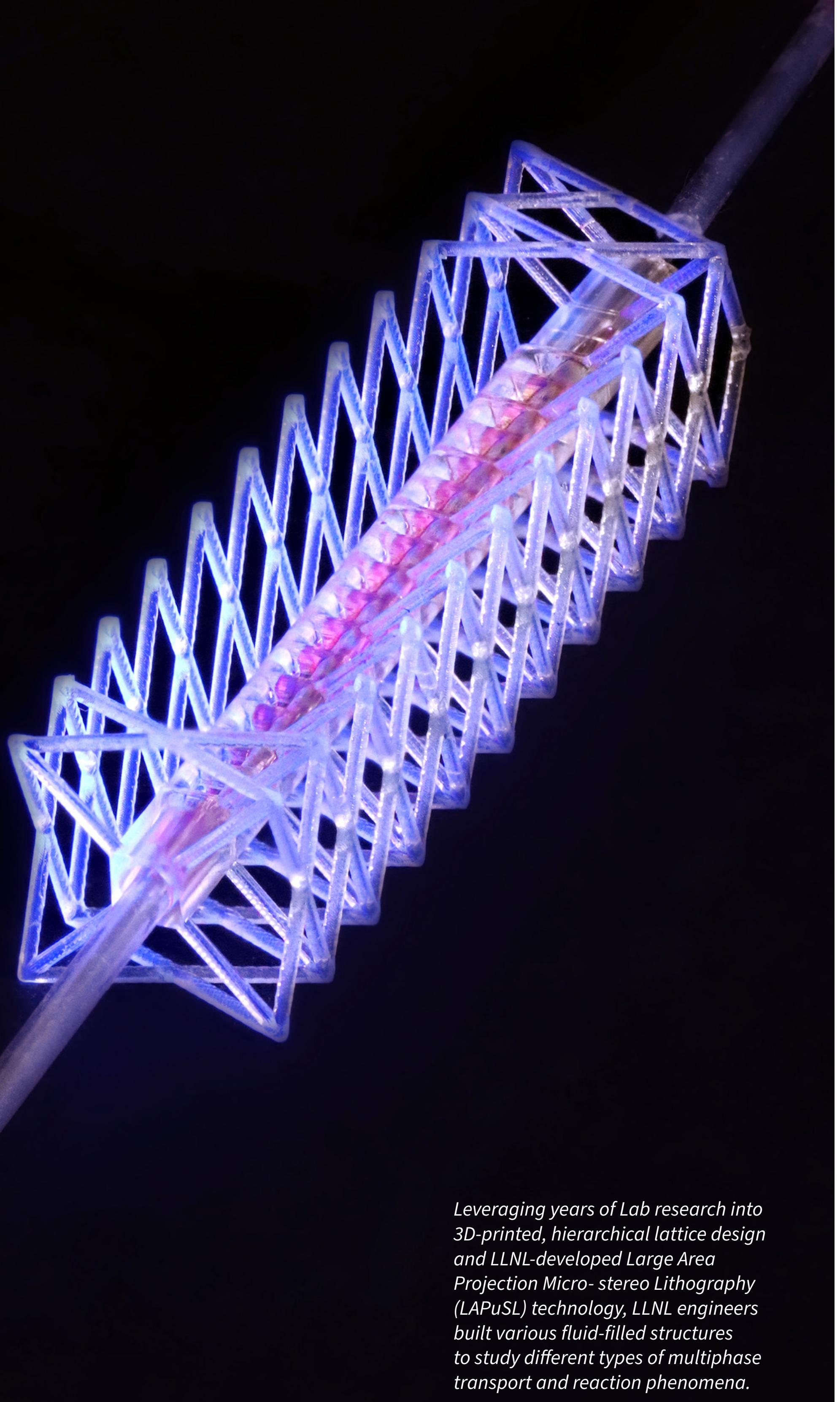
i-GATE

DAYBREAK LABS

Daybreak Labs is currently in the process of securing a new facility, and beginning this fall, the incubator will partner with local venture fund Tri-Valley Ventures (TVV) to offer life sciences and deep startups up to $200,000 in capital and one year of no-cost R&D facilities, along with expert mentoring from TVV’s network of experienced startup operators.

Building on the success of the NextTech Speaker Series and Tri-Valley Life Sciences Summit, i-GATE has recently launched Startup Tri-Valley, an initiative aimed at making the Tri-Valley the go-to destination for science-based startups. Startup Tri-Valley will focus on growing the local ecosystem of resources supporting early-stage companies, including offering networking events, providing relevant domain expertise, and branding the region as a hub of science and innovation. Startup Tri-Valley includes a podcast hosted by i-GATE executive director Brandon Cardwell. LLNL Director Kim Budil was recently featured as a guest discussing the Laboratory’s role in the innovation ecosystem.

RECOGNIZING INNOVATORS



Leveraging years of Lab research into 3D-printed, hierarchical lattice design and LLNL-developed Large Area Projection Micro- stereo Lithography (LAPuSL) technology, LLNL engineers built various fluid-filled structures to study different types of multiphase transport and reaction phenomena.

R&D 100 AWARDS 2022

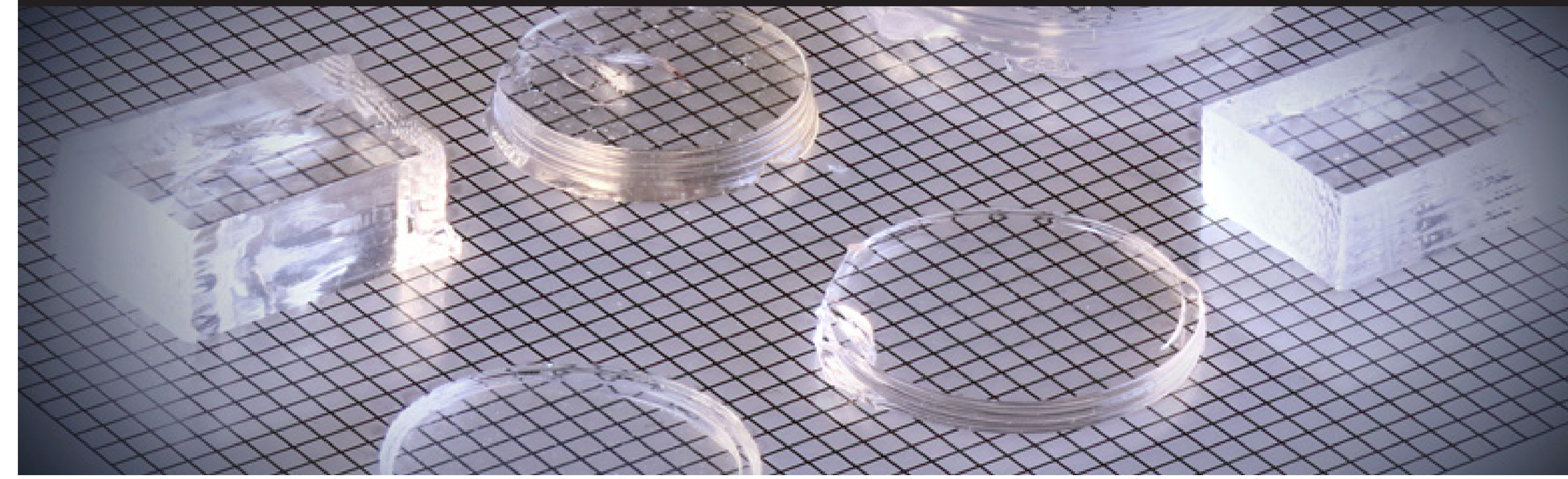
R&D World Magazine announced three awards for LLNL scientists and engineers. Often referred to as the "Oscars of invention," the R&D 100 awards recognize the top 100 industrial inventions worldwide.

This year's LLNL winners are:

- HELD Gratings
- Tailored Glass by Direct Ink Writing
- 3D Printed Energy Inks

HELD GRATINGS

LLNL's High-Energy Low-Dispersion (HELD) gratings is a novel design and improvement on existing multilayer dielectric pulse compression gratings used in optics within laser systems to protect the optics from laser damage. HELD gratings enable a new class of high-energy, 10-petawatt ultrafast laser systems for extremely high and unprecedented peak power. Meter-scale HELD gratings have the potential to facilitate future multiple tens of petawatt-class ultrafast laser systems. The gratings can deliver 3.4 times more total energy than the current state-of-the-art technology. The new grating configuration allows for significantly higher laser outputs and permits us to access new regimes of science.



An array of polished, 3D printed gradient refractive index lenses made of titania-doped silica glass. Grid squares are 1 millimeter on each side.

TAILORED GLASS BY DIRECT INK WRITING

Tailored Glass by Direct Ink Writing is an additive manufacturing process that prints silica-based optics and glass components with customizable forms and spatially varying material properties. The process involves the flow and fine control of multiple glass-forming inks to achieve the desired structure and optical properties. Subsequent heat treatment renders a dense, transparent glass product.

Some of the possible applications for the technology are producing flat custom lenses, lighter weight optics, custom containers, new support structures for catalysts, chemically tuned microfluidics, and art, such as glass sculptures.

3D PRINTED ENERGY INKS

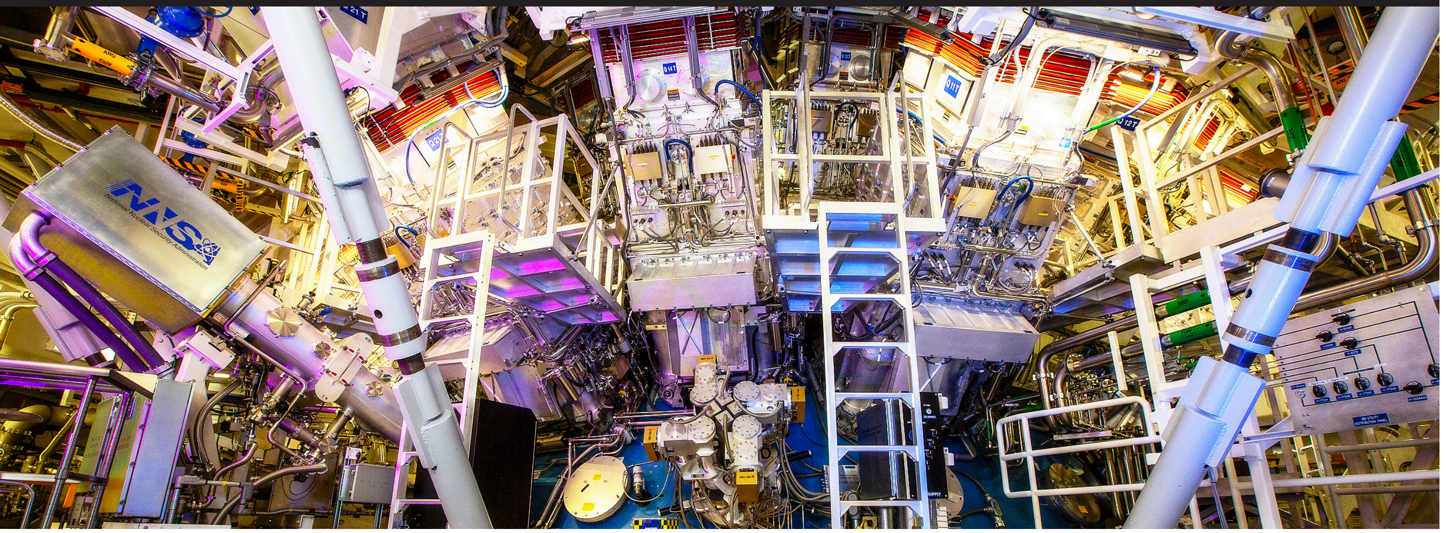
LLNL scientists and engineers have developed a trio of Energy Inks for use as 3D printer feedstock. Each ink has unique properties that will impact the production of energy sector-related products.

The Graphene Oxide ink is well suited for battery, supercapacitor, electrocatalysis energy storage applications. The graphene-based ink promises fast charge rates, increased cycle-life, and improved gravimetric capacitance.

The Yttria Stabilized Zirconia ink is a ceramic feedstock ink that remains chemically and mechanically robust in extreme temperatures and high pH environments. These porous ceramics are ideal for use in sensors, filtration, catalysis, and thermal insulation due to high surface area and tunable porosity.

The Ultra-High Temperature B_4C ink is a boron carbide-based, lightweight, super-hard, ultra-high-temperature ceramic material. It can be used to construct complex shapes, and its properties make this ink ideal for components subjected to extreme temperatures and high-wear environments, such as nuclear reactors, or for light-weight body armor.

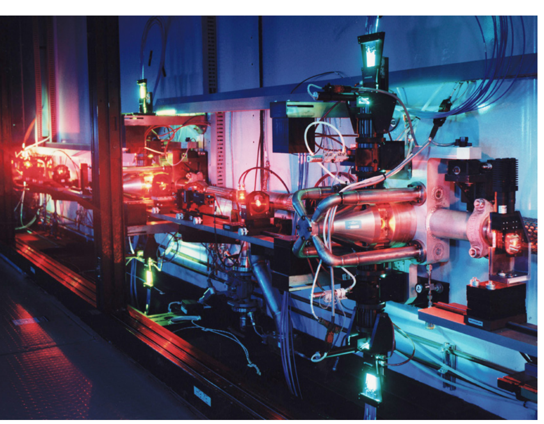
LLNL material and biomedical scientist Fang Qian (left) and engineer Cheng Zhu demonstrate a direct ink writing 3D printer they used to manufacture supercapacitors out of a graphene-based aerogel.



THREE INDUCTED INTO LLNL’S ENTREPRENEURS’ HALL OF FAME

One current and two former LLNL scientists have been inducted into the Laboratory’s Entrepreneurs’ Hall of Fame (EHF). The trio, who represent the third class of inductees into the Lab’s EHF, have been honored for developing technologies during or after their Lab careers that created major economic impacts or spawned new companies.

Laser physicist Mary Spaeth joined the LLNL Laser Program in 1974, in part for the opportunity to use tunable dye lasers to produce enriched uranium, a technology later transferred to the U.S. Enrichment Corporation for further commercial development. She rapidly became known as an innovator in laser physics, optical design, and device engineering, as well as one of the original innovators in tunable dye lasers, which revolutionized the laser industry. Later, she became chief technologist for the National Ignition Facility (NIF), the world’s most energetic laser. Building NIF required breakthroughs in laser and optical element manufacturing at scales more than 100 times smaller than previously available, with unprecedented precision and accuracy. As the lead systems engineer, Spaeth played a key role in ensuring that the requirements, quality, acceptance, installation, and commissioning processes for more than $1.2 billion of equipment progressed flawlessly.



Mary Spaeth was one of the original innovators in tunable dye lasers, which revolutionized the laser industry.

Tony Ruggiero joined the LLNL Physics directorate in 1990, and his career evolved over the next 18 years, highlighted by significant research and development advances in ultrahigh bandwidth laser optical free-space communications. The technology transmitted data at 2.5 gigabits per second on a single laser channel, a rate comparable to 400 channels of television or 40,000 simultaneous phone calls.

In March 2009, his work in photonics, laser technologies, and optoelectronics led him to start what would become a highly successful entrepreneurial venture known as Sierra Photonics. The company became so successful in producing exceptional technologies that it caught the eye of Google. Ruggiero guided Sierra Photonics through a smooth acquisition by Google Inc.

Materials scientist Natalia Zaitseva joined LLNL in 1993 to lead the development of rapid growth technology for large potassium dihydrogen phosphate (KDP) and potassium dideuterium phosphate (DKDP) crystals for NIF, a technology that proved critical for the laser’s eventual success. With traditional growth methods, it would have required 2–3 years to grow the 55-centimeter-size KDP crystals needed for the Livermore laser. Zaitseva’s new technology increased the growth rate for the KDP crystals from the traditional method’s rate of about 1 millimeter per day to 10 to 20 millimeters per day, allowing the growth time for crystals to be cut to 1 to 1 ½ months. Cleveland Crystals Inc. partnered with LLNL in the 1990s to commercialize Zaitseva’s new technology, providing KDP crystals to NIF.

One current and two former LLNL scientists have been inducted into the Lab’s Entrepreneurs’ Hall of Fame. ***From left:*** *Mary Spaeth, Tony Ruggiero and Natalia Zaitseva.*

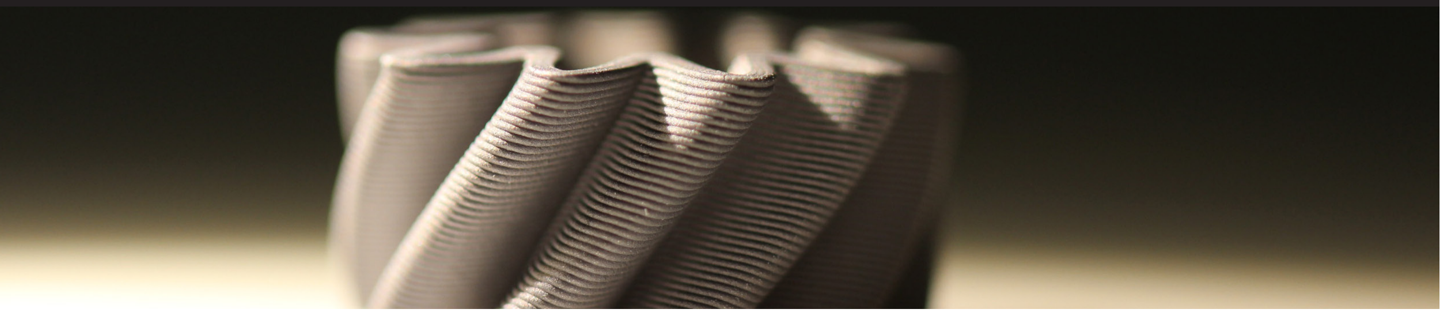
Following her rapid crystal growth research, Zaitseva applied her skills to a radiation detection problem for DHS. The agency was seeking technology to better detect the illicit smuggling of nuclear materials that might be used in the creation of weapons of mass destruction. Zaitseva developed stilbene crystals for detecting neutrons from these materials, a technology commercialized by Inrad Optics.

In 2012, Zaitseva led a team of LLNL researchers in developing the first plastic material capable of efficiently distinguishing neutrons from gamma rays, something not thought possible for the previous five decades. The new technology detected nuclear substances such as plutonium and uranium, that terrorists might use in improvised nuclear devices. The technology has been commercialized by a Texas-based company.

LABORATORY TECH TRANSFER EMPLOYEES CAPTURE NATIONAL AWARDS

DOE’s Technology Transfer Working Group has awarded two LLNL employees with “Best in Class” awards during a spring meeting in Washington, D.C.

Annemarie Meike, a business development executive in LLNL’s IPO, received the Innovative Lab Technology Transfer award for her work with the Lab’s 3D



***From left:** Annemarie Meike, a business development executive within the IPO, received the Innovative Lab Technology Transfer award for her work with the Lab's 3D printing feedstock inks. Mary Holden-Sanchez, a digital assets coordinator within the IPO, won a "Best in Class" licensing award for her work with LLNL's Numerical Electromagnetic Code Antenna Modeling Software.*

printing feedstock inks. These inks enable next-generation, high-performance, 3D-printed devices for energy storage, catalysis, filtration, sensors, and other applications by meeting the flow conditions needed for 3D printing while maintaining and improving the functional properties of the original material.

The commercialization of these inks presented a challenge because of a gap in suitable partners in both the 3D printing and the materials supply chains. The collaboration with MilliporeSigma substantially increases the number of researchers and thus the number of applications for the direct ink write inks in commercial products. In addition, MilliporeSigma regularly solicits feedback from researchers, which it supplies to LLNL for possible ink augmentations.

To meet this challenge, a Technology Commercialization Fund CRADA and special license terms were established with MilliporeSigma, a global science and technology company, that enabled the partnership to collaborate on shelf-life, packaging, and quality assurance, as well as placing the inks in MilliporeSigma's customer catalogs.

MilliporeSigma provides research quantities of materials and has a worldwide customer base of researchers at companies and universities and is the perfect small-scale step toward large-scale commercialization by companies for their specific products. Researchers and potential commercialization partners can purchase small amounts of inks from MilliporeSigma for testing and evaluation. LLNL and MilliporeSigma are now seeking to increase the variety of LLNL's functional inks that will be offered in the Millipore Sigma catalog.

MilliporeSigma

Mary Holden-Sanchez, a digital assets coordinator in the IPO, won a "Best in Class" licensing award for her work with LLNL's Numerical Electromagnetic Code (NEC) Antenna Modeling Software. NEC was originally developed to provide a more accurate method for modeling antennas on naval vessels and became a game-changer for antenna mapping. Once publicly released, NEC was instantly adopted by amateur and professional antenna designers. Commercially, it paved a path toward modern-day cellular, Wi-Fi, and satellite connectivity.

To date, Holden-Sanchez has executed nearly 600 license agreements for NEC with commercial entities, individuals, and government institutions worldwide. NEC remains the most licensed technology in LLNL's software portfolio. NEC versions 4 and 5 continue to be licensed, yielding a continual revenue source for LLNL under Holden-Sanchez's direction.

LICENSES, CRADAS, AND PARTNERSHIP PROVIDE BENEFITS TO THE U.S. ECONOMY

Materials scientist Natalia Zaitseva tests plastic material that distinguishes neutrons from gamma rays.

DOE's national laboratories use licensing agreements with industry partners as the primary vehicle for transferring their innovations into commercial products, and cooperative research and development agreements (CRADAs) with federal agencies and other partners to jointly develop new technologies. In 2021, NNSA sponsored an economic impact study examining all technology transfer agreements that LLNL executed from 2000 through 2020. The survey was conducted by TechLink—a federally funded technology transfer center located at Montana State University.

LLNL staff provided TechLink with information on 205 CRADAs and 218 license agreements they formed with 307 partners. TechLink then sent a survey to the partners, and 96% responded. Some of the partners had multiple agreements. The research team examined a total of 200 CRADAs and 208 licenses, including patent and copyright licenses and other types. NNSA's goal was to quantify the extent to which technology licenses and CRADAs with outside partners contributed to new products and services that benefit the national economy and create jobs, and which agreements transitioned into new technologies that support the U.S. nuclear security enterprise. Results of the study showed that NNSA and LLNL are important contributors to the U.S. economy, and these agreements have

LLNL's laser peening system allows compressive stress to be imparted on metal surfaces approximately four times deeper than conventional shot peening, making components like aircraft parts stronger and extending service lifetime by as much as 10x.

resulted in scientific and nuclear weapons advancements for U.S. safety and security. The areas that TechLink examined included total sales resulting from LLNL's license agreements and CRADAs, nationwide impact, job creation, and cost savings for the U.S. government.

TOTAL ECONOMY-WIDE IMPACT: $8.1 BILLION

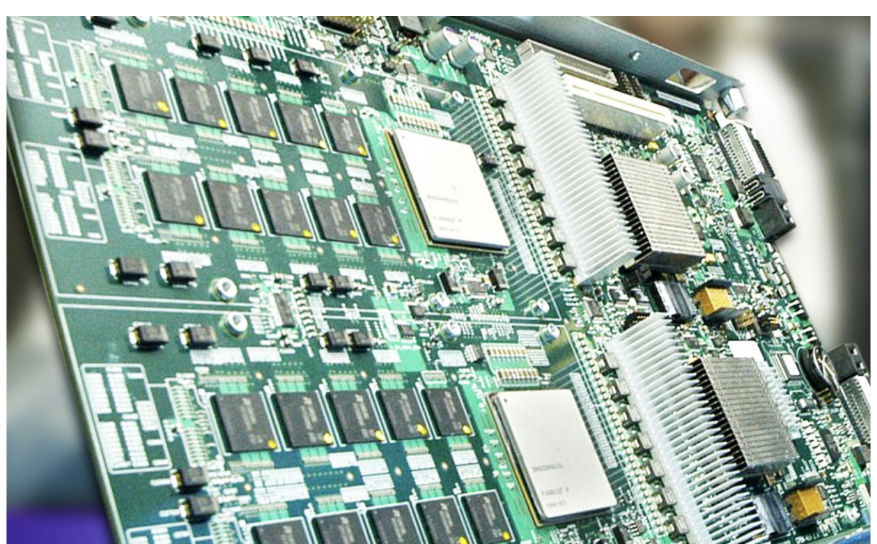
Total sales of products and services manufactured in the U.S. as a result of LLNL's license agreements and CRADAs was $3.5 billion. A total of $2.5 billion of this amount came from sales to non-government clients. The agreements generated an additional $4.6 billion in sales economy-wide—$2.5 billion from inter-industry purchases, and $2.1 billion from increased household spending. For every dollar spent on U.S.-produced goods and services as a result of LLNL's CRADAs and licenses, an additional $1.30 in sales was generated economy-wide. Total cost savings for the U.S. government was estimated to be over $696 million.

The sales resulting from the agreements also supported an estimated 29,072 jobs. The average compensation for the 29,072 jobs was approximately $88,000. For comparison, the third quarter 2020 median earnings in the U.S. was approximately $51,700. Direct labor income from the $3.5 billion in sales of U.S. manufactured products and services was $1.1 billion, or approximately $138,000 per job.

Results from TechLink's survey also found that LLNL's agreements resulted in the creation of 70 new companies, 64 of them were created to pursue the transfer agreements with LLNL, and 6 were created to commercialize the technology results of the agreements.

SPANNING A WIDE RANGE OF U.S. INNOVATION

The products and services that were manufactured as a result of the licenses and CRADAs included electronics, advanced materials, sensors, semiconductors, various computer-related technologies (including cybersecurity and artificial intelligence) environmental technologies, biotechnologies, energy-related technologies, and nuclear weapons



Microchips created with extreme ultraviolet lithography.

Fabricated Stilbene cylinders can detect neutrons in the presence of gamma rays.

development. Instruments and sensors was the most common category (17 percent). Other commonly reported categories were biological or environmental (13 percent), advanced materials (11 percent), advanced manufacturing (10 percent), and lasers and optics (9 percent).

SUCCESS STORIES DEMONSTRATING RESULTS

TechLink published the results of six exceptional agreements in a series of success stories that highlight the contributions of the partnerships. These success stories (listed below) demonstrate how the projects were used to advance scientific understanding and support NNSA's missions.

- Laser peening technology with major impacts on the F-22 and F-35 B and C model fighter jets.
- Satellite imaging technology used by DoD in the Middle East for intelligence.
- Software modeling for simulating structural integrity testing at nuclear power plants and nuclear weapons facilities.
- Stilbene crystals to detect and monitor nuclear radiation, treaty compliance, and nonproliferation applications.
- Molecular testing technology development that has been used in the battle against SARSCoV-2.
- A multi-lab CRADA involving LLNL, Sandia, and Lawrence Berkeley collaborating with private consortium EUV LLC, which allows the semiconductor industry to reduce the cost of chips and speed up the time it takes to develop new chips.

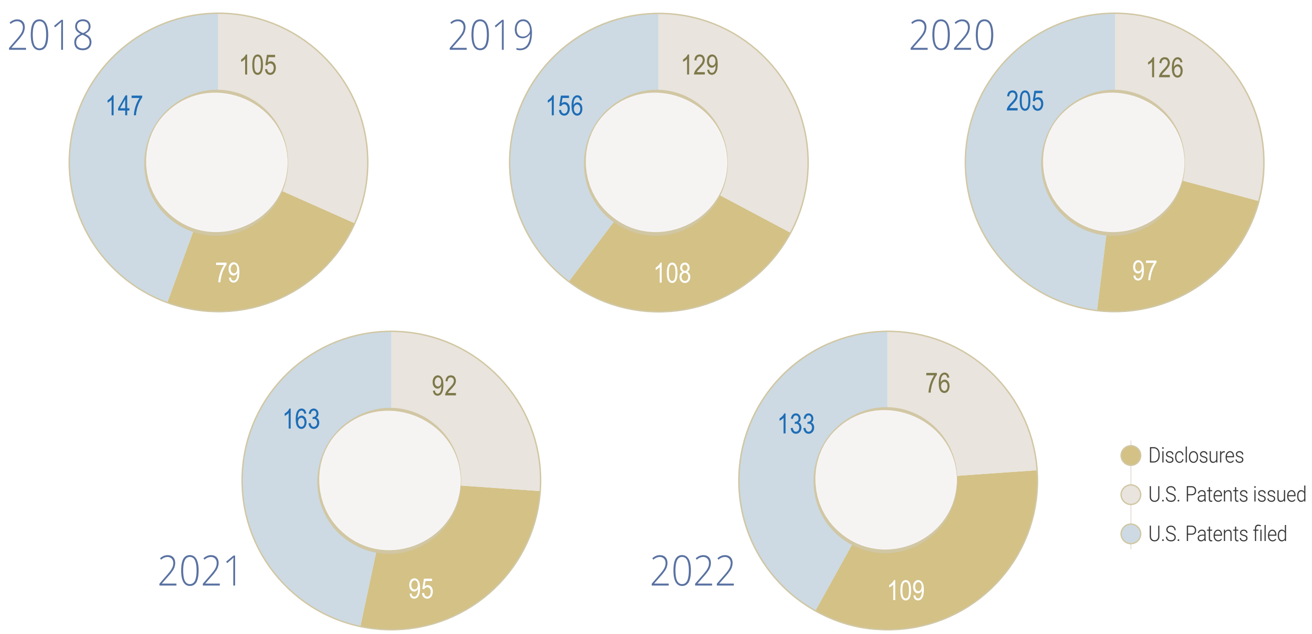
In addition to reporting on sales of new technologies and other economic benefits, the most common responses from the respondents were that the license(s) or CRADA(s) they formed with LLNL provided new knowledge and insight about the technologies, benefits from collaboration and exchange of expertise, and new or marketable improved products. Benefits respondents viewed for LLNL, NNSA, or DOE included that the license(s) or CRADA(s) provided royalties to the Lab, new knowledge on Lab technologies, a practical application to which LLNL can apply their technologies, and access to new data, feedback, and test results.

METRICS

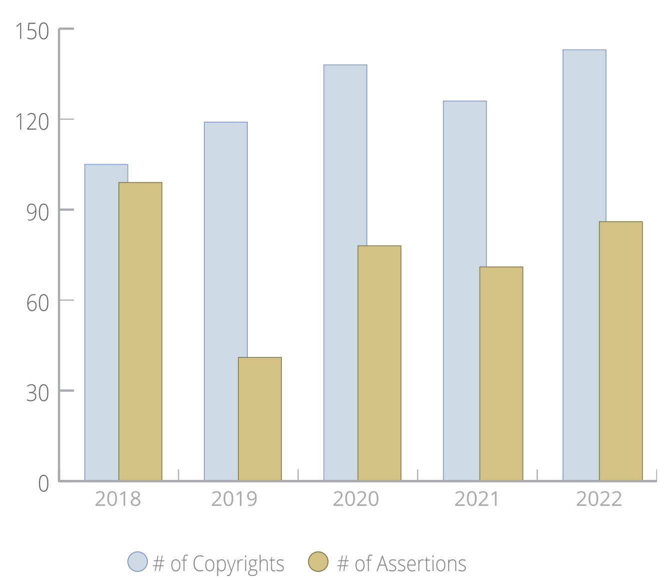
While narratives that describe scientific discoveries at LLNL provide evidence of innovation in action, they do not tell the whole story. Here, we share metrics that serve as quantitative indicators of our success in transferring technology from LLNL to commercial partners.

INTELLECTUAL PROPERTY

LLNL-based inventions were protected by more than 1,000 issued patents and patent applications, including provisional patents, from 2018 to 2022.



COPYRIGHTS

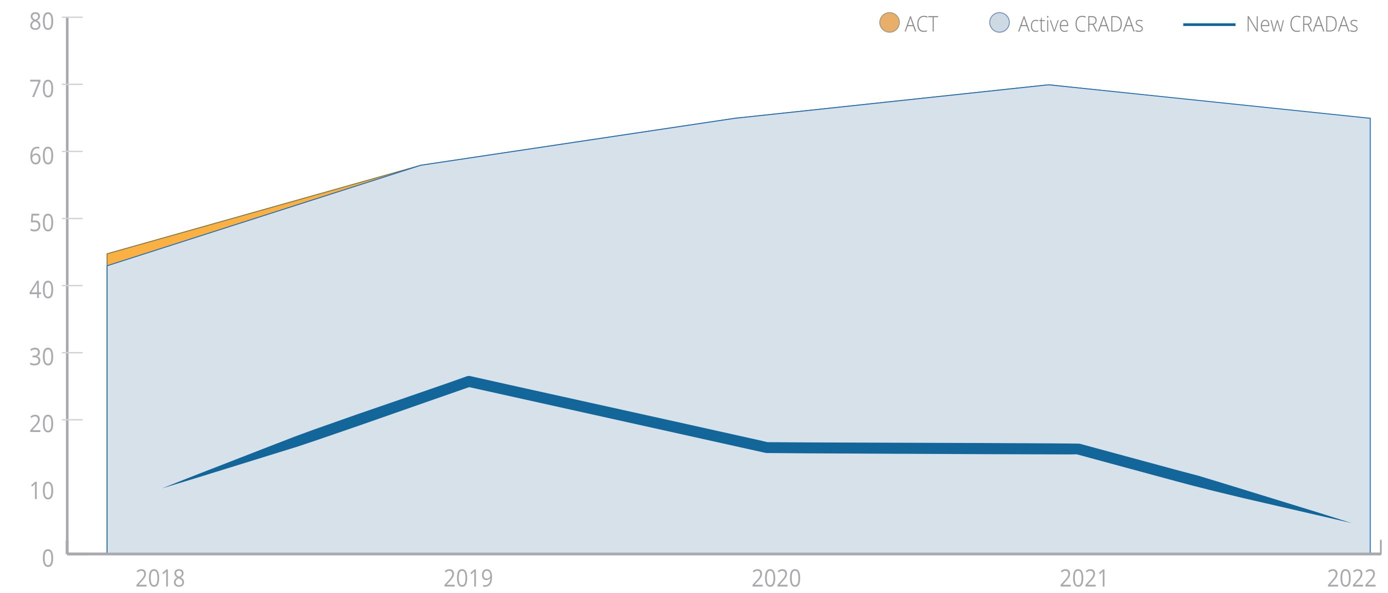


LLNL obtained more than 300 copyright assertions from 2018 to 2022, helping to protect our scientists' intellectual property.

INDUSTRY AGREEMENTS

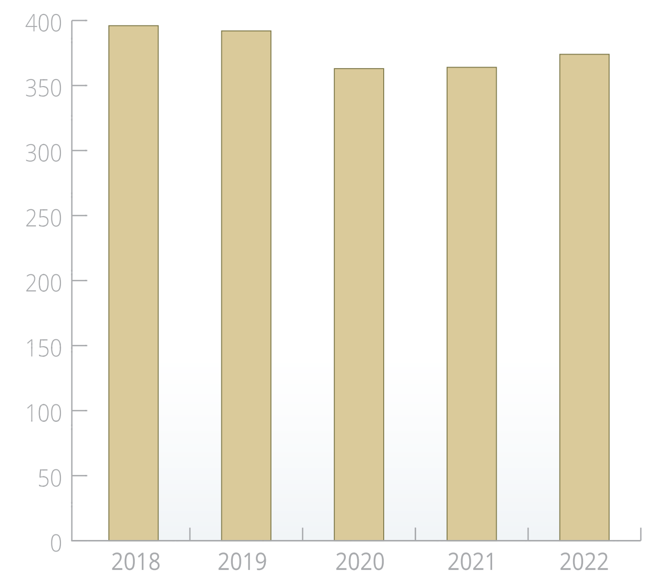
LLNL has maintained nearly 55 active cooperative research and development agreements (CRADAs) annually from 2018 to 2022, which helped our scientists transform promising technology into marketable products.

CRADA/ACT AGREEMENTS



ACTIVE COMMERCIAL LICENSES

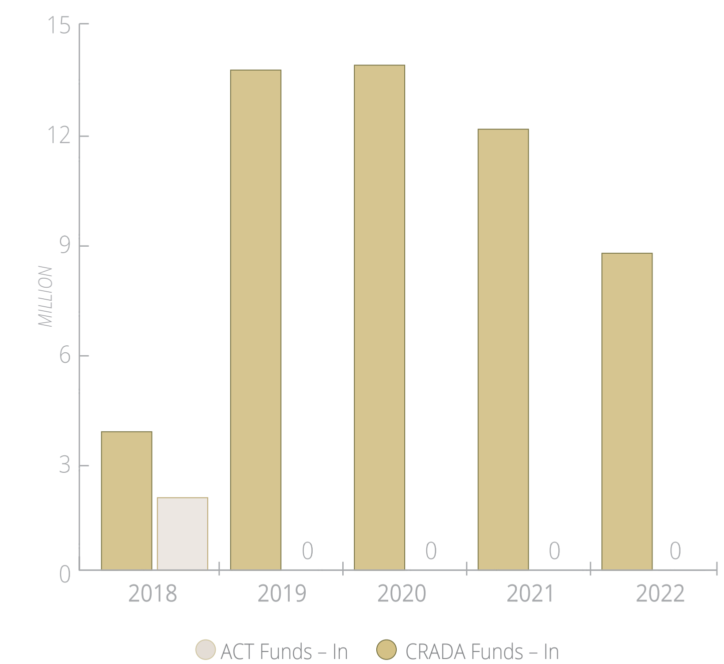
LLNL has maintained nearly 400 active commercial licenses annually from 2018 to 2022.



CRADA/ACT PARTNER FUNDS TO LLNL

($ Millions)

Funds received by LLNL from our CRADA and ACT partners play a key role in our technology transfer activities.



IN MEMORIAM

Richard A. Rankin

Richard Allen Rankin, former director of LLNL's IPO, passed away in June, shortly after his retirement. Richard had led the IPO since 2013, working to broaden the focus to a more business development perspective that closely couples IPO with the Lab's scientific and engineering programs and the local economic development community.

Richard was born on July 4, 1954, in Ladysmith, Wisconsin and graduated from Winter High School in Winter, Wisconsin. He acquired a BS in chemistry from the University of Wisconsin, a MS in chemistry from University of Idaho, and multiple doctorate degrees from British charter schools. He enjoyed a historic career in technology transfer, with more than 35 years' experience in the development, management, and commercialization of innovative technology.

Previously, Richard led the Technology Transfer Office at Idaho National Laboratory (INL). He received the INL Lifetime Achievement Award for Inventorship, received an R&D 100 Award, a George Westinghouse Innovation Award for the Westinghouse Corporation's top inventors, a George Westinghouse Signature Award for engineering excellence, and was inducted into the INL Inventors Hall of Fame. Many of his co-workers described his approach as nurturing and supportive. Upon his arrival to LLNL, he said, "One of the hardest parts of the technology commercialization business is picking winners among the wealth of intellectual property, and then coaching, shepherding, and helping to give birth to a commercial product."

Rich was a gifted manager and outstanding technology transfer professional. Most of all, he was a valuable colleague, mentor, and friend to many. He is missed. Richard is survived by his wife, Janice Rankin; son, Collin Rankin; son, Joshua (Charlee) Rankin; son, Christopher Rankin; daughter, Lindsay Rankin; son, Brian (Emily) Rankin; son, Andrew (Kristen) Rankin; brother, Robert Rankin; grandchildren, Aliyah Rankin, Ryder Rankin, Austin Rankin, Abigail Rankin, Bailee Rankin, Claire Rankin, Amelia Rankin, Liam Rankin, Mila Rankin, Aria Ritthaler, Benjamin Rankin, and Brooklyn Rankin.

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Lawrence Livermore National Laboratory