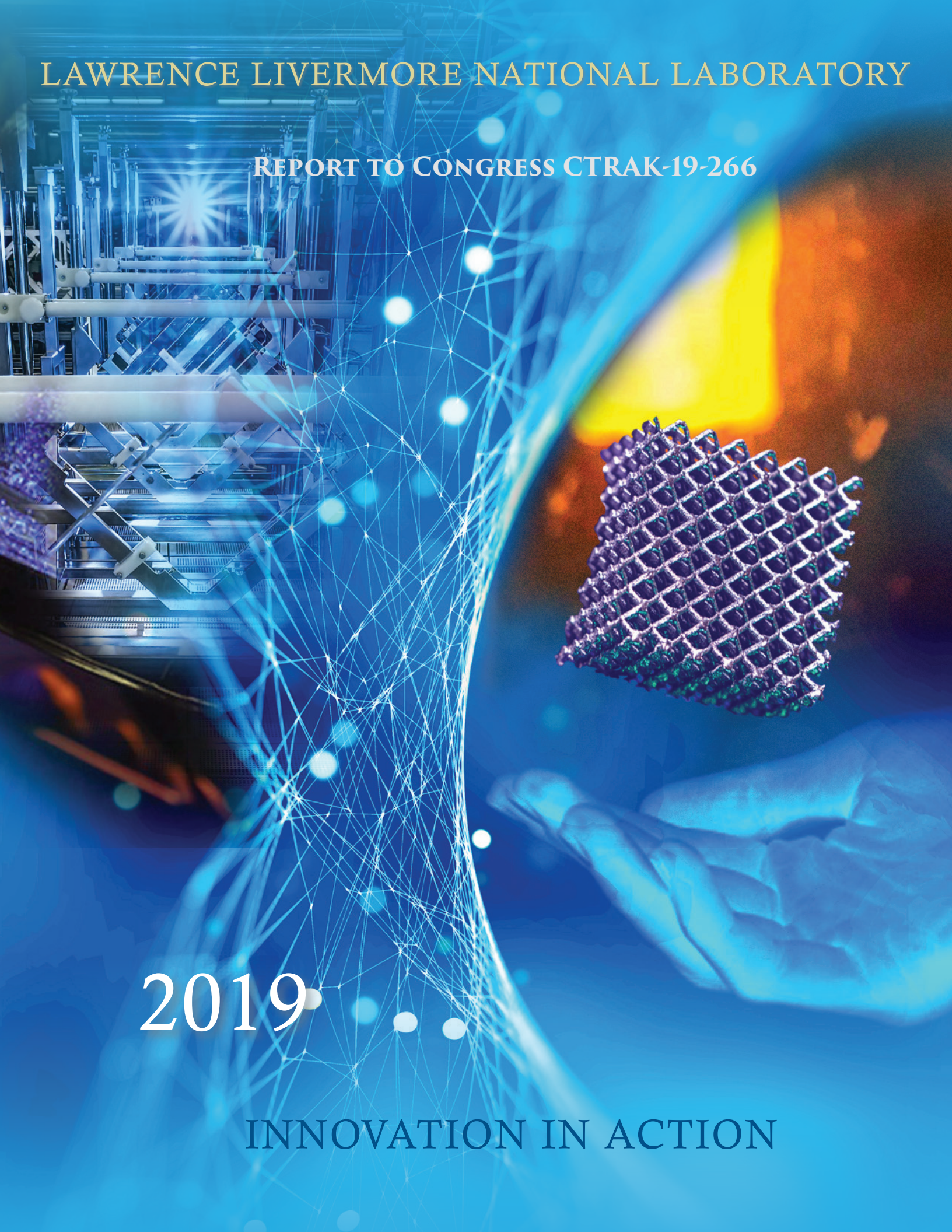
LAWRENCE LIVERMORE NATIONAL LABORATORY

Report to Congress CTRAK-19-266



2019

INNOVATION IN ACTION

Scientific Discoveries
Change Lives and Fuel Economic Growth

Intellectual property (IP) is a driving force in our economy and significantly contributes to our quality of life and culture. According to a 2016 U.S. Patent and Trademark Office report, there are 81 IP intensive industries, and they are diverse in size, scope, and mission. They include software publishing, pharmaceuticals, biomedical devices, and radio and television broadcasting. These 81 IP intensive industries account for more than 38% of U.S. gross domestic product and more than 45 million jobs . . . roughly 30% of all jobs in the U.S.

For decades, research conducted by Lawrence Livermore National Laboratory (LLNL) has improved the lives of U.S. citizens and contributed significantly to the nation's economy. For example, the research results from the Human Genome Project alone generated over $1 trillion in economic output, and benefits the medical, agricultural, environmental and energy sectors. Another example is the Micropower Impulse Radar, a small, accurate, short range, inexpensive radar system that has dozens of applications, including home alarm systems and automobile crash avoidance systems.

Today, LLNL's Innovation and Partnerships Office (IPO) serves as a focal point for the Laboratory's engagement with industry. Our goal is to identify and leverage new economic opportunities and move those opportunities to the private sector. Whether by technology commercialization, encouraging entrepreneurship, or via Laboratory business development activities, IPO's mission is to grow the economy by advancing the development and commercialization of scientific discoveries.

—Richard A. Rankin

Director, Innovation & Partnerships Office

INNOVATION & PARTNERSHIPS OFFICE

COMMERCIALIZING LLNL TECHNOLOGY

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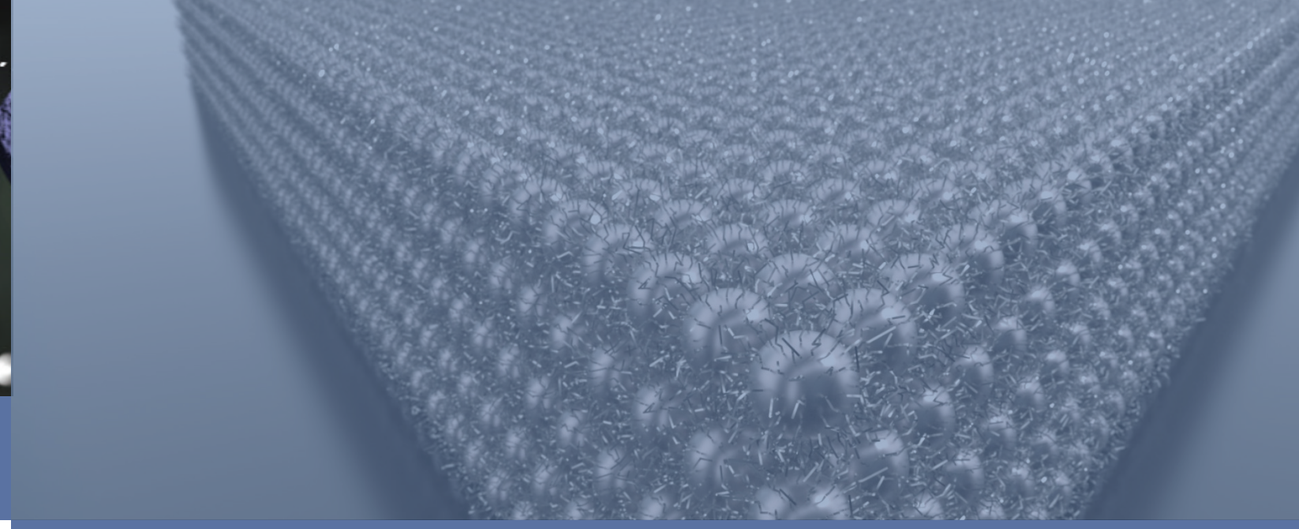
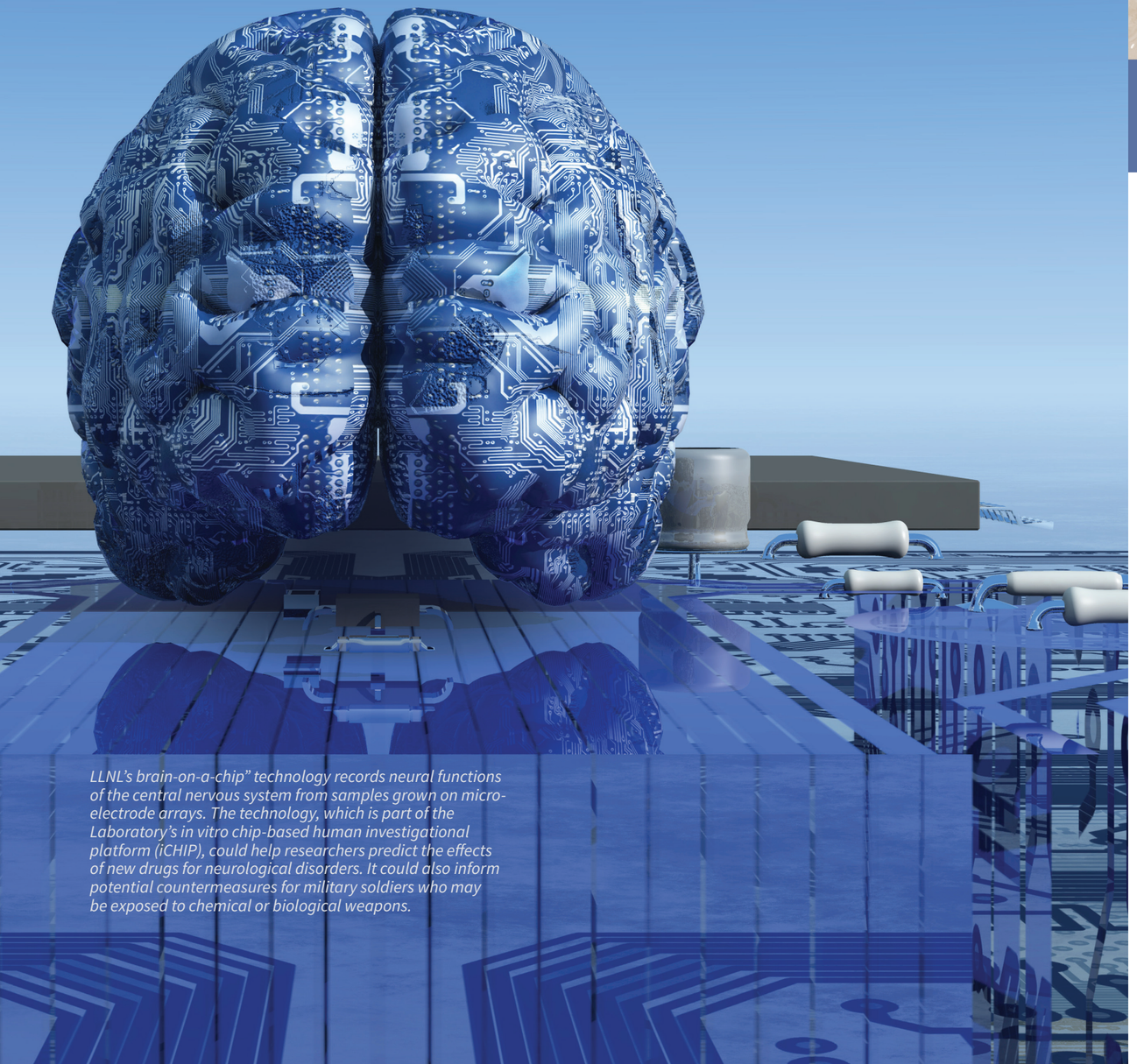
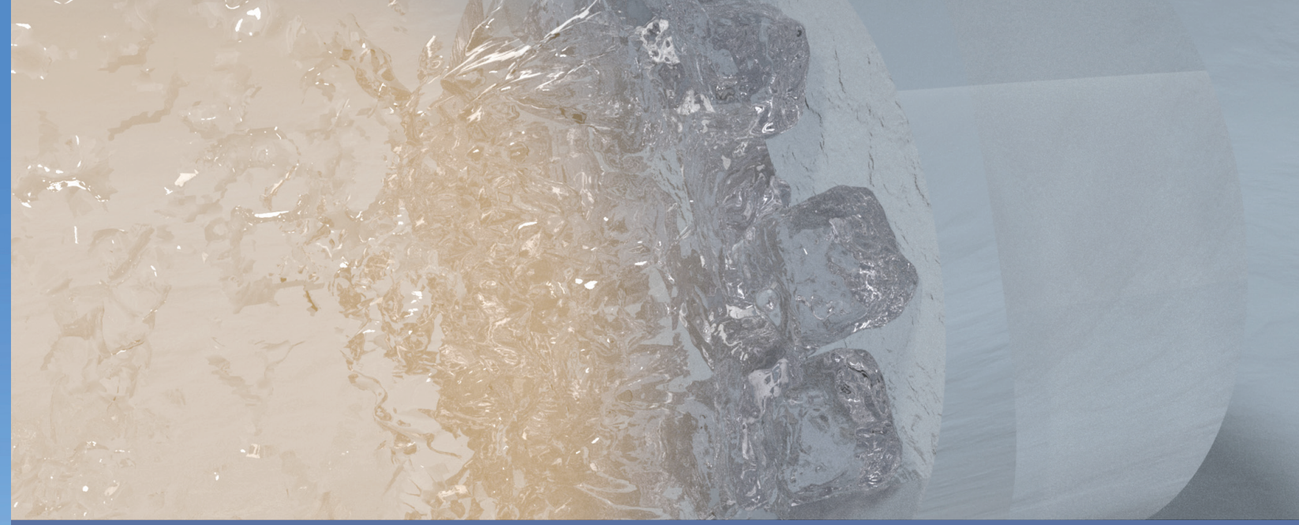


CONTENTS

From the Laboratory
to the **WORLD**



LLNL's brain-on-a-chip" technology records neural functions of the central nervous system from samples grown on micro-electrode arrays. The technology, which is part of the Laboratory's in vitro chip-based human investigational platform (iCHIP), could help researchers predict the effects of new drugs for neurological disorders. It could also inform potential countermeasures for military soldiers who may be exposed to chemical or biological weapons.



EXECUTIVE SUMMARY

In the past 20 years, licenses from Lawrence Livermore National Laboratory (LLNL) helped companies generate more than $3 billion in revenues, resulting in more than $76 million in royalties.

LLNL's world-class science, engineering, and technology programs strive to deliver game-changing solutions to solve challenging problems in national security and in our day-to-day lives. The Innovation and Partnerships Office (IPO) serves as a focal point for the Laboratory's engagement with industry to promote the commercialization of LLNL's scientific discoveries through collaborations and partnerships.

This year's Technology Transfer Report highlights some of IPO's achievements that have helped grow the economy and further Laboratory missions. For example, we have developed technologies that improve laser optics performance and prevent damage to optics mirrors. We are using high performance computing to control variables in additive manufacturing processes and to advance clean energy technologies. Our researchers have also developed software for areas of health; for example, to model the human heartbeat, and to create three-dimensional (3D) images of the brain to diagnose and treat traumatic brain injury.

A number of our technologies continue to make an impact for decades such as: a digital polymerase chain reaction technique that is regarded as the most accurate method for determining the genetic composition of a specimen, a micropower impulse radar that has made radar use possible for a myriad of short-range applications across many global industries, and the first high-throughput microarray that can resolve complete microbial genomes.

In addition to working with innovative Laboratory technologies, IPO sponsors programs such as the NLEA, LLNL Pitch events, and hosts the National Lab Accelerator to enhance the entrepreneurial skills of LLNL's workforce. Sharpening the business skills of our Laboratory researchers strengthens the impact that can be achieved through collaborations and provides LLNL valuable feedback on how the institution can best support our communities regionally, nationally, and globally.

Technologies to Transform Our World

LLNL is at the cutting edge of technology, developing innovations to meet our National Security Mission and transform our world.

Through its high-performance computing (HPC) and advanced manufacturing capabilities, the Laboratory brings together world-class computing resources and scientific and engineering expertise to deliver solutions that can potentially revolutionize state-of-the-art processes. A few of the exciting technologies highlighted in this section include:

- A fabricated surface-relief grating structure that extends overall laser optical power handling capability
- An innovative software package for building three-dimensional (3D) images of an object using just a few views for computed tomography (CT) reconstruction
- A method for combining modeling and simulation with machine learning to control metal additive manufacturing (AM) processes
- A code that models the human heartbeat at roughly the spatial resolution of a heart cell, enabling researchers to model heart conditions with a level of detail not previously achieved

MULTI-LAYER DIELECTRIC GRATINGS ENABLE HIGHER POWER LASERS

Extending Laser Output Power with Multi-Layer Dielectric Gratings

Challenge:

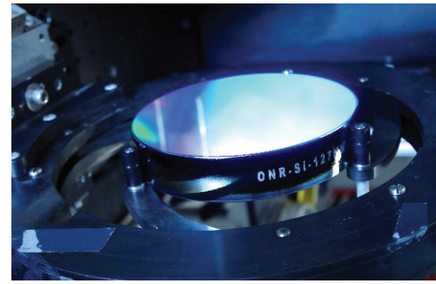
The increased demand for high-power laser sources with diffraction-limited beam quality has led to significant increases in the output power of laser systems. Previous attempts to increase single-output lasers to beyond a few kilowatts have been limited by waste heat removal, maintaining beam quality, and avoiding optical damage. A current approach to increase laser power levels involves using spectral beam combining (SBC), in which a diffraction-grating element combines individual narrowband laser beams, each with nonoverlapping spectra, into a single, broadband high-power output beam. A diffraction grating is an optical component that disperses incoming light into its constituent wavelengths. The SBC concept is in essence a use of the diffraction grating's dispersion properties in reverse. However, in order for SBC to be effective for scaling to 100's of kilowatts, an ultra-low-loss diffraction grating optics system is necessary.

Solution:

LLNL researchers in the Diffractive Optics Group of the NIF Directorate have precisely designed and fabricated surface-relief grating structures embedded into the topmost layer of a highly reflective, ultra-low loss, multilayer dielectric (MLD) thin film stack. These gratings have shown greater than 98% diffraction efficiency over greater than 40 nm bandwidth, extending overall laser optical power handling capability. The Laboratory's SBC grating optics combine the following LLNL key technologies:

- LLNL proprietary optical coating designs utilizing more than 100 thin film layers, enabling ultra-low-loss, part-per-million transmission loss levels through the coating, high diffraction efficiency, and large bandwidth
- LLNL proprietary dispersive surface relief structure design with perfect impedance matched to the thin film stack for optimum optical performance
- Ability to fabricate dispersive surface relief structure and advanced optical thin film coating on superior, thermally conductive materials such as silicon and silicon carbide
- LLNL proprietary processing techniques permitting the fabrication of optimum optical design

LLNL demonstrated the first hafnium oxide (HfO_2) SBC grating optic with ultra-low absorption and 2.8MW/cm^2 laser damage performance. The researchers' tests showed that the HfO_2 SBC grating optics have 2× less heating when illuminated with 2.8MW/cm^2 and 6× higher laser damage threshold than the current baseline configuration when contaminated with carbon particles. The team achieved the new generation of a high-power SBC grating optic by reducing the MLD grating mirror stack absorption more than sixty-fold to sub-part-per-million levels, resulting in smaller heat loading, less optics distortion, and a more robust and higher laser damage threshold performance. These innovative MLD grating solutions improve the performance, reliability, and lifetime of optics, permitting higher power operation without laser-induced optical damage.



LLNL's new generation of high-power SBC grating optics has numerous advantages over the current baseline configuration being provided.

Collaboration:

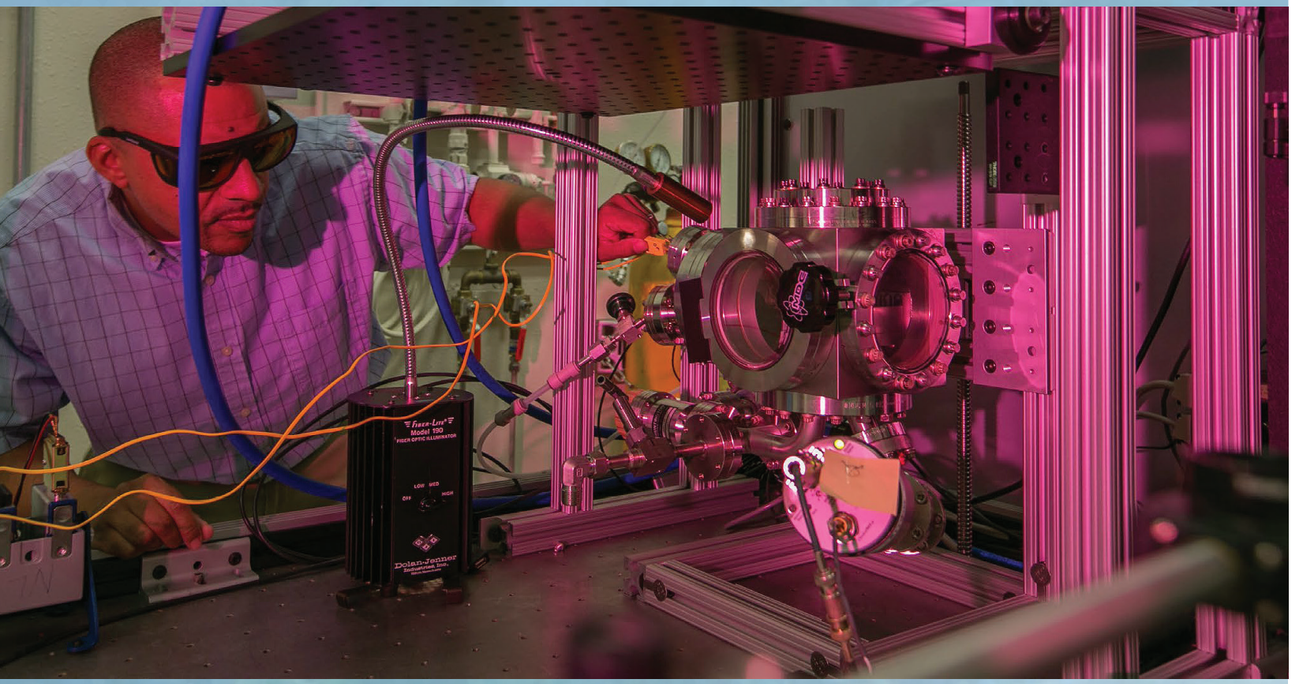
Several high-power laser system and optical component manufacturers are interested in partnering with LLNL through CRADAs and licenses to commercialize the revolutionary new SBC optic and related MLD grating technologies. These new partnerships build on past successes such as the collaboration with Lockheed Martin and Advanced Thin Films which demonstrated SBC scaling to 30kW, netting the team a 2014 R&D 100 Award entitled: EXtreme-power, Ultralow-loss, Dispersive Element (EXUDE).

In 2018, LLNL built and delivered the High-repetition-rate Advanced Petawatt Laser System (HAPLS) to the Czech Republic's Extreme Light Infrastructure Beamlines Facility. HAPLS represents the ultimate advancement of ultrashort pulse laser technology made possible by the 2018 Nobel Prize winning Chirped Pulse Amplification innovation, which was co-invented by former LLNL researcher Donna Strickland and enabled with LLNL's highest performance MLD gratings.

LLNL's Multilayer Dielectric Grating enables the use of higher power lasers by combining separate laser beams into a higher-power single beam. It thus reduces heat and protects laser optics from damage.

Impact:

LLNL is the preeminent research lab developing large-aperture, high-damage-threshold diffraction gratings and other diffractive optics which are important to high-energy and high-power laser system manufacturers and users. We are the only developer of polarization-insensitive SBC grating optics. LLNL's MLD grating technology extends the lifetime and performance of high-average-power pulsed laser systems for scientific applications and lasers for emerging directed-energy systems. As demand for higher laser power levels increases, LLNL's SBC optic and MLD grating technologies are a force multiplier for directed energy solutions to meet critical national security needs.



INTELLIGENT FEED FORWARD (IFF) FOR ADVANCED MANUFACTURING

Accelerating the Certification of 3D-printed Metal Parts

Challenge:

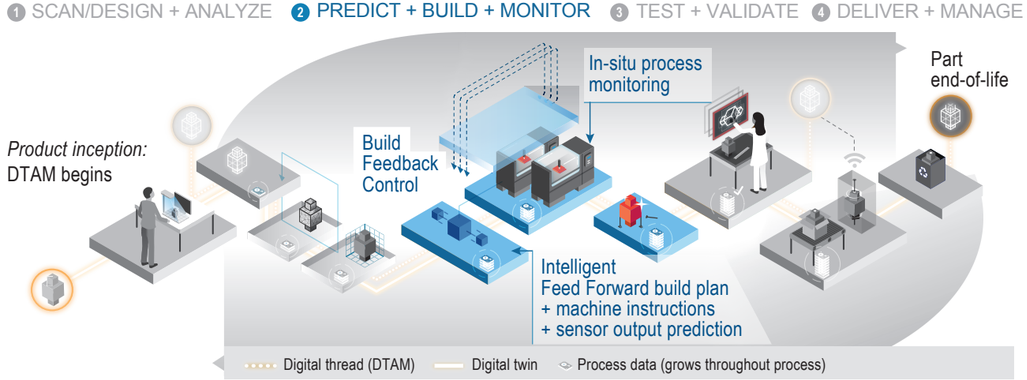
Interest in additive manufacturing (AM) technologies continues to grow as advances are made in the hardware, software, and design processes that are involved and as industries reap the benefits from its diverse applications. However, ensuring the quality of the final manufactured part is a costly and time-consuming process because the thermal boundary conditions that exist during the manufacturing process change as a function of the geometry of the part being manufactured. In addition, about 150 parameters such as laser power, speed, and beam size; metal particle size; particle type; etc., also influence the thermal state of the part and must be controlled throughout the process. In traditional powder bed fusion (PBF) systems, researchers can set geometry-specific parameters for the material's characteristics; however, there is a limit to the control they have over all the various parameters. Researchers must conduct multiple trial and error post processing runs to optimize the build, reduce residual stresses, and meet the required tolerances. Inherent variabilities throughout the processing lead to inconsistent tolerances, mechanical properties, and defects.

Solution:

Controlling the geometry-specific process throughout a build to achieve a precise, optimized, 3D map of input parameters is referred to as intelligent feed forward (IFF) control. A team of LLNL researchers came together and suggested that modeling and simulation combined with machine learning, diagnostics, and HPC optimization had the potential to gain control over the metal AM process. The team developed high-speed, part-scale surrogate models that approximate the critical physics to implement IFF, and they used process simulation and optimization to "teach" the AM machine how to build the part on a voxel-by-voxel basis (voxels are values on a grid in 3D space, usually expressed relative to each other). The team incorporated a monitoring feedback control system to correct the simulation-based build where necessary. After completing the build, they compared the process monitoring data with a prediction of the output from the simulation. They demonstrated that IFF mitigates a broad array of part defects that occur with commercial AM machines.

Collaboration:

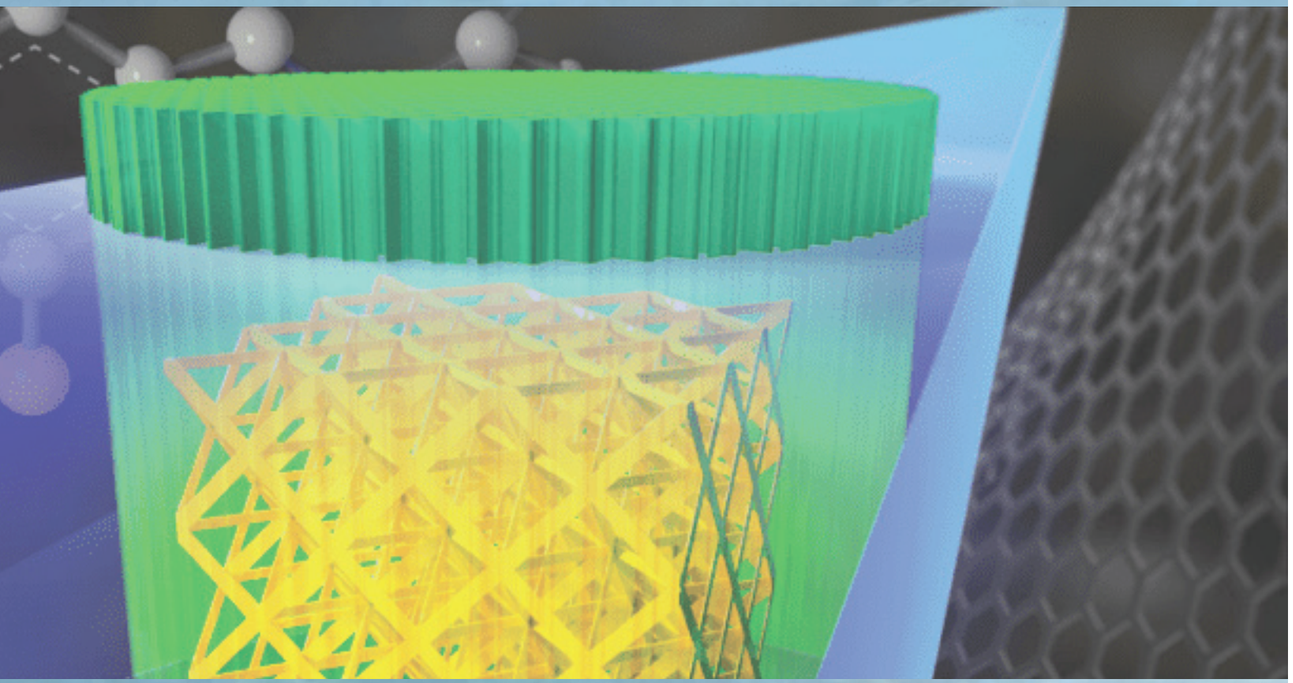
In 2016, recognizing the value in designing a deployable system on a commercially available laser PBF machine, LLNL researchers established a CRADA with General Electric (GE) Global Research Center, an innovator in the AM space. The company's AM machines, which use laser PBF technology (also known as direct metal laser melting), was the ideal platform to serve as a candidate for IFF. LLNL and GE created an open source software platform that can support IFF and utilize sensors to monitor the process in real time to ensure quality AM metal parts.



An overview of the metal AM process flow. LLNL's technology (in blue) builds in feedback control, provides in-situ process monitoring, and creates an IFF build plan to ensure the correct product is developed right, every time.

Impact:

IFF helps ensure "every time right" production of complex metal parts and reduces the need to lock down processes for production runs. It also compensates for machine-to-machine and alloy-to-alloy variation, which makes the technology attractive for a wide array of industries. Adopting IFF at Kansas City Nuclear Security Campus (KCNSC) and other NNSA laboratories will enable the facilities to meet their production demands in shorter time and lower cost to the U.S. government.



LIVERMORE TOMOGRAPHY TOOLS (LTT) RECONSTRUCT 3D IMAGES

An Accurate, Fast, and Flexible Software Solution for Image Data Processing and Reconstruction

Challenge:

Computed tomography (CT) is one of the most common imaging modalities used in industrial, healthcare, and security settings. It is widely used at LLNL for non-destructive evaluation. During a CT scan, a narrow beam of x-rays is used to produce signals that are processed by a computer to generate cross-sectional images or slices of an industrial product or part of the human body, in the case of its use in healthcare. A number of these tomographic image slices are then digitally stacked together to form a 3D image.

The method allows the reconstructed 3D image to be viewed in space or as individual slices; however, conventional CT scanning systems require the number of projections (views) to be roughly equal to detector pixels in a projection. When the number of projections is one or more orders of magnitude smaller than this, streak artifacts pollute the reconstructed image, unless specialized algorithms are applied. Frequently, the specialized algorithms take much more time to process and/or may not significantly reduce the noise in the image. Consequently, CT scanning systems aren't as helpful for applications that require high throughput (i.e., industrial non-destructive evaluation or cargo screening) or low doses (medical). This deficiency limits industry adoption. CT performance improvement is essential as the need for more challenging CT imaging with different materials in various sizes increases.

Solution:

LLNL has developed an innovative software package for CT reconstruction. Livermore Tomography Tools (LTT) implements advanced algorithms to build 3D images of an object using just a few views, compared to the thousands of views that are typically necessary for traditional CT scans. LTT is platform independent and capable of processing data on one or more graphical processing units (GPUs) or other hardware accelerators.

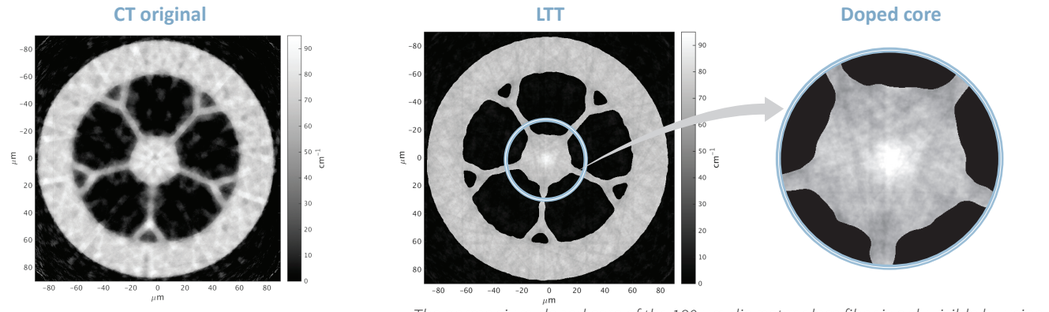
LTT can be used as a stand-alone application, accessed as a library from existing applications, or used with a separate graphical user interface. This versatility greatly enhances LTT's usability and provides a means to simultaneously process, reconstruct, and analyze CT data and volumes. The algorithms in LTT are capable of processing CT data from raw detector counts to reconstructed volumes and are designed to provide quantitatively accurate results (with specified units) in a timely manner. Most conventional scanner geometries are supported, as well as modern fixed gantry systems in which the user provides the location of every x-ray source and detector pair and the detector orientation in a text file.

LTT's Value

Reduced Processing Time: Requires only a few views of the original object for accurate 3D reconstruction

Accuracy: Provides quantitatively accurate results independent of the system

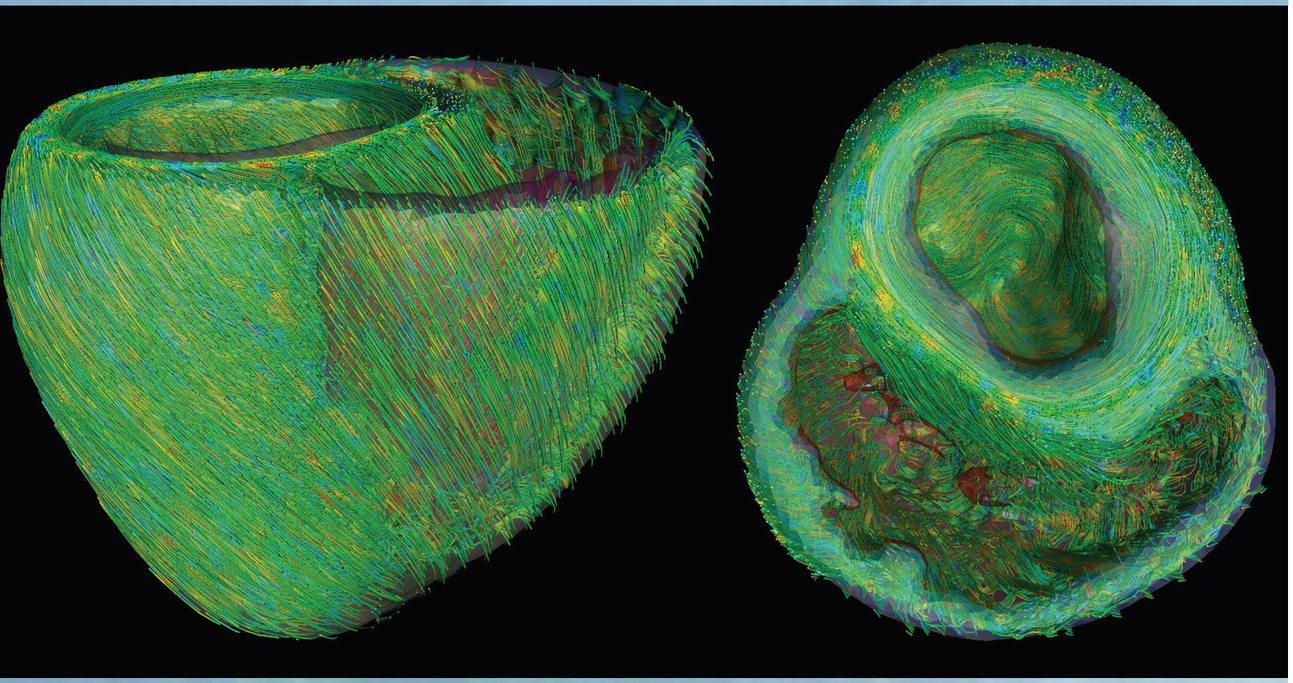
Flexibility: Processes data from any CT geometry, independent of the computing platform



The germanium-doped core of the 180 um diameter glass fiber is only visible by using LTT to reconstruct the 19-view dataset.

Impact:

By reducing the time needed to properly reconstruct a 3D image of a scanned item, LTT can increase throughput and reduce image processing labor costs for applications such industrial quality control scanning and airport baggage screening. If used for medical diagnostics applications, LTT has the potential to significantly reduce the number of scans required—which further reduces both the patients' exposure to radiation and the operational costs and time demands on healthcare providers. LTT provides quantitively accurate results independent of the system, and its flexibility allows data to be processed from any CT geometry, independent of the computing platform, making it suitable for many industrial applications.



CARDIOID SIMULATES HEARTS MAKING SAFER DRUGS

Cardioid: Electromechanical Simulation of a Heartbeat

Challenge:

Accurately simulating the electrophysiology involved in a heartbeat is a challenging task. Although scientists understand how a heart beats, representing that in a simulation code requires deep expertise in both biology and computer science. A big motivation for simulating the heart stems from the need to avoid cardiotoxicity—the toxic effect of drugs on the heart. Understanding how a drug might cause an irregular heartbeat prior to the administration of the drug to a patient can save time, money, and lives. Currently, cardiotoxicity studies are done using animal models. The ability to accurately simulate how a drug might create an irregular heartbeat could mean that animal studies could be reduced if not replaced.

Solution:

A team of LLNL researchers has optimized a code that models the human heartbeat for GPU-based supercomputers. The Cardioid code allows simulation at roughly the spatial resolution of a heart cell, providing researchers with a level of detail not previously achieved. With the combination of a 3D discrete model of the human heart and software to reconstruct the anatomy of a torso, Cardioid offers a multiscale simulation capability spanning from subcellular mechanisms up to clinical signals collected from actual patients.

The software suite simulates the electrical current running through the heart tissue, triggering cells to contract like cascading dominoes and causing the heart to beat. With Cardioid simulations, one can generate as much virtual data as needed, and then train a machine learning algorithm that can bring actual clinical results on how the heart is functioning. Cardioid provides the extended cardiac simulations necessary to investigate how specific medications affect the heart rate—information that could aid medical centers, pharmaceutical companies, and medical device firms in discovering new drugs and patient-specific therapies to treat cardiovascular disease and improve heart health.

Collaboration:

The original version of Cardioid was developed by LLNL's computational scientist David Richards, and IBM for the Laboratory's Sequoia, at one time the world's fastest supercomputer. Cardioid was a finalist for the 2012 Gordon Bell Prize, supercomputing's top honor. Researchers wanted Cardioid to be portable to other computers, so in 2016, computer scientist Rob Blake came to the Laboratory and was tasked with scaling the code for the heterogenous CPU/GPU systems that would displace Sequoia: Sierra and its counterpart, Lassen.

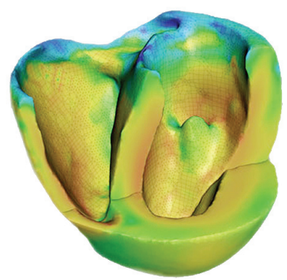
With help from computational biologists at IBM's Center of Excellence, Blake and his team set out to release Cardioid as open source and to generalize the code for the new supercomputing systems, redesigning the code to be portable as well as fast. A community of open users were then able to validate and optimize the code for various purposes.

"To take hard medical problems, simulate them first and study what will happen, and then apply the therapy, that's going to be the future of medicine."

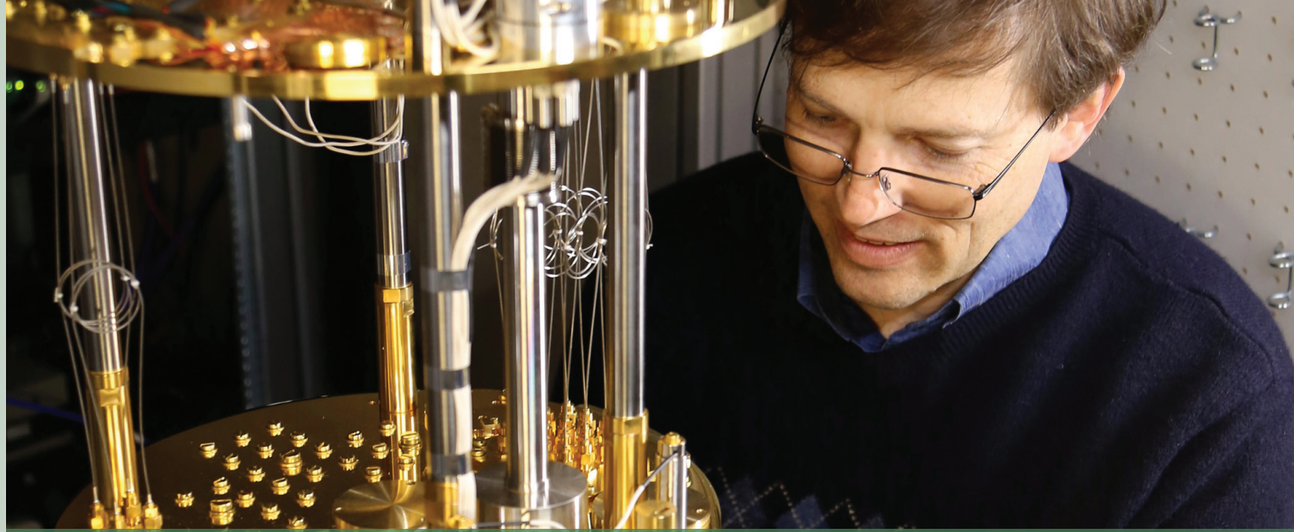
—Rob Blake,
LLNL's lead Cardioid inventor, giving a presentation about this heartbeat simulation tool at the Center of Excellence Celebration in July 2019.

Impact:

A collaboration with the Food and Drug Administration (FDA) for Cardioid's use in a clinical setting would take the simulation code to the next level to virtually screen potential new prescription drugs for their effect on the heart without having to test drugs on animals. Cardioid has the potential for a wide range of applications, such as helping medical researchers better understand the mechanisms leading to heart ailments and the potential drug interactions that may occur during treatment.



Cardioid allows one to test for heart arrhythmias, and it simulates EKGs in nearly real-time using LLNL's supercomputers.

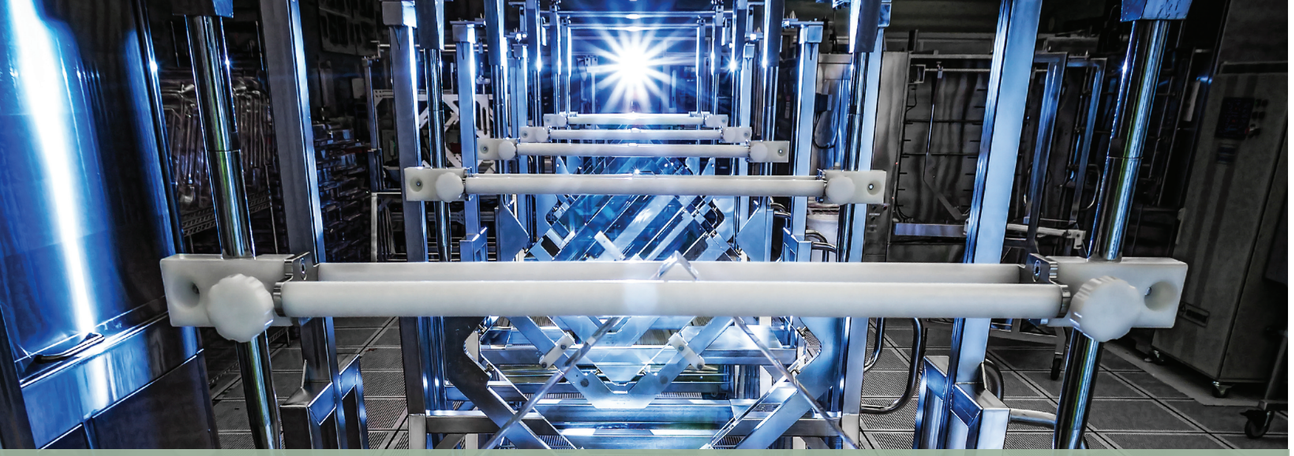


Partnering to Boost Economic Development

Partnerships enhance core capabilities, nourish cross-fertilization of ideas, and contribute to maintaining a vibrant intellectual environment. Strategic partnering includes working with academia and the local community, where agreements bring fresh ideas and talent to basic research projects.

Partnerships facilitate new ideas from industry and academia to help Laboratory researchers better serve LLNL missions. For example:

- A collaboration with Stanford University is focusing on creating multi-scale models and prototype devices for the electrochemical production of chemicals from CO_2
- A partnership with Edmund Optics, a global leader in laser optics manufacturing, is extending an LLNL-developed technology into a commercial system capable of polishing high-quality industrial lenses and mirrors
- An initiative that includes Lawrence Berkeley National Laboratory (LBNL), Argonne National Laboratory (ANL), and University of California San Francisco (UCSF) is using supercomputing and artificial intelligence to “read” MRI and CT scans and develop a method to inform the diagnosis and treatment of traumatic brain injury (TBI)
- The HPC4Energy Innovation program offers a low-risk path for U.S. manufacturing companies interested in adopting high-performance computing (HPC) technology to advance clean energy technologies and increase energy efficiency



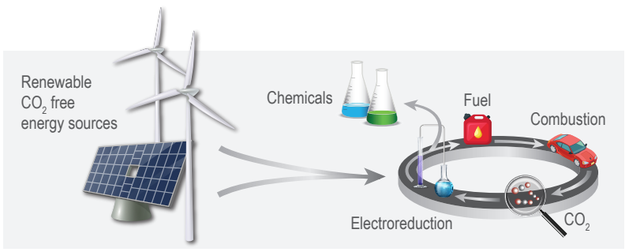
COMMERCIAL PARTNERSHIPS

Developing Prototype Electrochemical Reactors for CO_2 Reduction

TOTAL American Services, a U.S. subsidiary of the French multi-national oil and gas corporation, TOTAL S.A., once again sponsored a research collaboration with LLNL and Stanford University's Center for Interface Science and Catalysis (SUNCAT). The collaborative research initiative focuses on creating multi-scale models and prototype devices for the electrochemical production of chemicals from CO_2 and will provide a basis for industrial-scale design rules for electrodes, reactors, and system considerations.

The project is part of TOTAL's efforts to be a leader in carbon capture, utilization, and storage technologies—a research area that is also a key emphasis at LLNL and SUNCAT. Together, the organizations will explore ways to increase the rate of performance optimization, and therefore commercialization, of CO_2 electrochemical reactors. The broad impact of commercialization of this technology will be allowing waste CO_2 to be used as a feedstock for electrochemical reactors, thereby reducing CO_2 emissions and reliance on fossil resources for fuels and chemicals.

TOTAL will invest more than $10 million over 5 years in this collaboration. The effort leverages the institutions' complementary capabilities and experience in advanced manufacturing, high performance computing, multiscale modeling and design optimization, catalysts, electrodes, and electrochemical flow devices.



Electrochemical reduction of CO_2 to valuable fuels and chemicals using renewable sources of electricity.

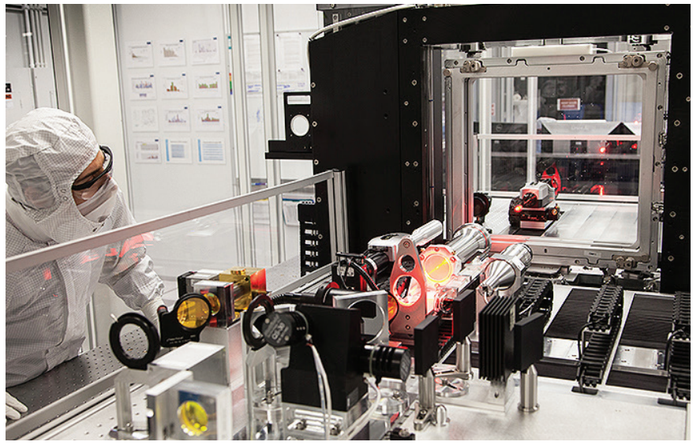
Using Lasers to Repair Optics Spawns New Partnership

A new optical technology collaboration has been formed between LLNL's National Ignition Facility (NIF) and New Jersey-based Edmund Optics. When very large fluxes of energy pass through the optics of the 192 beams comprising the world's highest-energy laser, tiny pits in the optical glass can enlarge to become damage sites that compromise performance. Edmund Optics became interested in partnering with the Laboratory after hearing a presentation that LLNL Materials Science Group Leader Ibo Matthews and staff scientist Nan Shen gave describing the Laboratory's approach used to mitigate damage to NIF's optics.

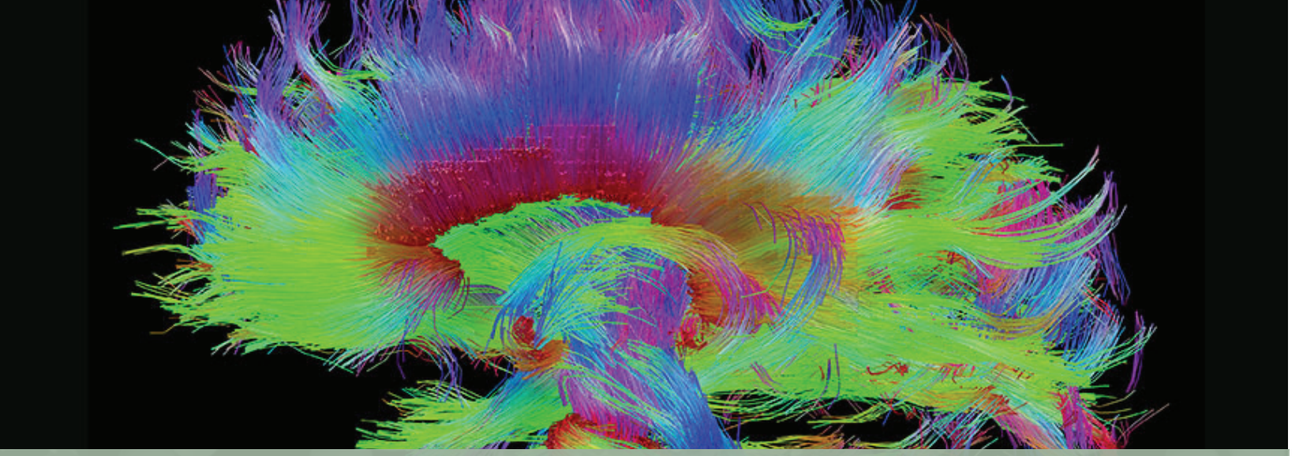
Research for LLNL's mitigation process was primarily funded by the Laboratory Directed Research and Development (LDRD) Program. The researchers developed a method that uses carbon dioxide lasers to repair damage on the surfaces of silica optics, smoothing their imperfections. The scientists realized that the same process could be used for the laser polishing of glass, even the localized repair of NIF optics.

Edmund Optics has invested heavily in research and development toward becoming a global leader in laser optics manufacturing. The company established a Cooperative Research and Development Agreement (CRADA) to work with LLNL. The partnership's goal is to extend LLNL's technology into a commercial system capable of polishing industrial lenses and mirrors to the same high surface quality demanded by NIF. Edmund Optics is considering using the LLNL's new Advanced Manufacturing Facility (AMF) for the later phases of the collaboration.

Optics Mitigation Facility operator Constantine Karkazis inspects the facility's CO_2 laser processing hardware. Credit: Bruno Van Wonterghem.



NIF researchers have developed a method to mitigate optics laser damage using laser ablation.



TECHNOLOGY IMPACTS

LLNL Supercomputers Accelerate Diagnosis and Therapy of Traumatic Brain Injury

Since 2000, more than

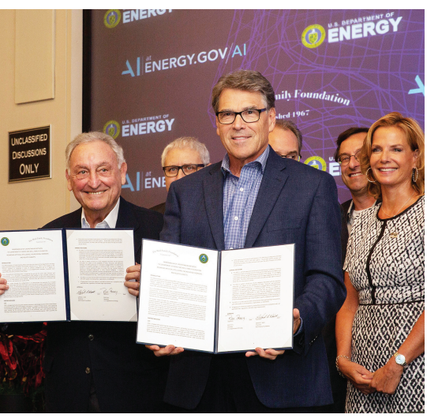
380,000

servicemen and women have been diagnosed with TBI.

Since the wars in Afghanistan and Iraq began in 2001, more than 380,000 cases of TBI in servicemen and women have been reported to the Department of Defense (DoD). There is currently no acute treatment for TBI and few tools exist to aid clinicians in providing a prognosis for TBI patients. Researchers from LLNL, LBNL, and ANL are collaborating with UCSF's Transforming Research and Clinical Knowledge in the Traumatic Brain Injury (TRACK-TBI) initiative to use supercomputing and artificial intelligence (AI) to enable better diagnosis and treatment of TBI.

The team will combine clinical data (e.g., MRI and CT scans) from 3,000 patients with HPC simulation and AI to develop a predictive model to better understand how the brain works and responds to trauma. The model could be used to categorize or triage patients into risk categories and assess potential outcomes combining clinical data.

In addition to enhancing existing capabilities within DOE's mission space, the TRACK-TBI effort aligns with the goals of Energy Secretary Rick Perry and other high-ranking DOE officials to use advanced computing technology and capabilities at the national laboratories in service of veterans. LLNL's TBI research began this January when the Laboratory hosted a visit from several national laboratories, the Department of Veterans Affairs, and UCSF. In March, Perry visited the Laboratory and scientists demonstrated that using supercomputers to process MRI data reduces tasks from the hours it normally takes at state-of-the-art research university settings to minutes. This reduction in time could enable researchers to use the methods in a clinical setting. In August this year, Perry and Sandy Weill of the Weill Family Foundation signed a MOU to apply DOE's HPC and AI capabilities to study how the technologies can be used to prevent, treat, and repair neurological damage.



U.S. Secretary of Energy Rick Perry and Sandy Weill, founder of the Weill Family Foundation, signed a MOU to form a partnership that will apply DOE's AI capabilities to advance transformative scientific opportunities in biomedical and public health research.

A greater understanding of TBI incidents in the military also has implications for promoting safety for athletes. The National Football League (NFL) has studied concussions and TBI for several years and has collaborated with DoD, the National Institutes of Health, and the National Institute of Standards and Technology on research. In 2018, the NFL awarded two grants totaling more than $11 million to the TRACK-TBI initiative.

If successful, the TRACK-TBI project will improve TBI diagnosis and classification/taxonomy, improve TBI outcome assessment, help identify the health and economic impact of mild TBI, and create a "information commons" to promote collaboration and acceleration of TBI research.

TRACK-TBI
Transforming Research and Clinical Knowledge in Traumatic Brain Injury
International Traumatic Brain Injury Research Initiative

A CLOSER LOOK

A traumatic brain injury (TBI) is caused by a bump, blow, jolt, or penetration to the head, causing an injury that disrupts the normal function of the brain. Not all blows or jolts to the head result in a TBI. The severity of a TBI may range from "mild," i.e., a brief change in mental status or consciousness to "severe," i.e., an extended period of unconsciousness or loss of memory after the injury.

"This type of project is possible only when we bring together the new levels of computing capability available in the Department of Energy with the revolutionary analytics being developed through machine learning"

— Jim Brase,
LLNL's Deputy Associate
Director for Computation

SUPERCOMPUTERS ACCELERATING INDUSTRY

HPC4 Energy Innovation

The High Performance Computing for Manufacturing (HPC4Mfg) program has expanded to include two other areas of energy innovation: the HPC for Materials in Applied Energy Technologies (HPC4Mtls) program, and the HPC for Mobility (HPC4Mobility) program. HPC4Mfg, HPC4Mtls, and HPC4Mobility, were funded by different DOE programs, and now they have now been brought together under one roof called the HPC for Energy Innovation (HPC4EI) to leverage the world-class computational resources at the national laboratories that connect with industry to advance the national energy agenda. The program pays laboratories up to $300K for industry access to HPC resources and expertise while industry pays at least 20 percent of project costs. Companies submit concept papers and if accepted, a laboratory PI is assigned to help the company develop a full proposal. Winning proposals are selected 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.

HPC4Mfg Program

The goal of the HPC4Mfg program is to enhance the adoption and advancement of HPC through addressing manufacturing challenges such as optimizing production processes, enhancing product quality, and speeding up design and testing cycles while decreasing energy consumption.

LLNL leads the program and is joined by LBNL and ORNL. 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 while reducing risk of HPC adoption.

From September 2018 through June 2019, DOE awarded $7.2M for 24 new projects to improve U.S. energy technologies through HPC. LLNL expanded its involvement with the HPC4Mfg program in FY19 through partnerships with:

DOE labs involved in the HPC4Mfg program include:

Lawrence Livermore National Laboratory

Berkeley Lab, Lawrence Berkeley National Laboratory

Oak Ridge National Laboratory

- **VAST Power Systems Inc., and ANL**—Machine Learning tools applied to engine design
- **Seurat Technologies**—Increase speed of additive manufacturing processes
- **US Steel**—Predict microstructure growth during the hot strip mill process
- **AK Steel**—Machine learning tools applied to the hot strip mill process
- **Arcelor Mittal**—Machine learning tools applied to steel slab casting
- **Applied Materials**—Improve magnetron sputtering for LED manufacture

HPC4Mtls Program

In FY19, DOE announced an opportunity to fund up to $3M in projects related to improving materials in severe or complex environments through the new HPCMtls 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.

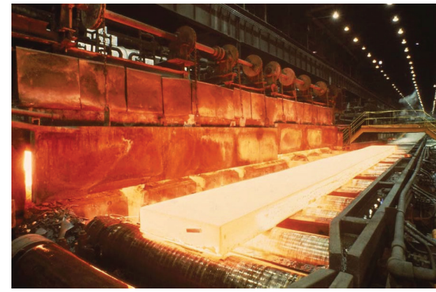
LLNL leads the program and is joined by ORNL, NETL, LANL, and PNNL. HPC4Mtls offers a low-risk path for U.S. manufacturing companies interested in adopting the application of HPC, modeling, simulation, and data analysis to address key challenges in developing, modifying, and/or qualifying new or modified materials. From September 2018 through June 2019, DOE awarded $3.3M for 11 new projects to improve U.S. energy technologies through HPC. LLNL partners with:

- **United Technologies Research Center**—Investigate mechanisms of high-temperature corrosion in nickel-based alloys
- **Carpenter Technologies**—Understand antiphase boundary energies in material microstructures
- **PPG and PNNL**—Increase understanding of polymer aging in auto adhesives

HPC4Mobility Program

In FY19, DOE announced an opportunity to fund up to $1M in projects to create new knowledge tools, insight, and technology solutions that increase mobility energy productivity for individuals and businesses through the new HPC4Mobility program. The HPC4Mobility program brings together industry partners and DOE laboratory scientists to work on short-term, collaborative projects focused on applying HPC to challenges associated with mobility technologies and systems.

ORNL leads the program and is joined by LLNL, NREL, PNNL, LBNL, and ANL. The HPC4Mobility program offers a low-risk path for U.S. companies and local municipalities 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 software, hardware, and implementation solutions that perform well in complex mobility systems. The first projects in this portfolio are expected to be awarded in fall 2019.



The HPC4Mfg CRADA with US Steel focuses on predicting microstructure growth during the hot strip mill process, pictured above.

DOE labs involved in the HPC4Mtls program include:

Lawrence Livermore National Laboratory

NETL, National Energy Technology Laboratory

Oak Ridge National Laboratory

Los Alamos National Laboratory, Est. 1943

DOE labs involved in the HPC4Mobility program include:

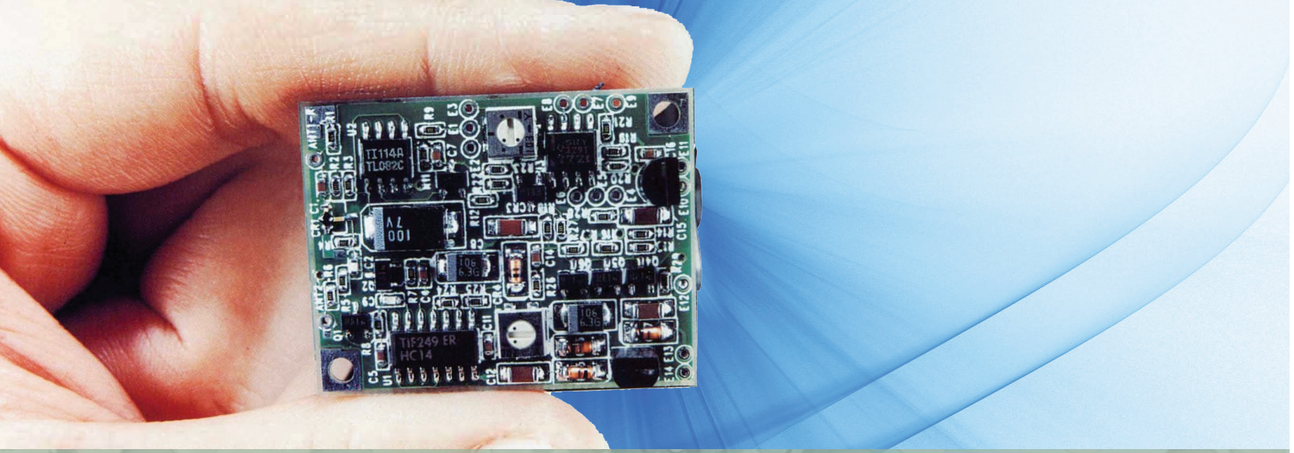
Lawrence Livermore National Laboratory

NREL, National Renewable Energy Laboratory

Argonne National Laboratory

Pacific Northwest National Laboratory

Berkeley Lab, Lawrence Berkeley National Laboratory



LEGACY INVENTIONS STILL SPARK INNOVATION

"The great virtue of this invention is its simplicity"

— Edward Teller

Micropower Impulse Radar

LLNL has a rich history of developing technologies in support of important DOE missions and licensing the technologies that researchers use in those missions to qualified manufacturers. Since 1994, the Laboratory's micropower impulse radar (MIR) has held 197 patents and 44 licenses—more than any other technology in LLNL history. It was developed using $10 off-the-shelf materials, enabling public companies and government agencies to economically integrate radar technology into various applications. MIR has achieved lifetime sales in the tens of millions.

MIR's success has been due to a remarkable mixture of an imaginative inventor, a technology that had market potential, a team with scientific and technical expertise, support from management in legal, licensing, funding, and publicity, issues, and timing. Its genesis traces back to LLNL's Nova Laser in the late 1980s. Created for nuclear fusion research, Nova generated subnanosecond electrical events, each of which required precise recording. LLNL electronics engineer Thomas McEwan, along with other LLNL engineers, developed a high-speed diagnostic system capable of capturing Nova's subnanosecond pulses. The system became the fastest solid-state transient digitizer in the world and won a coveted R&D 100 Award in 1993. During the transient digitizer's development, McEwan realized that its sampling circuits could form the foundation for a sensitive receiver used in a compact, low-power radar system. In May 1995, a patent was filed for MIR, as scores of companies expressed interested in licensing the technology.

Radar works by sending out radio waves and listening for their reflections. By analyzing the reflections, the radar can determine the distance and direction of objects encountered by the radio waves. Because it comprises a small number of common electronic components, it is compact and inexpensive.

The technology can be integrated into a range of applications, including fluid level sensing, heart monitoring and other medical applications, motion detection devices, and devices to detect breathing through walls or rubble (see sidebar). The technology was the first truly portable radar system that SWAT and land-mine detection teams were able to use in the field. Search and rescue missions, including those on 9/11, have used MIR devices to detect lung or heart movements of people buried under rubble.

MIR's gate range capability makes it extremely useful for physical security applications. The user can set the radar's "gate" or echo acceptance range, to open only at the right time to receive echoes from a certain distance and ignore all other echoes. Although the MIR emits a million or so pulses each second, the pulses are not evenly spaced. The amount of time between pulses varies randomly to create a distinctive pattern. That makes it easy for the radar to recognize its own echo, even when other radars are operating nearby.

MIR is a pulsed radar like other ultra-wideband radars, but it emits much shorter pulses than most and because the pulses are so short, MIR operates across a much wider band of radio frequencies than conventional radars. MIR devices are able to penetrate water, ice, heavy dirt, wood, concrete, and substances with moderate electrical conductivity, such as human tissue. It is not affected by temperature and noise, and is less susceptible to interference from other radar systems.

The transportation industry has been a huge adopter of MIR. For example, prior to MIR, the industry used costly and destructive drilling to analyze bridge and road infrastructure. In 1995, the Federal Highway Administration declared that over 40% of the 600,000 highway bridges in the U.S. were deficient or obsolete, so the agency commissioned LLNL to develop a MIR-based device to nondestructively image bridges. By the end of the year, LLNL created the High-performance Electromagnetic Roadway Mapping and Evaluation System (HERMES), which converted its MIR units' synthetic aperture radar data into high-resolution images of internal bridge structure, flaws, and defects. HERMES pioneered and continues to lead the field of non-destructive infrastructure imaging and analysis, providing a method that is cost-effective, accurate, and traffic-mitigating.

MIR revolutionized radar technology, making radar use possible for a myriad of short-range applications across many global industries. The technology has been integrated into many aspects of our daily lives and promises to continue to deliver many new exciting technologies to come.

MIR-based Product Examples

Automotive

- Backup warning
- Automatic cruise control
- Air-bag deployment
- Electronic tollbooth
- Fluid level sensing
- Proximity sensing

Home Security

- Motion sensing/alarms
- Child monitoring
- Auto-shut-off (heaters, tools, lights, etc.)
- Keyless locks, automatic doors
- Aid for the blind

Appliances

- Stud finder
- Electronic tape measure
- Automatic thermostats or dispensers
- Toys/games/virtual reality

Communication

- Digital LAN for home or office
- Computer cable replacements
- Voice communications

An array of MIR sensors were incorporated into the HERMES bridge inspection trailer in an ultrawideband-based non-destructive evaluation system. By driving the trailer over a bridge at 55 mph, a 3D image of the bridge deck's structural integrity is created without closing the bridge to traffic.

Numerical Electromagnetic Code

LLNL researchers created the NEC more than 40 years ago.

Since then, new versions of the code have been released, and as computer capability to handle heavy calculations.

Antennas are a foundational component of our global communication and information systems. Cell phones, Wi-Fi networks, and satellite links couldn't exist without them. Through much of the 20th century, antenna designers used hand calculations to model and fine tune their antennas; however, as antenna designs grew more sophisticated, hand calculations became inadequate. In the 1960s, researchers used computers to develop their antennas, but the performance improvements were incremental.

Poor antenna performance impacted the U.S. military's ability to carry out missions. By the 1970s, the U.S. Navy needed to improve their ship-mounted antennas, specifically those that supported their communication and radar systems. At the time, the Navy was forced to design ship antennas without considering the ship's architecture or its effect on an antenna's performance. This approach produced poor designs for ship radar and communication systems, leading the Naval Ocean Systems Center and the Air Force Weapons Laboratory to turn to LLNL for a solution.

Utilizing the Method of Moments calculation (a method of estimation) technique, LLLN scientists, Gerald Burke, Andrew Poggio, and Edward Miller created the Numerical Electromagnetic Code (NEC), an antenna modeling system for wire and surface antennas. NEC's ability to more accurately calculate currents along the antenna wires, and the junctions between them, offered a significant improvement over the antenna modeling program that was being used at the time. NEC became a game-changer for antenna mapping and was quickly pressed into service. The code gave the Navy insight into how a ship's structure would affect an antenna's performance and informed modifications to both ship and antenna designs. The result was significantly improved radar and communication systems that saved time, money, and resources.

NEC-3 and NEC-4 have been the most licensed technology in LLNL's software portfolio, and the most widely used code for analyzing antenna performance. The original code and NEC-2 are still available to the public.

NEC	Original code that accurately calculates currents along antenna wires and the junctions between them
NEC-2	Improvements to the original code
NEC-3	Can be used for antennas buried in the ground or placed close to the ground
NEC-4	Improved modeling for very small antennas, such as those used in cell phones and Wi-Fi routers

Droplet Digital PCR

In 2008, LLNL scientists Bill Colston and Fred Milanovich patented a fundamentally distinct digital polymerase chain reaction (PCR) technique known as droplet digital PCR (ddPCR). The technique converted an LDRD-developed technology aimed at detecting dangerous pathogens to commercial medical applications. Colston and Milanovich left LLNL to form the California-based company QuantaLife, Inc. LLNL's IPO licensed ddPCR technology to QuantaLife and RainDance Technologies, Inc. in 2009. The technology is now regarded as the most accurate genetic analysis method available, allowing researchers to quickly identify extremely low concentrations of pathogens contained within a sample.

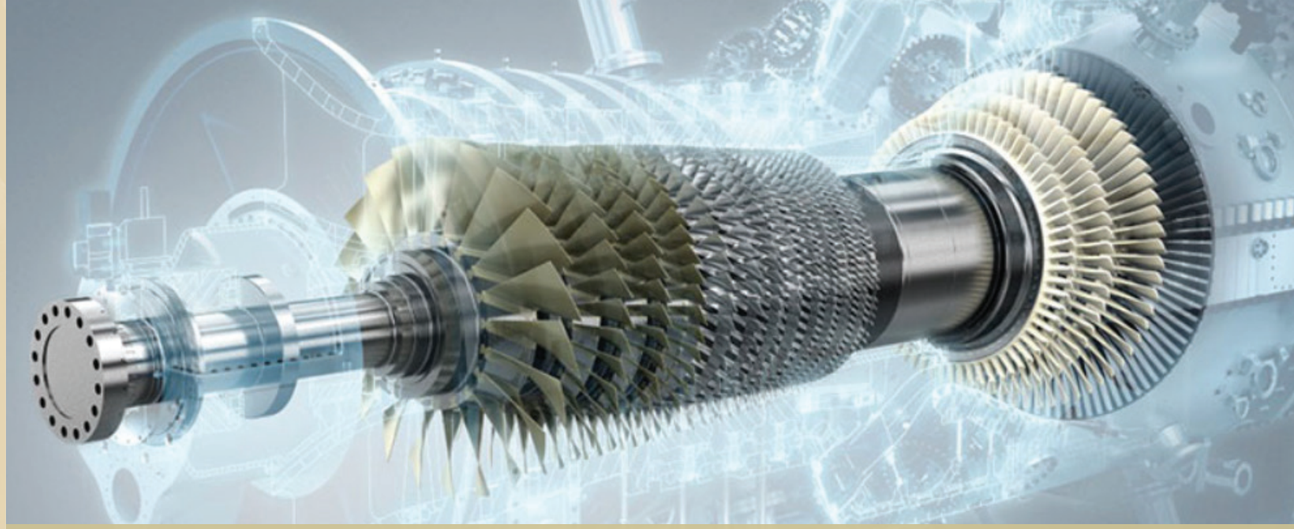
LLNL Director Bill Goldstein presents Bill Colston with the LLNL's Entrepreneurs' Hall of Fame award. Colston co-founded QuantaLife, Inc., which commercialized a breakthrough LLNL technology for detecting and identifying pathogens.

Traditional PCR can only analyze a few samples at a time, and the technique uses standard curves that can lead to inaccurate analysis, as it can miss extremely small amounts of DNA or RNA that signal the presence of a pathogen. ddPCR can sample 20,000 nanoliter-sized droplets using water-in-oil emulsion. The PCR reactions are carried out in the individual droplets, thus allowing a single sample to generate 20,000 data points. In this way, ddPCR detects rare DNA that might typically be lost in the background, and it provides absolute quantification with unparalleled precision.

California-based Bio-Rad Laboratories Inc., acquired QuantaLife for $162 million in 2011, and RainDance for an undisclosed amount in 2017. Today, ddPCR technology has helped Bio-Rad to become a top-tier company in quantitative PCR and digital PCR technology, accounting for about 16% of the market share in 2018 with about $643 million in revenue. ddPCR has wide and growing applications in cancer and infectious disease diagnosis, viral load monitoring, and fundamental research.

QuantaLife was honored as the "most promising company" at the Personalized Medicine World Conference in 2010. Later versions of ddPCR earned the Best New Life Sciences Product in 2013, and a Western Regional Federal Laboratory Consortium Outstanding Commercialization Success Award. In 2017, Colston and Milanovich were inducted into LLNL's Entrepreneurs' Hall of Fame.

Bio-Rad Laboratories QX200TM Droplet Digital PCR (ddPCRTM) System.

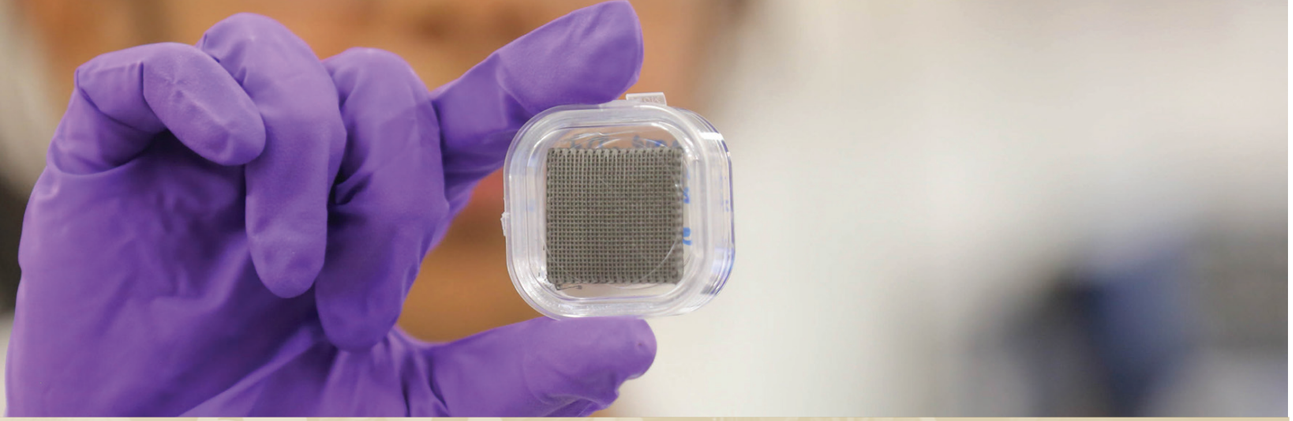


Investing in Innovation

LLNL's IPO engages with industry leaders and investors to identify new opportunities for collaboration. It also invests in outreach activities and in educating entrepreneurial staff members, offering a range of programs that help scientists refine their ideas and promote their discoveries to investors.

IPO works hard to ensure that LLNL-developed technologies achieve their full commercial potential. We continue to develop an entrepreneurial culture and participate in innovation and economic development programs. Among our 2019 achievements we:

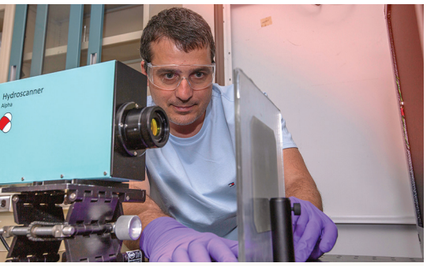
- Received more than $6.2 million from DOE's Technology Commercialization Fund (TCF) for six new LLNL projects
- Received a "best in class" national technology transfer award for formulating a four-institution cancer research collaboration agreement called Accelerating Therapeutics for Opportunities in Medicine, or ATOM, consortium
- Received an East Bay Legacy Innovation Award from the East Bay Economic Development Alliance, for the Laboratory's long-standing regional leadership in innovation
- Received one national Federal Laboratory Consortium (FLC) award and three Far West Regional FLC awards for excellence in technology transfer
- Hosted a three-day entrepreneurship business training course specifically designed for Laboratory scientists and engineers
- Hosted the annual Better Plants Technology Days event, and participated in the InnovationXLab summit showcasing technologies developed at LLNL and encouraging public–private partnerships
- Led the National Lab Accelerator, a pitch competition involving 12 national labs designed to highlight laboratory technology and provide a leading-edge entrepreneurship experience for lab scientists and engineers.



TECHNOLOGY TRANSFER PROGRAMS

Technology Commercialization Fund

The DOE Office of Technology Transitions (OTT) is providing funds for six new LLNL projects in its fourth Technology Commercialization Fund (TCF) cycle. Of that total, $2.6 million will come from DOE and $3.6 million will be in matching funds from industrial partners. TCF's goal is to support the commercialization of DOE national lab technologies to a point where the commercial potential can be accurately assessed. Since 2016, sixteen technologies and innovator teams from LLNL have been involved in this program which over the years has expanded its support. It includes Energy Efficiency and Renewable Energy—the Advanced Manufacturing Office, Bioenergy Technologies Office, and Solar Energy Technologies Office; Fossil Energy; Office of Electricity; Nuclear Energy; Cybersecurity, Energy Security, and Emergency Response; and others. Below is a description of the six projects for 2019:



Mihail Bora, a physicist in Engineering's Materials Engineering Division, sets up a check for a hydroscanner camera, which is capable of imaging water content in polymer materials with high spatial resolution.

Hydroscanner for Water Ingress Imaging in Photovoltaic Module Packaging Materials

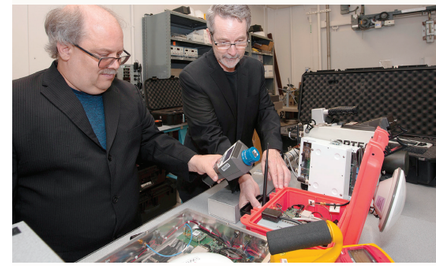
Physicist Mihail Bora will evaluate the commercial feasibility of an innovative technology for imaging water ingress in photovoltaic module packaging materials. The research will offer a more effective approach to proactively prevent moisture-related damage and identify the root causes of performance failures. The work is intended to increase the technology's commercial potential through prototype development and fabrication, creation of user training material, and pilot testing in collaboration with commercial partners.

LLNL Composite Sorbents to Economically Upgrade Biogas to Biomethane

Materials and chemical chemist Sarah Baker and her team plan to demonstrate a new class of sorbents for upgrading raw biogas to biomethane. The approach offers the potential to significantly reduce cost barriers to biomethane production, which will allow small to mid-scale producers to leverage this renewable energy resource to generate revenue, rather than waste the resource and emit methane into the atmosphere. The group has previously worked with SoCal Gas, the nation's largest natural gas distribution utility.

Instrument Providing Realistic Radiation Training to First Responders

Computer scientist Greg White will lead an effort to commercialize an instrument that allows first responders to train for the aftermath of radiological accidents or nuclear terrorism. RaFTS (Radiation Field Training Simulator) produces a response in the user's regular equipment that exactly replicates the physics of real-world use in radiation hazard-level situations. The technology will enhance emergency preparedness while cutting training and acquisition costs.



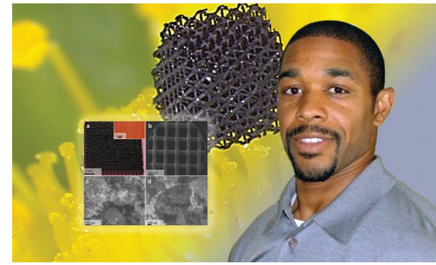
Computer scientist Greg White (left) and Steven Kreek, leader of N Program's radiation detection research, are leading a project to commercialize the Radiation Field Training Simulator.

Cold Spray Manufacturing of High-Performance Magnets and Energy-Harvesting Materials

Physicist Harry Radousky and his team are collaborating with a Virginia-based company, TTEC, to commercialize a technology to additively manufacture high performance magnets and energy-harvesting materials using a cold spray process. Traditional manufacturing for rare earth magnets produce substantial waste material. The team's cold spray process, which uses specialized nozzle designs, could reduce waste by 60 percent. The new technology could be used to fabricate magnets for electricity generation, electric vehicle motors, and high-performance compact actuators at lower cost and higher efficiency.

3D-Printable Feedstocks for Advanced Manufacture of Energy Products

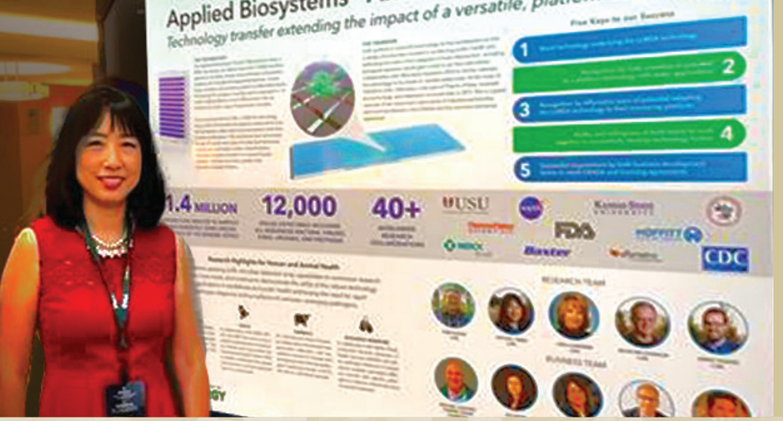
Chemical engineer Marcus Worsley and his team will partner with MilliporeSigma, to commercialize a large portfolio of LLNL-developed 3D printing feedstock inks with a variety of unique properties. These feedstocks include flexible graphene, inorganic, and carbon-based inks. Among the energy storage devices that could be produced are solid state batteries, aerogel electrodes, supercapacitors, hydrogen fuel cells, and carbon-fiber composites for lightweight vehicles.



Marcus Worsley, a chemical engineer in the Materials Science Division, is leading a collaboration with a Missouri-based company to refine and commercialize feedstock inks developed at LLNL.

Low-Cost Seismic Interferometry Tool for Subsurface Monitoring

Seismologist Robert Mellors is leading a team that is adapting its technology on seismic interferometry to create a cost-effective commercial software tool for monitoring subsurface areas. The technology can be used to monitor underground carbon dioxide storage reservoirs and assist in oil recovery with carbon dioxide injection. Underground carbon storage requires the injection of carbon dioxide into a suitable reservoir rock, and continued monitoring of plume characteristics and induced seismicity is necessary to ensure effectiveness and safety. The team's technology is well-suited to detect change using time-lapse-based analysis.



RECOGNIZING LLNL INNOVATORS

FLC Technology Transfer Awards

LLNL has won:

36 national FLC awards
from **73** entries since 1985.

National Award for LLMDA and Applied Biosystems Axiom Microbiome Array

LLNL's Applied Biosystems™ Axiom™ Microbiome Array (ABAMA) received a 2019 National Federal Laboratory Consortium (FLC) award for excellence in technology transfer. The ABAMA is the commercialized successor to LLNL's earlier microarray called the Lawrence Livermore Microbial Detection Array (LLMDA), which was licensed in 2016. Through a technology-transfer partnership with Thermo Fisher Scientific, LLNL transformed the LLMDA platform into the ABAMA, increasing the array's throughput and earning a 2017 R&D 100 Award.

Lawrence Livermore Microbial Detection Array (LLMDA)

ABAMA is the most comprehensive microorganism detection platform built to date and the first high-throughput microarray that employs whole genome resolution for identifying all sequenced microbes. It can detect more than 12,000 unique microbial species, 1,000 of which cause diseases in humans, and it can analyze 96 samples in parallel. In contrast, PCR can typically detect no more than about 50 different organisms at one time, and it is a very time-consuming process.

ABAMA's quick, accurate, and inexpensive technology has been utilized in many ways, including to study bacterial pathogens in soldiers' combat wounds, investigate microbes aboard the International Space Station, detect diseases in the swine industry, identify plague in ancient human remains, find impurities in infant vaccines, and research possible emerging viral diseases.

Charted in 1974, the FLC is a nationwide network that helps accelerate the transfer of technologies from federal laboratories into the marketplace. It comprises more than 300 federal laboratories, agencies, and research centers.

LLNL Receives Three Far West Regional FLC Awards

LLNL received three Far West Regional FLC awards in 2019. IMPEDE Embolization Plug won for Outstanding Commercialization Success; CyberSecure Integration of Networked Distributed Energy Resources (CINDER) won for Outstanding Partnership; and Spack won in the Outstanding Technology Development category.

IMPEDE® Embolization Plug

The IMPEDE® Embolization Plug (shown at right), developed by Shape Memory Medical Inc., LLNL, and Texas A&M University is a permanently implanted vascular occlusion medical device featuring fast, easy deployment with low radial force and high vessel conformability. It combines a novel biodegradable shape memory polymer foam with a radiopaque markerband and anchor coil for positioning, rapid clotting, and integrated healing response.

CyberSecure Integration of Networked Distributed Energy Resources

The CINDER project integrates an LLNL-developed cyber risk analysis toolset with distributed energy resources—small grid-connected devices that can generate energy such as solar photovoltaic systems—deployed at DoD's White Sands Missile Range, Hurlburt Field, and the VA Medical Center facility in Las Vegas. The DOE-funded Cyber and Infrastructure Resilience program engaged in a successful technology transfer partnership with the Department of Veterans Affairs, DoD, and FoxGuard Solutions. While the project has showcased how an integrated patch and network analytics/management solution can identify and mitigate risks to the physical and cyber operations of microgrids, the partnership has exemplified how stakeholders can bridge their respective levels of expertise and accomplish a larger task that each would not have been able to achieve alone.

Spack: A Package Manager for HPC Systems for Outstanding Technology Development

Spack is an open source software package management tool for scientific computing. It simplifies and accelerates building, installing, and customizing complex software stacks. Spack unifies software deployment for laptops, clusters, and supercomputers, enabling a community of thousands of users to share and leverage more than 3,200 scientific software packages.

Co-developers of Spack include:
Argonne National Laboratory
Columbia University
École Polytechnique Fédérale de Lausanne
Fermi National Accelerator Laboratory
Iowa State University; Kitware, Inc
NASA Goddard Institute for Space Studies, Center for Climate Systems Research
National Energy Research Scientific Computing Center
Perimeter Institute; University of Hamburg
University of Illinois at Urbana–Champaign
University of Iowa

LLNL has won:

36 regional FLC awards
from **54** entries since 2007.

A compressed shape-memory-polymer foam is delivered by catheter to an aneurysm sac within the brain. Once it is activated by temperature change, the foam expands to match the sac's contours.

DOE's Technology Transfer Working Group Best in Class Award

Rich Rankin (top row, left), the head of IPO, presented a national technology transfer award to two business development executives – Candice Gellner (front row, left) and Charity Follet – and to Quentin Vaughan, an assistant general counsel in the Office of General Counsel.

DOE's Technology Transfer Working Group (TTWG) recognized IPO business development executives Charity Follet and Candice Gellner, assistant general counsel Quentin Vaughan from the Lab's Office of General Counsel (OGC), and the entire IPO and OGC offices with a "best in class" national technology transfer award for their work formulating a cancer research collaboration agreement. The award was given for innovation in partnering for the development of the four-institution Accelerating Therapeutics for Opportunities in Medicine, or ATOM, consortium. The new collaboration required new approaches for technical partnerships between the participating members, which include LLNL, the pharmaceutical firm GSK, the National Cancer Institute's Frederick National Laboratory for Cancer Research, and UCSF. The goal of the ATOM consortium is to create a new paradigm of drug discovery that would reduce the time from an identified drug target to clinical candidate to one year. It currently takes approximately six years for a drug to reach the clinical trial stage.

The TTWG awards are selected by a team of representatives comprising technology transfer professionals from the national laboratories, single purpose research facilities and production facilities, and the DOE/National Nuclear Security Administration field offices. The awards were given for five categories: intellectual property management, licensing, partnering, economic development, and innovative lab facilities. The TTWG strives to improve the technology transfer activities of the laboratories/facilities and the DOE by promoting DOE laboratory technology transfer policy in a mutually beneficial, supportive, and non-adversarial working environment that encourages open communication, teamwork, and professional development.

ATOM consists of the following members:

The Accelerating Therapeutics for Opportunities in Medicine (ATOM) consortium is a public-private partnership with the mission of transforming drug discovery by accelerating the development of more effective therapies for patients. :

East Bay Legacy Innovation Award

The East Bay Economic Development Alliance (East Bay EDA) honored LLNL with its 2019 East Bay Legacy Innovation Award for its many economic contributions to the community. LLNL prides itself in being a good neighbor economically as well as through its science lectures and presentations, and engagement with K-12, community college, and undergraduate students. The Lab's community outreach efforts help grow the workforce necessary to continue the vital work of our science and technology institutions regionally and across the country.

East Bay EDA also applauded LLNL's IPO for its accomplishments and mission to grow the economy by advancing the development and commercialization of scientific discoveries through its engagements with the private sector via technology commercialization, entrepreneurship, and business development activities.

The East Bay EDA is a regional network of business leaders, educators, and elected officials who have formed a public/private partnership serving Alameda and Contra Costa counties. The Alliance is the regional voice and networking resource for strengthening the economy, building the workforce, and enhancing the quality of life in the East Bay

LLNL was invited to the East Bay Innovation Awards where it was honored with the Legacy Award for its many economic contributions to the Easy Bay. Photo credit: Ron Essex

Credit: Ron Essex https://www.ronessexphotography.com/index

LLNL-licensed technologies have enabled the launch of numerous new businesses that are helping drive economic growth locally, regionally, and beyond.

FOSTERING COLLABORATION

LIVERMORE VALLEY OpenCampus

Open Resources Foster Collaboration

Laboratory Collaboration Zone

The Livermore Valley Open Campus (LVOC) was established in 2011 with support from the DOE's NNSA and the Office of Science. The open, unclassified research and development campus serves as a meeting space where LLNL and Sandia National Laboratories (Sandia-California) researchers can collaboratively work with colleagues in industry and academia on unclassified research for a range of programs of national importance.

Livermore Computing (LC) is creating a Collaboration Zone within the LVOC that will serve as a model for accessing unclassified LC resources. The site is located on an approximately 110-acre parcel along the eastern edge of LLNL and Sandia bordering Greenville Road.

The motivation for the Collaboration Zone stems from current and future national security challenges that require increased coupling to the private sector in order to understand threats and deploy solutions in areas such as energy and environmental security, economic security, cyber security, high performance computing, and non-proliferation. Targeted academic alliances and industrial partnerships will help foster educational opportunities and future research collaborations.

Patrick Dempsey, director of strategic engagements in Engineering, speaks to US Industry representatives in the Advanced Manufacturing Lab during Better Plants Technology Days.

High Performance Computing Innovation Center

LLNL's High Performance Computing Innovation Center (HPCIC) serves as an outreach hub for industry and academia to broaden technologies that boost American competitiveness, accelerate advances in science and technology, and help develop the country's HPC workforce. In FY18, the HPCIC engaged in more than 20 collaborations that will help companies increase their understanding of complex technologies and systems, accelerate their innovation processes, and expand the value they derive from computing.

The HPCIC also fosters collaborative innovation by hosting events such as the Advanced Manufacturing Laboratory Industry Day and the 2019 Better Plants Technology Days, both of which brought Laboratory researches and industry partners together to encourage future public–private partnerships. The HPCIC creates and manages strategic partnerships to boost LLNL capabilities in research areas that will provide mutually beneficial value. IBM, the RAND Corporation, and Georgetown University are three strategic partners that add value to the Laboratory's mission through HPC activities. The HPCIC also hosts the annual Current Challenges in Computing (CCubed) conference and the institutional Computational Grand Challenge program, both of which encourage advanced explorations of HPC applications.

HIGH PERFORMANCE COMPUTING
INNOVATION CENTER

Advanced Manufacturing Lab

LLNL's Advanced Manufacturing Laboratory (AML) is a 1,300 m^2, first of its kind facility that is designed for shoulder-to-shoulder R&D collaboration with partners in the private sector and academia to create new materials and technologies in a laboratory setting. The facility furthers LLNL's national security missions while enabling partners to release new products and services into the market.

Located in the LVOC, the AML has established eight partnerships to date, and the number of collaborations continues to grow. LLNL anticipates these partnership efforts will lead to development of innovative technologies that enhance the Laboratory's program R&D efforts. The facility enhances LLNL's ability to actively promote collaborative relationships between NNSA laboratories, production plants, academia, and industry to provide mutual benefit to the Laboratory and its partners. Current partnerships and their associated LLNL leads are:

- Vector Atomic—Robert Panas
- Aerotech—Adam Jaycox
- GE—Ibo Matthews
- Artveoli—Congwang Ye
- AFRL—Aiden Martin
- Duramat—Mihail Bora
- Total—Sarah Baker
- Edmund Optics—Nan Shen

AML's strategic plan offers five tracks for partnerships: design, materials, processes, applications, and qualification and certification. Each track focuses on a particular area of manufacturing relevant to industry's interest. The partnerships with industrial and academic counterparts accelerate innovation that benefits U.S. industry and advances the Laboratory's missions in the face of rapid transformation in these arenas.

A sneak-peak of the inside of the wet lab space inside of the Advanced Manufacturing Lab.

ENGAGING ENTREPRENEURS

2019 National Lab Accelerator Program

42 LLNL and Sandia scientists and engineers participated in formalized business training

8 LLNL scientists and engineers were selected to participate in the National Lab Accelerator Pitch Competition

12 National Labs will compete in the National Lab Accelerator Pitch Competition title

Entrepreneurial Programs

Entrepreneurs are creative, hard-working innovators who think outside the box to achieve big goals. When faced with a grand challenge, some of LLNL's best and brightest have come up with revolutionary ideas to solve problems in national security, health, energy, and other areas of our life. LLNL's IPO sponsors and manages programs to enhance the entrepreneurial skills of the LLNL workforce to spur innovation and seed commercialization of LLNL intellectual assets.

National Labs Entrepreneurship Academy

Since 2015, LLNL's IPO has partnered with the University of California Davis Graduate School of Management to host six academies teaching LLNL and Sandia National Laboratories (Livermore) scientists and engineers (S&Es) the fundamentals of entrepreneurial business. Each three-day course teaches S&Es communication skills for working with funding sponsors. The program focuses on the value of a technology to solve a problem that people care about, rather than focusing on the technology alone. For example, private investors want their capital to grow in the marketplace; government sponsors want their capital to solve an important national problem. In both cases, the skilled team offering a value proposition with highest return on investment will get funded. In November 2018, 42 S&Es participated in the Academy, bringing the total trained to 212 since 2015. The seventh Academy will be taught in November 2019.

National Lab Accelerator

Laboratory solutions to civilian problems important to the U.S., such as energy challenges, are implemented through the business sector; therefore, it is important for LLNL S&Es to have some knowledge in working with businesspeople. The LLNL-hosted National Lab Accelerator is a DOE-funded program designed to train national laboratory S&Es in optimizing the flow of laboratory-developed technologies into the private sector to create value for the US economy. With a stronger understanding in business, S&Es 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. The Accelerator program provides S&Es the opportunity to work with an experienced external business mentor who will help them develop a value proposition and business concept around a market need and a technology and pitch it to the investment community to "sell" the concept.

In FY19, eight LLNL S&Es participated in the program from February to August and competed on September 3. The winner of that competition will compete in the September 25th National Lab Accelerator Pitch Competition. LLNL IPO will host 12 trained national laboratory S&Es to name an overall DOE winner, who will be awarded a $25,000 prize by DOE Office of Technology Transitions (OTT).

Energy I-Corps

Established in 2015, DOE's Energy-I-Corp pairs teams of researchers with industry mentors to train entrepreneurs on moving technologies into commercialization. LLNL was one of the initial laboratories to pilot the Energy-I-Corps program. S&E participants go through an intensive two-month training in which the researchers define technology value propositions, conduct customer discovery interviews, and develop viable market pathways for their technologies. Researchers return to LLNL with a framework for industry engagement to guide future research and inform a culture of market awareness.

Six LLNL teams have participated in Energy I-Corps since 2015. A seventh team, led by LLNL scientists Patrick Campbell and Steven Hawks, will begin Cohort 10 in September 2019.

FedTech

FedTech is a D.C.-based startup studio and accelerator that builds startups around deep technology from federal laboratories, universities, and corporations. For the fall 2018 cohort, LLNL's IPO worked with FedTech to match two Laboratory technologies with FedTech-recruited entrepreneurs. LLNL scientists Peer-Timo Bremer and Jacqueline Peila spent eight weeks sharing the benefits of their technology, Segmentation Ensembles and OneID, with the program entrepreneurs. The entrepreneurs developed business models and pitches. FedTech is a valuable new resource to the entrepreneurial programs provided by the IPO.

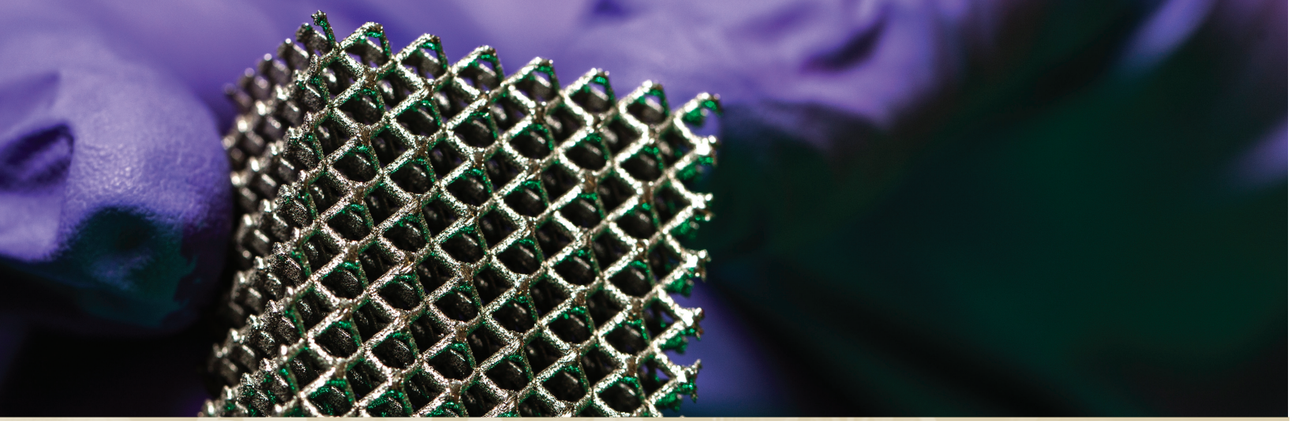
For the Fall 2019 cohort, Yining Qin is funded by DOE OTT to participate in the FedTech program. His participation will further the commercialization of C-BEST, an Energy I-Corps alumni technology for commercial building energy optimization.

"I'd just like to say I am REALLY enjoying the Entrepreneurial Academy. Definitely feeling fortunate for being given this opportunity. And I'm looking forward to learning more and using this knowledge in my career at the lab"

— Michael Zelinski,
LLNL Computational Engineer

ENERGY I-CORPS
U.S. Department Of Energy

FedTech™



LAB CAPABILITIES TO INDUSTRY

"We've seen some really interesting partnerships come out of the previous Technology Days."

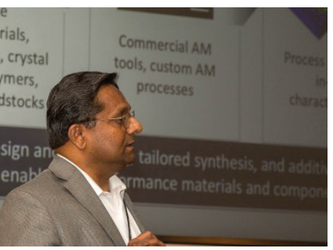
—Eli Levine, Program Manager
EERE's Advanced Manufacturing Office

Better Plants Technology Days

Representatives from more than two dozen companies visited LLNL on April 9 for the 2019 DOE Better Plants Technology Days. The annual event is aimed at showcasing the technologies developed at the national laboratories and encouraging public–private partnerships. IPO and the HPCIC hosted the event, which began with a presentation by LLNL managers and scientists highlighting the Laboratory's capabilities and emerging technology in materials and manufacturing, HPC and modeling, water management, and cyber defense.

LLNL engineer Saad Khairallah discussed using the ALE3D code to simulate the complex physics involved in metal 3D printing and how the simulations help reduce defects in printed parts.

Visitors toured the AML, the NIF, the HPC facilities, and the Fiber Draw Tower.

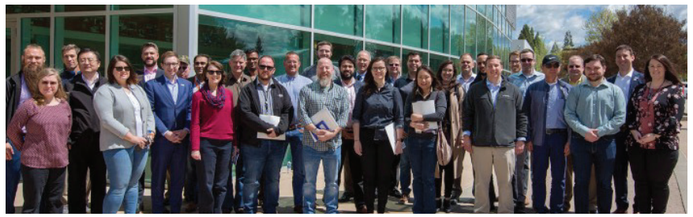


LLNL's Associate Director in Engineering Anantha Krishnan described Lab breakthroughs in advanced manufacturing that could impact the commercial sector.

"For the companies, it gives them exposure to what the Lab is working on."

"From the Lab's perspective, there are two benefits; the potential for commercialization of technology and more importantly, finding partners in industry that have similar objectives and can accelerate our development of mission-critical technologies."

—Patrick Dempsey, director of strategic engagements in Engineering



InnovationXLab Summits

IPO commercialization experts and Laboratory scientists worked together to participate in two 2019 InnovationXLab summits hosted by the Office of Technology Transitions (OTT). The summits are designed to expand the commercial impact of the substantial investment in the national Laboratory innovation portfolio. InnovationXLab summits facilitate a two-way exchange of information and ideas between industry, universities, manufacturers, investors, and end-use customers with innovators and experts from across the national laboratories and broader DOE R&D complex.

INNOVATION X LAB℠

Grid Modernization Summit

January 24-25, Seattle, WA

Research and advancements from LLNL's Cyber and Infrastructure Resilience program were highlighted in the January summit. Speakers held discussions on a variety of topics, including building resilience into the modern power grid, grid cybersecurity, and next-generation transmission and distribution solutions. Project areas included:

- Skyfall, a cyber-physical test bed for simulating and studying infrastructure cyber attacks
- Smart grid innovations, including microgrid and building efficiency solutions
- A partnership with DoD, VA, and Foxguard Solutions to redefine strategies for distributed energy resources at DoD facilities.

LLNL team at the Grid Modernization Summit

Advanced Manufacturing Summit

May 7-8, Oak Ridge, TN

Laboratory managers and scientists provided an overview of LLNL capabilities and competitive advantage in the AM sector. Three major areas that sparked conversation with industry representatives were:

- LLNL's extensive AM intellectual property portfolio protecting innovations in new instruments, new materials, and computational design and optimization
- The AML, a facility with the goal of bringing together science and engineering expertise, leading-edge technology, academic partners, and industry experience under one roof
- HPC4Manufacturing program, an LLNL-managed DOE program bringing national laboratory HPC facilities and modeling and simulation expertise to manufacturing industry problems

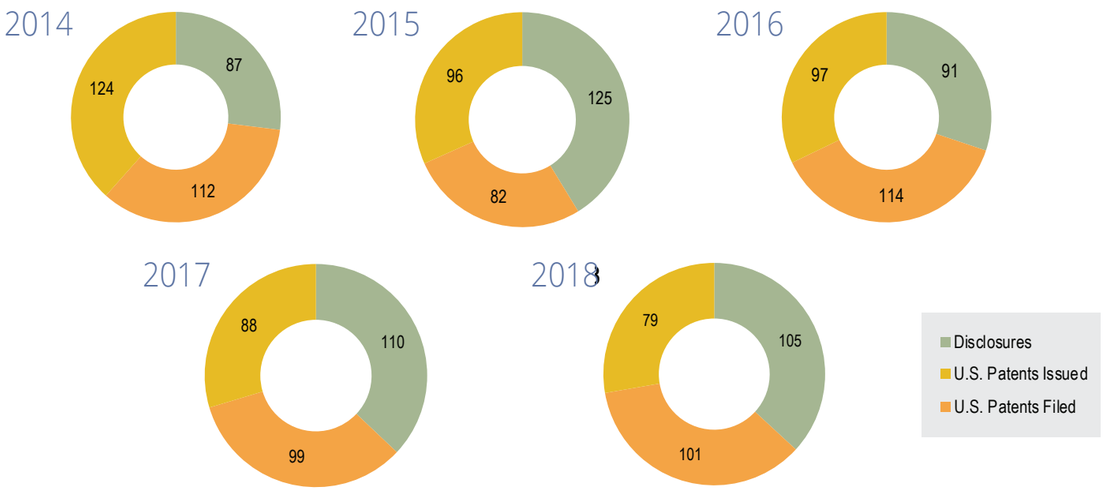
Genaro Mempin, BDE in IPO, represents LLNL at the Advanced Manufacturing Summit

METRICS

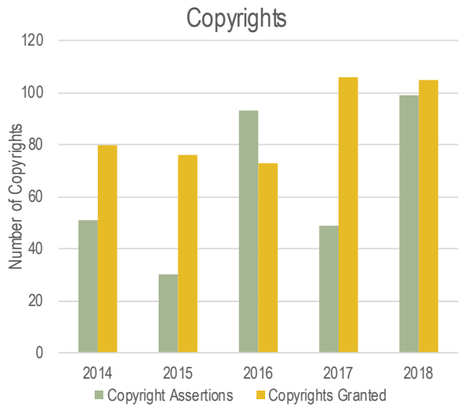
While narratives that describe scientific discoveries at LLNL provide evidence of innovation in action, they do not tell the whole story. Here, we share metrics that serve as quantitative indicators of our success in transferring technology from LLNL to commercial partners.

Intellectual Property

LLNL-based inventions are protected by nearly 1,000 active patents and patent applications from 2014 – 2018.

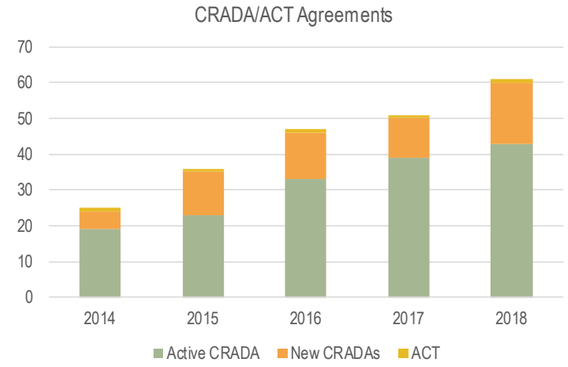


LLNL obtained more than 300 copyright assertions, helping protect our scientists' intellectual property from 2014 – 2018.

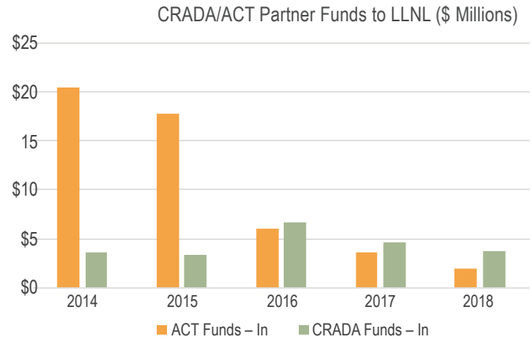


Industry Agreements

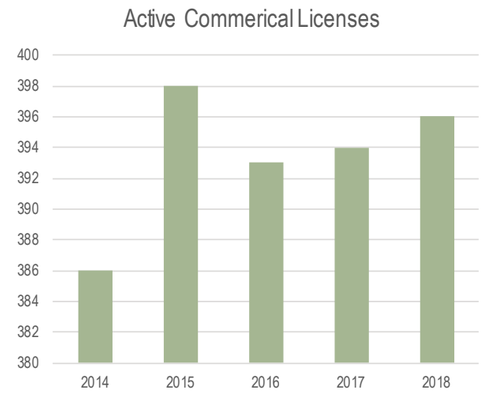
LLNL had more than 150 active CRADAs from 2014 – 2018, which helped our scientists transform promising technology into marketable products.



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



LLNL had nearly 2,000 active commercial licenses from 2014 – 2018.



Contacts

LLNL Innovation & Partnerships Office
ipo.llnl.gov

POC for external parties to contact the IPO:

Richard A. Rankin, Director of the Innovation & Partnerships Office

Lawrence Livermore National Laboratory
P.O. Box 808, L-795 Livermore, CA 94551
Phone: 925.423.9353
Email: *rankin8@llnl.gov*

For questions and comments, contact
ipo@llnl.gov

For information about specific partnership areas, contact the following individuals:

Roger Werne, Senior Advisor, Outreach
Werne1@llnl.gov, 925.423.7302

Elsie Quaite-Randall, Deputy Director, IPO
Quaiterandal1@llnl.gov, 925.423.7302

Nina Potter, Manager of IP & Agreements Management
Potter14@llnl.gov, 925.423.7310

Michael Sharer, Manager of Regional Engagements
Sharer1@llnl.gov, 925.422.9839

Annemarie Meike, Business Development Executive, Chemicals & Materials, Energy & Environment
Meike1@llnl.gov, 925.422.3735

Candice Gellner, Business Development Executive, Computational Biology Software
Gellner2@llnl.gov, 925.423.9724

Charity Follett, Business Development Executive, Computing, Communications, Software
Follett2@llnl.gov, 925.422.1817

David Dawes, Business Development Executive, Lasers & Optics, Radiation Detection
Dawes4@llnl.gov, 925.422.0801

Genaro Mempin, Business Development Executive, Advanced Manufacturing, Instruments/Sensors/ Electronics
Mempin1@llnl.gov, 925.423.1121

Hannah Farquar, Business Development Executive, Technology & Market Discovery
Farquar3@llnl.gov, 925.423.0587

Jeff Stewart, Business Development Executive, National Security
Stewart28@llnl.gov, 925.422.3752

Yash Vaishnav, Business Development Executive, Life Sciences, Biotech, Healthcare
Vaishnav1@llnl.gov, 925.422.3538

Lawrence Livermore National Laboratory