LAWRENCE LIVERMORE NATIONAL LABORATORY

Report to Congress CTRAK-21-____

2021 Technology Transfer Report

INNOVATION IN ACTION

INNOVATIVE TECHNOLOGIES

Growing the Regional Economy and Improving Health and Safety

The primary mission of the Lab's Innovation and Partnerships Office (IPO) is to grow the economy by advancing the development and commercialization of LLNL's science and technology discoveries. The IPO has 363 active commercial licenses with 342 companies, and 58 cooperative research and development agreements. Over the previous five years, products based on LLNL technology generated more than $905 billion in sales.

An important objective for the IPO is to make an impact on the local region. LLNL-licensed technologies have led to the launch of numerous new businesses that are helping to drive economic growth and support high-technology business opportunities in the Tri-Valley and greater San Francisco Bay region. For example, LLNL's Droplet Digital™ Polymer Chain Reaction (ddPCR) was licensed to Pleasanton CA-based QuantaLife, Inc. This technology quickly screens biological samples for pathogens. It is currently being used to detect the presence of COVID-19 in infected patients. LLNL's advanced laser peening system was licensed to Livermore CA-based, Metal Improvement Co. Inc. This technology significantly strengthens metal components and has peened more than 40,000 jet engine fan blades on commercial aircraft. Laser peening was also used to form the Boeing 787-8s wings to make the aircraft the world's most fuel efficient per passenger mile. LLNL-developed DYNA3D was the first computer code to accurately model the bending, folding, and collapsing of metal structures. DYNA3D was licensed to Livermore CA-based Livermore Software Technology Corporation and is the underlying technology used by the auto industry for vehicle crash testing.

As 2022 approaches, the IPO, with Laboratory support, will continue to seek out opportunities to nurture and sustain regional growth. We will also continue to identify and leverage new opportunities to commercialize LLNL's innovative technologies to benefit the health and safety of the nation.

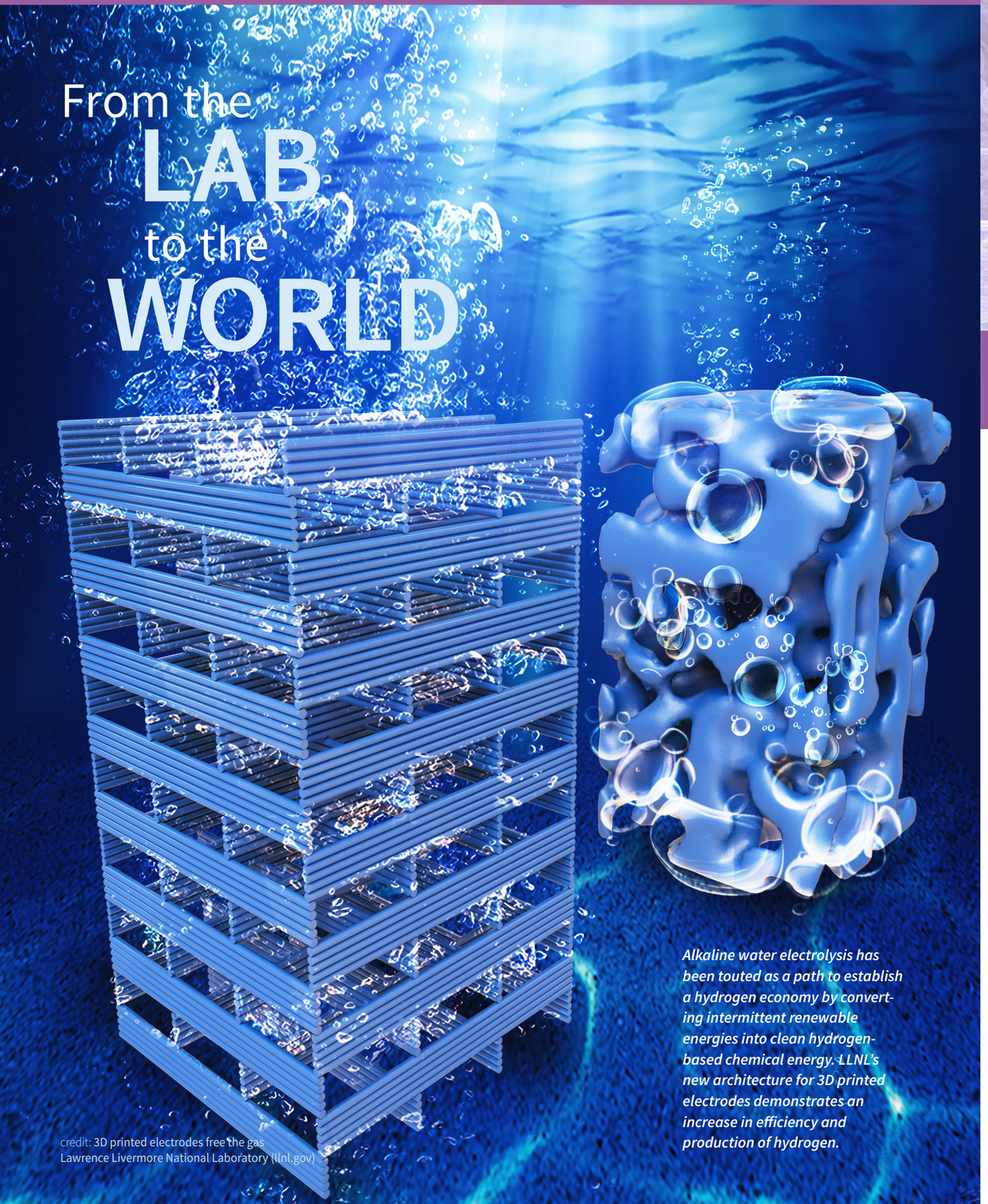
—Richard A. Rankin
Director, Innovation & Partnerships Office

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

LLNL is managed by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration, under contract DE-AC52-07NA27344.

LLNL-XX-_____

CONTENTS



credit: 3D printed electrodes free the gas
Lawrence Livermore National Laboratory (llnl.gov)

Alkaline water electrolysis has been touted as a path to establish a hydrogen economy by converting intermittent renewable energies into clean hydrogen-based chemical energy. LLNL's new architecture for 3D printed electrodes demonstrates an increase in efficiency and production of hydrogen.

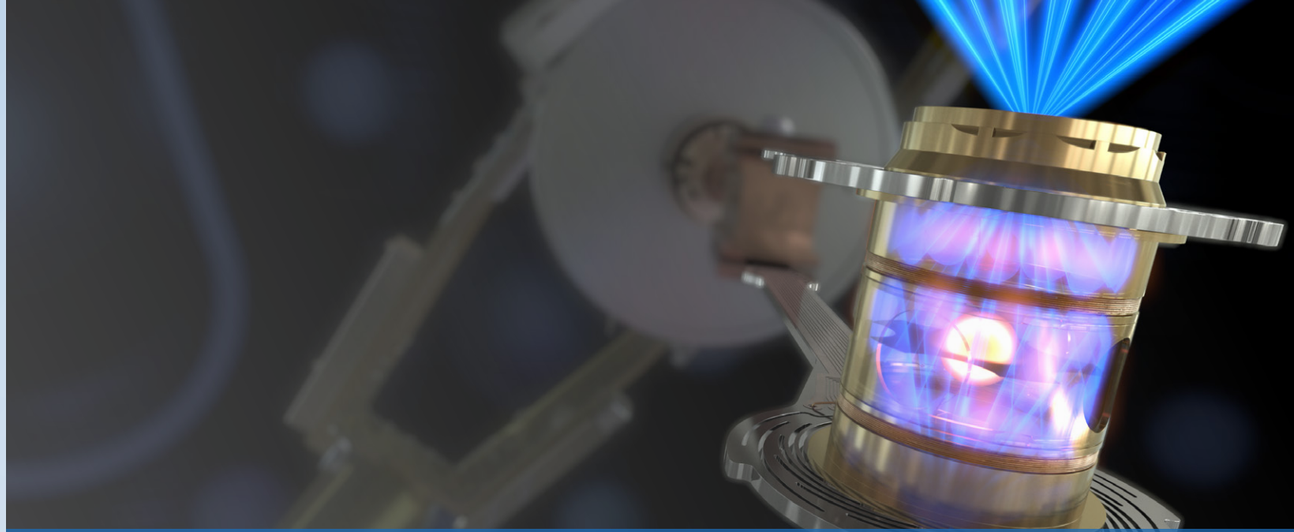
EXECUTIVE SUMMARY

Over the past five years, products based on LLNL technologies generated more than $905 billion in sales.

This past year, LLNL's workforce demonstrated resiliency to any challenges imposed by the COVID-19 pandemic. As presented in these pages, technologies continued to advance, collaborations were forged with external partners, and IPO executed licenses and agreements that benefit the Laboratory and help launch new businesses in local and national regions. For example, new technologies for high performance computing will aid in search and rescue efforts and improve the process of scientific workflows. Partnerships were strengthened and new ones built, and IPO established CRADAs for a range of applications, including technology for directed energy weapons, a bio printer for complex biological constructs, and a chemical solver for combustion engines. Partnerships were formed with NASA to utilize LLNL's CODA telescope and to use NASA codes and equipment to further Laboratory efforts.

The Additive Manufacturing Laboratory began two new thrusts with industries, and two buildings were constructed in the Livermore Valley Open Campus. The High Performance Computing Innovation Center (HPCIC) formed two new industry partnerships, and HPCIC and the Data Science Institute held its first Machine Learning for Industry forum. The Lab increased the region's awareness of the national labs through sponsored events, and a new DOE COVID-19 Technical Assistance program enables the Lab to provide assistance to external organizations. The National Labs Entrepreneurship Academy and the National Lab Accelerator continue to build scientists' entrepreneurial skills. DOE's Technology Commercialization Fund awarded funding to five LLNL projects, and the Lab received three Federal Laboratory Consortium awards.

Teams achieve the best results when they build an inclusive culture, and a multidisciplinary team developed an experiential learning tool, Lunar R3BUILD, to increase inclusion awareness. The copyrighted game is available for organizations and educational institutions. As the Lab continues to meet the challenges brought on by the pandemic, IPO will stay focused on Lab investments and advancing the development and commercialization of scientific discoveries.



Technologies Transform Our World

LLNL-licensed technologies are helping to grow numerous businesses locally, regionally, and beyond.

The Laboratory's technologies and methods advance state of the art to solve problems in the U.S. and around the world. For example, the rapid growth of data science requires improvements in high performance computing (HPC) systems and applications to confidently predict the behavior of complex systems and to improve communication networks between devices. Biometric authentication systems are increasingly used worldwide, requiring secure and safe transfer of data. Highlights in this report include:

- The Decentralized Estimation for Autonomous Sensor Networks (DEASN) is an application-agnostic algorithm that allows sensors to exchange relevant information across an entire network, which will aid in search and rescue efforts.
- Flux is a next-generation workload management software framework that combines fully hierarchical resource management with graph-based scheduling to improve the performance, portability, flexibility, and manageability of scheduling and execution of complex scientific workflows on HPC systems.
- *verihand™* is the world's first contactless, multi-modal hand biometric system. The technology raises the security level of hand biometric authentication and provides safe and sanitary identification via contactless scanning.
- One of the Laboratory's strengths is that it draws from a diverse pool of talent and experience. A multidisciplinary LLNL team developed an experiential learning tool called Lunar R3BUILD, to increase inclusion awareness. Organizations with an inclusive culture experience higher productivity, profitability, and employee engagement.

BIOMETRIC IDENTIFICATION

Multi-modal Contactless Hand Biometric ID System for Secure and Hygienic Authentication

Challenge:

Companies and institutions are increasingly incorporating biometric authentication systems to verify the identity or credentials of individuals. Most biometric devices today use physiological biometrics such as face or eye recognition, and thumbprints to confirm identity. However, these conventional systems face challenges. For example, retina eye-scans can become harmful after prolonged or continuous exposure to IR radiation; voice and facial recognition can be duplicated; and finger or handprints can be falsified by traces left on the machine. These issues are further complicated by the recent pandemic, as users hesitate to touch any scanning surface not disinfected prior to use.

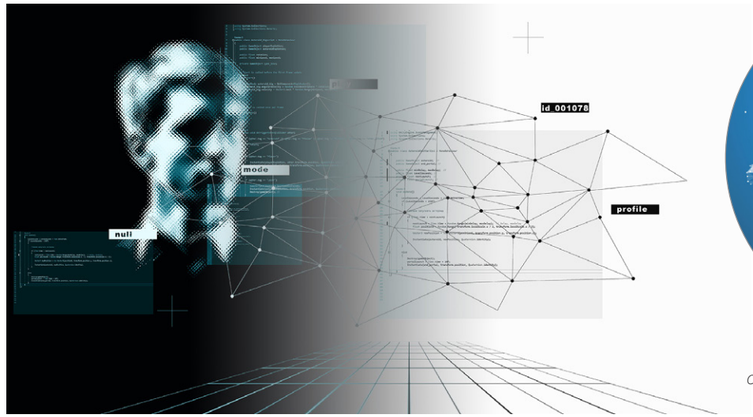
Solution:

verihand™ is the world's first contactless, multi-modal hand biometric system. It captures thousands of data points to create a pure digital ID from the entire hand without the hand touching the scanner. *verihand™* raises the security level by capturing data points from not only the finger and palmprint, but also from vein prints, making it the most difficult-to-copy hand biometric authentication system. Combined with the contactless reader, *verihand™* becomes not only the most secure, but also the most hygienic, biometric system that can be utilized with any desired application.

According to 2020 NewsWatch Tech Report: "The pandemic has forced us to re-imagine how we interact with the world around us. Things that once seemed normal are getting an overhaul from design up. Hackers have been emboldened by the world moving online, so now is the time to be more diligent with our security than ever. *verihand™* by nVIAsoft is the most hygienic, contactless method of secure digital ID available in the marketplace today."

Collaboration:

LLNL filed the patent application for the *verihand™* core technology in 2014, and granted a non-exclusive license to nVIAsoft Corporation in 2017, the same year the patent issued. After developing a working prototype, nVIAsoft was granted an exclusive license in 2020 to enable the company to raise funds for commercialization.

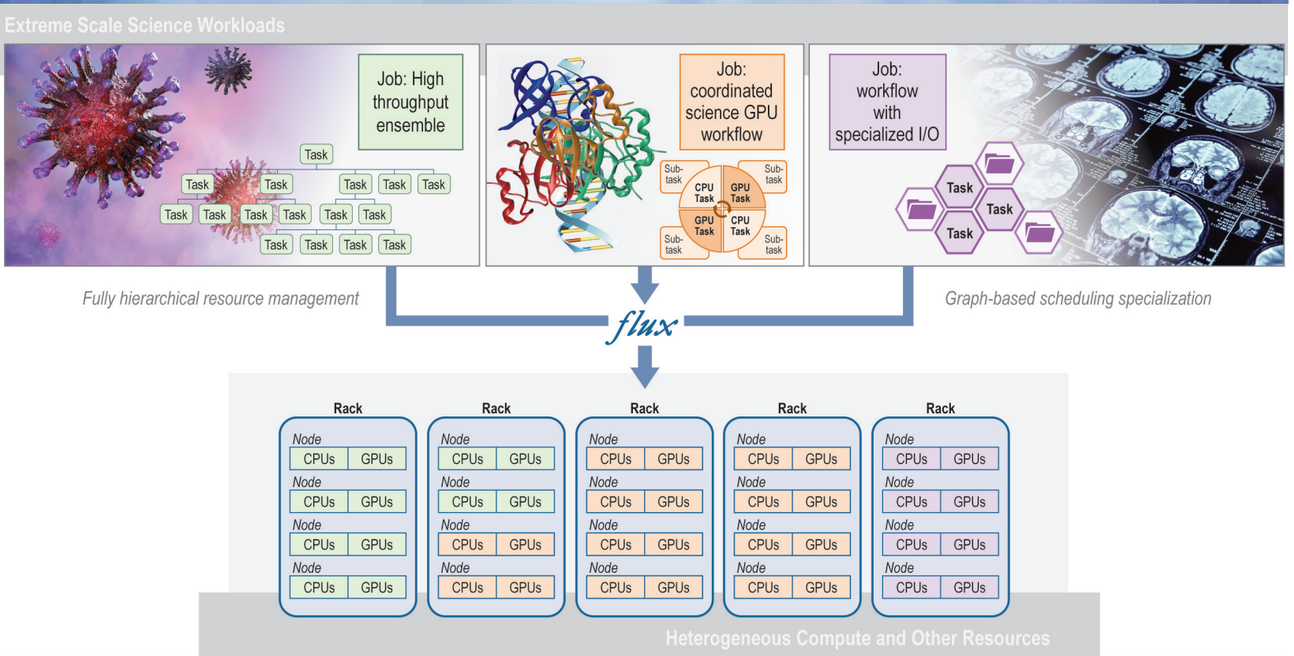


Capturing thousands of data points to create Pure Digital ID from the entire hand through contactless method.

Impact:

verihand™:

- Raises the security level of hand biometric authentication by combining fingerprint, palmprint, and vein imaging (multi-modal) data into one pure digital ID unique to a single individual
- Provides safe and sanitary precautions during authentication via contactless scanning
- Revolutionizes the hand biometric authentication industry by addressing both the public's security and health concerns



FLUX

A Fully Hierarchical Workload Manager for Supercomputing

Challenge:

Today's researchers require more computing applications than ever before in their scientific workflows. A single computing job may need to run multiple simulation applications at different scales along with in situ visualization, data analysis, machine learning (ML), and artificial intelligence (AI). At the same time, hardware innovations such as multi-tiered disk storage, combinations of general and specialized processors, and power efficiency advancements are yielding emerging supercomputing architectures and enabling computing resources to run applications faster and more efficiently. However, such heterogeneity also makes it increasingly difficult to realize full hardware potential. Today's scientific users performing extreme-scale science and engineering such as for cancer research, COVID-19 pandemic scenario modeling, drug design, additive manufacturing process optimization, and large AI need a workload manager with high performance, portability, flexibility, and manageability to run their scientific applications and complex workflows on extremely diverse computing resources that are in the cloud, at remote locations, on a laptop, or on next generation architectures. Traditional workload management software cannot handle the complicated workflows and adaptations needed to take advantage of these innovations.

Solution:

Flux is a next-generation workload management software framework for high-performance computing (HPC). It combines fully hierarchical resource management with graph-based scheduling to improve the performance, portability, flexibility, and manageability of scheduling and execution of complex scientific workflows on HPC systems both at the system and user level.

Flux's innovative capabilities drastically improve scalability and flexibility through a divide-and-conquer approach. Jobs and resources are divided among the schedulers in the hierarchy and managed in parallel. This approach has proven to increase the scalability of Flux significantly over traditional schedulers that rely on a single, centralized process. A unique and novel feature of Flux includes that its capability and scalability are provided for both single- and multi-user modes.

Collaboration:

Flux's adaptability to different use cases, along with easy availability under a permissive open source software license, has spurred wide adoption outside of LLNL. Flux has users worldwide, including our collaborators in both U.S. and European academic institutions, U.S. national labs, U.S. military and federal agencies, and prominent domestic and international scientific computing and HPC centers such as NERSC in California and RIKEN in Japan, home of the top-ranked Fugaku supercomputer.

Lassen is an unclassified, heterogenous IBM/NVIDIA system with 23 petaflops peak performance (23 quadrillion point operations per second).

Impact:

Spurred by the growing convergence of conventional HPC and new simulation, data analysis, and ML/AI techniques, the computational science community has been embracing much more diverse workflow solutions than ever before. These trends are already pushing the limits of the existing workload management products. Flux has been able to provide innovative solutions that enable scientific and engineering breakthroughs in cancer research, tools for antiviral drug design, designs for additive manufactured components, and massive ML and AI. Finally, many multi-disciplinary research teams have been successfully using Flux to enable major COVID-19 research. Flux is playing a central role in providing high job-throughput performance and portability required for urgent decision making—including scientific modeling of the spread of COVID-19 under various scenarios.

DECENTRALIZED ESTIMATION FOR AUTONOMOUS SENSOR NETWORK

Localizing a source via connected sensors

Challenge:

Networks that have multiple points of data collection often communicate that data back to a central hub/fusion center for decision making. However, this data transfer may be problematic in situations with limited bandwidth in the network, power constraints of the sensors, or very large data sizes. In addition, all data transfer to a fusion center constitutes a single point of failure (in the event that the fusion center is compromised or destroyed), leading to catastrophic failure of the network.

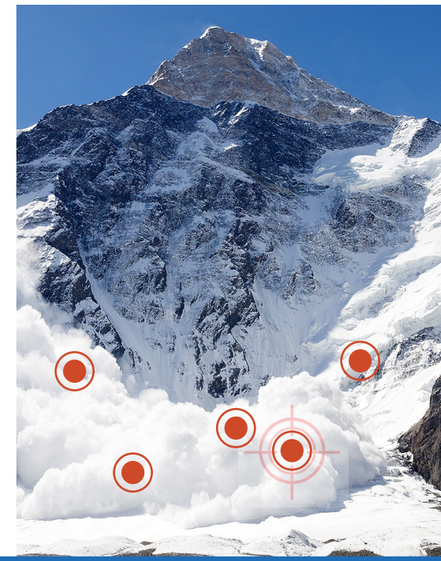
Solution:

The Decentralized Estimation for Autonomous Sensor Networks (DEASN) technology proposes a distributed Bayesian framework in which the sensors exchange small amounts of relevant information across the entire network by communicating with a random subset of the network often via multiple hops. This approach guarantees that the network converges on the result achieved, given access to all data, i.e., in a centralized scenario, while potentially reducing the communication bandwidth and power requirements of each individual sensor. Furthermore, because of the Bayesian framework, each sensor iteratively converges to a probability distribution instead of a point estimate, providing uncertainty quantification for decision making in critical applications.

The fully-decentralized nature of this invention makes it robust to any single point of failure, which means that if one or more sensors malfunction, the network can adequately function with data from the remaining sensors. Additionally, the data shared between sensors is free of any information on how it was collected, such as any proprietary details of the sensor.

The decentralized estimation algorithm is application-agnostic and can be designed to work with any network of sensors that make decisions based on collected sensor data. It is especially designed for networks with bandwidth limitations, sensors that collect large amounts of data, and scenarios in which sending that data back to a central hub is not practical. This algorithm facilitates interoperability between sensors of various modalities from different manufacturers, providing a seamless way to fuse data while potentially concealing sensitive information. The DEASN technology is robust and a secure and lightweight uncertainty quantification algorithm that can process information on premise without the need for a central hub.

Data from each location is collated and shared over a network to locate buried individuals



Impact:

The following is an example use case showing the impact of the DEASN technology:

Imagine you are backcountry skiing and one or more members in your party are caught in an avalanche. You and some of the other skiers turn on your avalanche beacons (the sensors) to search for buried skiers, who are also carrying avalanche beacons. In order for a beacon to find the buried skiers, the user must walk a potentially complex pattern based on the measured signal to converge on the buried skier's position; however, time is of the essence. What if there was a technology that required less training that could aid in finding the buried skier(s) faster, potentially saving their life?

DEASN technology would allow for the network of avalanche beacons to seamlessly communicate and estimate probable locations of a buried skier using data from any nearby beacons. Although various companies manufacture avalanche beacons, the DEASN technology would allow for various beacons to communicate with one another without the need to share any information about how each beacon works. Because the beacons communicate privately and iteratively for faster and more accurate results, the beacons can more quickly determine a buried skier's location, leading to better survival rates in the event of an avalanche.

"Experiential learning like Lunar R3BUILD is a great resource that assists in improving team engagement and in building an inclusive culture"

—Tony Baylis
Director: Diversity, Equity and Inclusion Office, LLNL

LUNAR R3BUILD

Fostering Inclusive Behaviors through Real Play

Challenge:

Workplaces have found that diversity, equity and inclusion (DEI) professional development tools are a useful way to improve awareness of innovative perspectives and bring the full breadth of employee experiences to bear on challenges and opportunities. DEI solutions for the workplace have proven to help inform and improve employee decision-making, productivity, competitiveness, and team-building. While businesses actively incorporate DEI into their core values, conventional training used primarily to inform typically misses the mark. Research indicates that traditional training focused exclusively on raising awareness has not significantly increased inclusion. To motivate change, firms must instead influence behavior.

Solution:

Lunar R3BUILD is LLNL's copyrighted, innovative experiential learning tool to increase inclusion awareness and promote cooperative behaviors, performance, and productivity. Developed by a multidisciplinary LLNL team, Lunar R3BUILD integrates proven game methodology with research-based identifiers to measure the level of player and team inclusiveness. The creative game design won a 2020 Adobe Government Creativity Award and teaches players DEI objectives and behaviors instead of trying to "gamify" an existing training presentation. Lunar R3BUILD challenges players to complete tasks and address obstacles when disaster strikes a distant moon base. Purposeful game design escalates inclusivity challenges and changes team dynamics as the game progresses. Moderated in-game discussions and digital surveys track each journey, helping participants identify more effective ways to behave and achieve better understanding of why DEI is critical.

Collaboration:

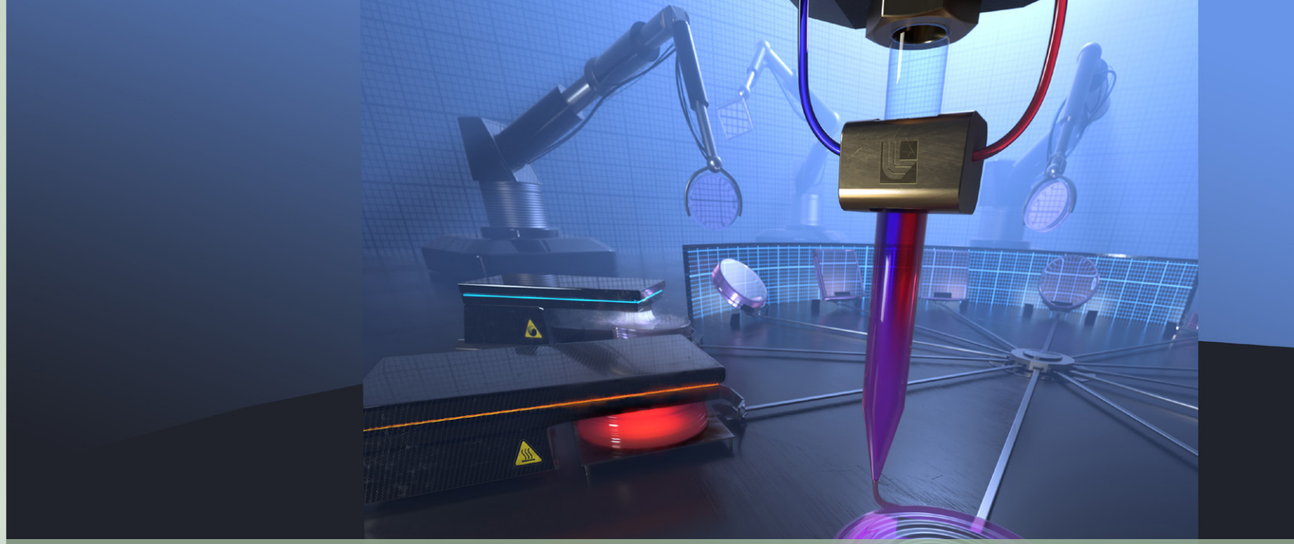
LLNL created Lunar R3BUILD to enable participants to more easily absorb and adopt DEI behavioral lessons while having fun. Everyone must work together to produce a sustainable solution to the crisis. Lunar R3BUILD leverages players' strengths as problem-solvers to create an impactful experience that reinforces the benefits of diversity and positive inclusive behavior. Unlike in role-playing, participants bring their true behaviors and natural tendencies, lending to a more robust, authentic, and potentially long-lasting experience. Players enjoy a shared experience in overcoming perceptions and bias to form inclusive teams; learn the benefits of diverse approaches to problem-solving; and develop skills that help increase inclusive behavior to maximize results.

Lunar R3BUILD was launched for licensing in 2021 after extensive playtesting within LLNL and with external partners, trialed under the temporary name "MoonQuake." Lunar R3BUILD is ready for in-person play for organizations interested in fostering inclusive behaviors, performance, and productivity. The game has proven to be a useful and transformative part of current DEI training solutions for private organizations, public entities, and educational institutions.

A hands-on game drawing on players' personalities, rather than role play, Lunar R3BUILD teaches players diversity, equity, and inclusion (DEI) objectives and behaviors instead of trying to "gamify" an existing DEI training presentation for a more positive, memorable experience.

Impact:

Lunar R3BUILD enables participants to absorb lessons and adopt behaviors that strengthen DEI values in a fun and engaging way. Trial participants responding to a follow-up survey reported they remembered the training and are actively applying the learning six to twelve months after they played the game. Organizations with an inclusive culture have experienced significantly higher productivity, profitability, employee engagement, customer satisfaction, and safety performance. Businesses that promote inclusion are more likely to meet or exceed financial targets, perform at a higher level, and achieve better overall results.



Partnerships Boost Economic Development

The IPO has active commercial licenses with 63 companies as well as dozens of cooperative research and development agreements (CRADAs).

IPO pursues innovation initiatives that develop public/private partnerships to advance the development and commercialization of scientific discoveries. Examples highlighted here include:

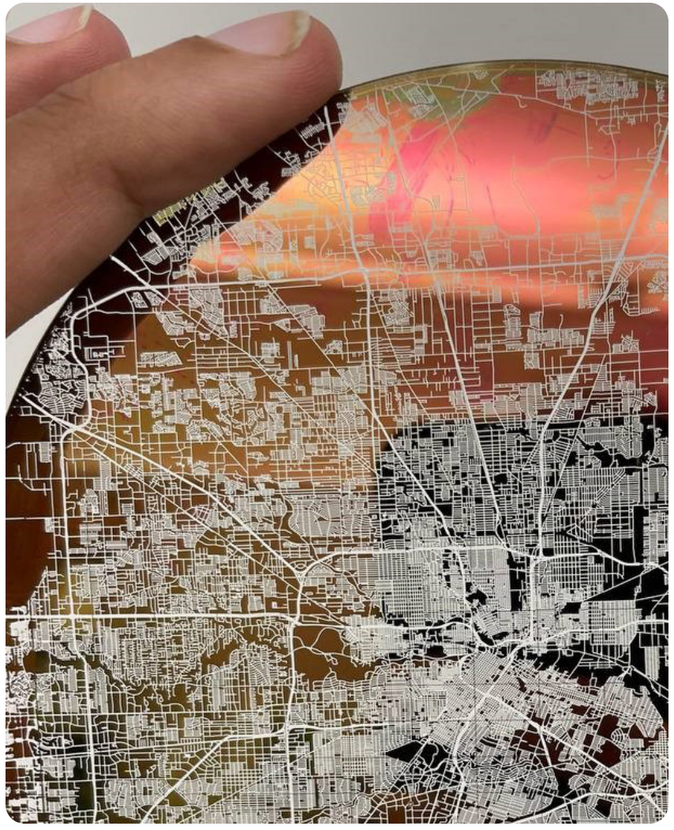
- A CRADA with Murrieta, California-based II-VI Aerospace and Defense, Inc. to develop a diffraction grating element to combine individual narrowband laser beams into a single, broadband high-power output beam for directed energy weapons.
- A DOE cooperative development grant with St. Louis-based MilliporeSigma to commercialize two sets of LLNL's 3D printing feedstock inks; a third set is pending commercial availability. These feedstock inks were selected for their potential use in a broad range of energy-related applications.
- A partnership with a NASA Goddard will launch Livermore's CODA telescope on a $30M SmallSat as part of the Pandora mission. The CODA telescope will study 20 stars and their 39 exoplanets. Under a Reimbursable Space Act Agreement, NASA Ames is providing NASA's hypersonic codes to advance the Laboratory's hypersonics program. And under a Non-Reimbursable Space Act Agreement, NASA Langley will permit LLNL to use their Mach 10 wind tunnel for key energy matter interaction experiments.
- A CRADA with Volumetric will develop LLNL's first-of-its-kind Large Area Micro Stereo Lithography (LAPµSL) into a bio printer, trademarked as the *Tessel™*, which will be used develop biological constructs of unprecedented complexity.
- A CRADA with Westmont, Illinois-based Gamma Technologies and Madison, Wisconsin-based Convergent Sciences, Inc., will commercialize LLNL's Zero-RK, which reduces the time it takes to simulate chemically reacting systems by as much as three orders of magnitude compared to state-of-the-art commercially available solvers.

COMMERCIAL PARTNERSHIPS

First-of-Its-Kind Bio-Printer Produces Biological Constructs with Unprecedented Complexity

Volumetric executed an exclusive license of LLNL's Large Area Micro Stereo Lithography (LAPµSL) technology in 2020 and began a CRADA to further develop LAPµSL into a first-of-its-kind, large area, large-volume, high-resolution, extremely fast bio printer. The purpose of this system, trademarked by Volumetric as the *Tessel™*, is for development of biological constructs of unprecedented complexity, including printing human lung and liver scaffolds. *Tessel™* technology allows large parts with tremendous detail to be built quickly. Speed is vital as the bio structures can require teravoxels (10^{12}) of information to be printed. For example, if printed at 1 voxel per second, 1 teravoxel would take 317,000 years to print. In the future, Volumetric's system roadmap will be capable of printing this in a little less than a week.

Volumetric is in progress to commercialize both the *Tessel™* printer as well as objects generated on a fleet of Tessels that the company is aiming to build. All tissue and organ scaffolds coming off the *Tessel™* assembly line will provide royalties back to LLNL. Additional CRADA extensions are anticipated to build Tessel 2 and get to the 10x throughput that will enable the production of a single organ scaffold in a week. Volumetric is raising funds to build a clean room to house a Tessel 2 print factory that could be capable of producing up to 1,000 organ scaffolds per year. This facility will serve as a key foundation for the extensive animal studies and pre-clinical studies that will enable future therapeutic testing in humans.



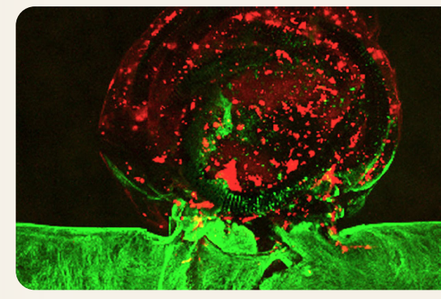
A photomask made on *Tessel™* showing a map of Houston demonstrates the intricacy that can be achievable for blood vessel architecture.

100,000 of these layers might be enough to make human organ replacements.

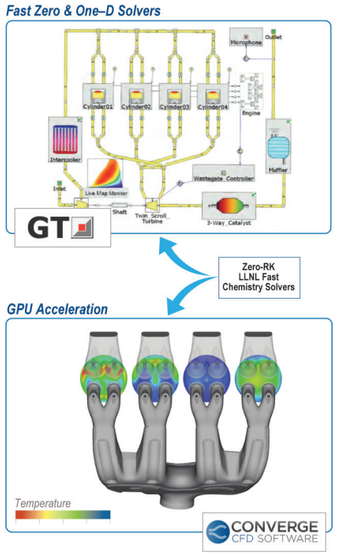
SPOTLIGHT:

The first living aneurysm

LLNL researchers bio-printed the first living aneurysm outside of the human body and performed an endovascular repair procedure by inserting a catheter into the blood vessel and tightly packing platinum coils inside the aneurysm sac. The team introduced blood plasma into the aneurysm and observed a blood clot form where the coils were located. With this platform, medical practitioners may be able to improve treatment methods, develop new personalized approaches, and perform "test runs" of procedures before attempting them on patients. The green areas depict the endothelial cells and the red indicates the formed clot.



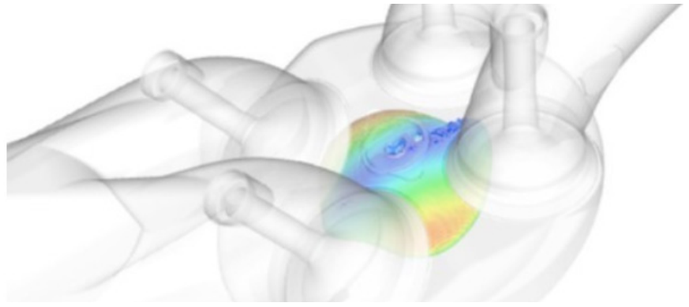
Optimizing Fuel Efficiency through High-Performance Computing-Enhanced Combustion Simulations



Project conceptual overview showing linkage of Zero-RK fast chemistry solvers to industry leading engine combustion software.

Strict emission and efficiency standards on combustion-powered energy systems drive a need to further understand how harmful emissions are formed and how combustion efficiency is limited in current devices. Improved capabilities in computation and simulation models have played an important role in this effort; however, more high-fidelity information is needed. LLNL has been working for more than ten years on reducing the computational cost to solve detailed chemical kinetics simulations to provide more predictive power to engineers analyzing and developing reacting flow systems. Researchers at LLNL developed a software package called Zero-order Reaction Kinetics (Zero-RK) that drastically reduces the time it takes to simulate chemically reacting systems by as much as three orders of magnitude compared to state-of-the-art commercially available solvers. Zero-RK, now available as open source, has application to automotive and stationary reciprocating engines, gas turbines, rocket engines, and industrial burners. LLNL engineers Matt McNenly and Russell Whitesides received an R&D 100 award in 2015 for their work on developing Zero-RK. LLNL has continued to develop the Zero-RK kinetics software with funding from the DOE Vehicle Technology Office and recently added high performance computing GPU solver technology that will further benefit commercial modeling and simulation software developers and provide more value to their customers by enabling simulations to run in minutes instead of days.

LLNL has initiated a collaboration with Westmont, Illinois-based Gamma Technologies (GT) and Madison, Wisconsin-based Convergent Science, Inc. (CSI) through a DOE Technology Commercialization Fund (TCF) CRADA project. The goal of DOE's TCF is to accelerate the transfer of national laboratory research to industrial applications. GT and CSI are leaders in the combustion engine simulation market. The 1- and 2-year Topic 2 projects, run by LLNL principal investigator Russell Whitesides, were awarded a total of $545K and are matched by in-kind contributions from GT and CSI.



Simulation of the flame propagation in an internal combustion engine using CONVERGE computational fluid dynamics software combined with LLNL's Zero-RK solver. The colored region is a surface of constant temperature colored by fuel concentration.

Collaboration Develops Spectral Beam Combining Technology for Directed Energy Weapons Systems

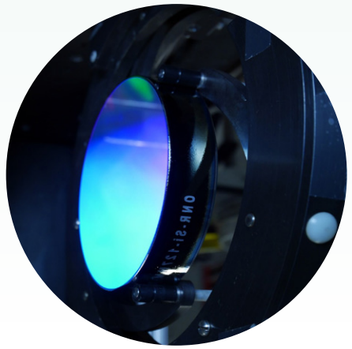
A new CRADA collaboration between LLNL's Multi-Layer Dielectric (MLD) Grating Development Group and Murrieta, California-based II-VI Aerospace and Defense, Inc. is developing key component products for directed energy weapons (DEWs) systems.

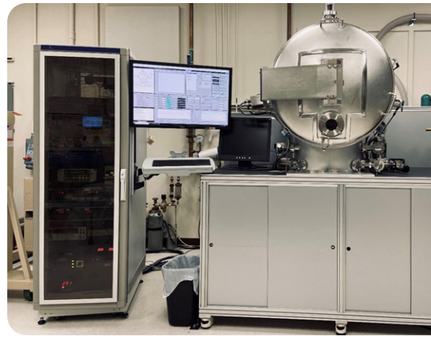
One of the current approaches to scaling lasers to higher power levels involves using a diffraction grating element to combine many individual narrowband laser beams, each with non-overlapping spectra, into a single, broadband high-power output beam. For this spectral beam combining (SBC) approach to laser power scaling to be effective for scaling to 100's of kilowatts required the development of ultra-low-loss dispersive grating optics. LLNL's SBC grating optics are precisely designed and fabricated surface-relief grating structures embedded into the topmost layer of a highly reflective, ultra-low loss, MLD thin film. The Livermore Diffractive Optics Group's new generation of high-power SBC grating optic was achieved by reducing the MLD grating mirror stack absorption more than sixty-fold to sub-part-per-million levels, resulting in a smaller heating load, less optics distortion, more robustness, and a higher laser damage threshold performance.

II-VI Aerospace and Defense was the first of several high-power laser systems and optical component manufacturers exploring partnerships with LLNL through CRADAs and licenses to commercialize the revolutionary new SBC optic and related MLD grating technologies. These new partnerships build on past collaborations such as the 2014 R&D 100 award-winning research for which LLNL collaborated with Lockheed Martin and Advanced Thin Films to develop the EXtreme-power, Ultralow-loss, Dispersive Element (EXUDE) technology for scaling SBC to 30kW power levels.

Under the CRADA, LLNL and II-VI A&D expect to develop and productionize high energy laser grating capabilities and products. The company plans to be a key supplier of high-power, fiber-laser component and subsystems for DEWs currently being developed, deployed, and envisioned for the future by US defense customers, DoD programs and applications.

II-VI AEROSPACE & DEFENSE





LLNL's custom reactive ion beam plasma etching system used to fabricate surface-relief grating structures.

COLLABORATIVE EXPLORATIONS

Partnering with NASA to Characterize Stars and Exoplanets

In January, the National Aeronautics and Space Administration (NASA) announced a NASA Goddard/LLNL partnership to launch Livermore's CODA telescope on a $30M SmallSat as part of the Pandora mission. The CODA telescope will study 20 stars and their 39 exoplanets to learn about starspots (akin to sunspots) and identify which of these exoplanets are hydrogen- or water-dominated and which are covered in clouds. LLNL is also leading the system engineering and overall program management for the Pandora mission.

Also in January, LLNL signed an umbrella Reimbursable Space Act Agreement that enables LLNL to reimburse NASA Ames for work performed for the Lab. As part of the agreement, NASA Ames is providing NASA's hypersonic codes and working with LLNL engineers to advance the Laboratory's hypersonics program. In June, LLNL signed a Non-Reimbursable Space Act Agreement with NASA Langley that permits LLNL to use their Mach 10 wind tunnel for key energy matter interaction experiments.

A composite false-color image of the Andromeda galaxy was created by stacking five wide-field-of- view channel images for an exposure of eight seconds. This image demonstrates the exceptional stability obtained by the Tyvak-0130 bus for a nanosatellite-class vehicle. During this series of exposures, two satellites moved through the field of view. Both are represented as two aligned streaks, with the bright set near the middle and the fainter and shorter streaks at left.

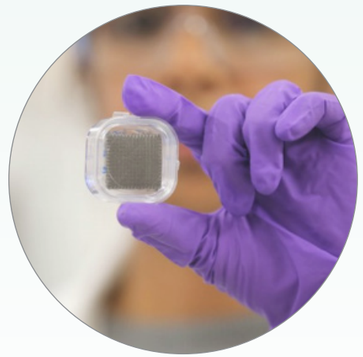
Commercializing 3D-printable feedstocks for advanced manufacturing of energy products

As a result of a two-year DOE cooperative development grant, LLNL and St. Louis-based MilliporeSigma, a global life-science company, explored, refined, and commercialized two sets of LLNL's unique 3D printing feedstock inks, with a third set of inks pending commercial availability. Feedstock inks, used for advanced manufacturing, enable the production of customizable new structures and materials with properties and performance far beyond previous capabilities. LLNL and MilliporeSigma selected these particular 3D-printing feedstock inks for their potential to impact a broad range of energy-related applications, such as energy storage, and high strength-to-weight material for improved fuel efficiency.

The first set of feedstocks are 3D-printable graphene-based inks that could improve energy storage through the design of aerogel electrodes with control-label, percolated, vascular structures, that provide fast charge/discharge rates, increased cycle-life, and improved gravimetric capacitances for next generation energy storage products.

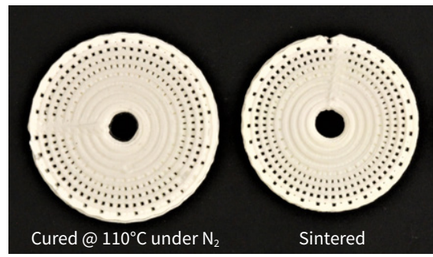
The second set of feedstocks are ceramic-based inks that can withstand harsh or extreme conditions, including micro-/nano-porous ceramic materials. These feedstocks are both chemically and mechanically robust at extreme temperatures and high pH, and thus should enable significant advances in 3D printing energy storage/conversion, separations, and sensor devices.

The third set of feedstocks are ceramic inks with ultra-high-temperature-resistant properties. Although traditional boron carbide inks used for heat exchangers and other components subjected to extreme temperatures are extremely hard, they are difficult to machine into complex shapes. LLNL's thixotropic ink overcomes this barrier with a high-volume fraction of aqueous ceramic suspension that can be patterned into complex and graded 3D structures. These ultra-high-temperature ceramic inks are expected to be commercially available soon.

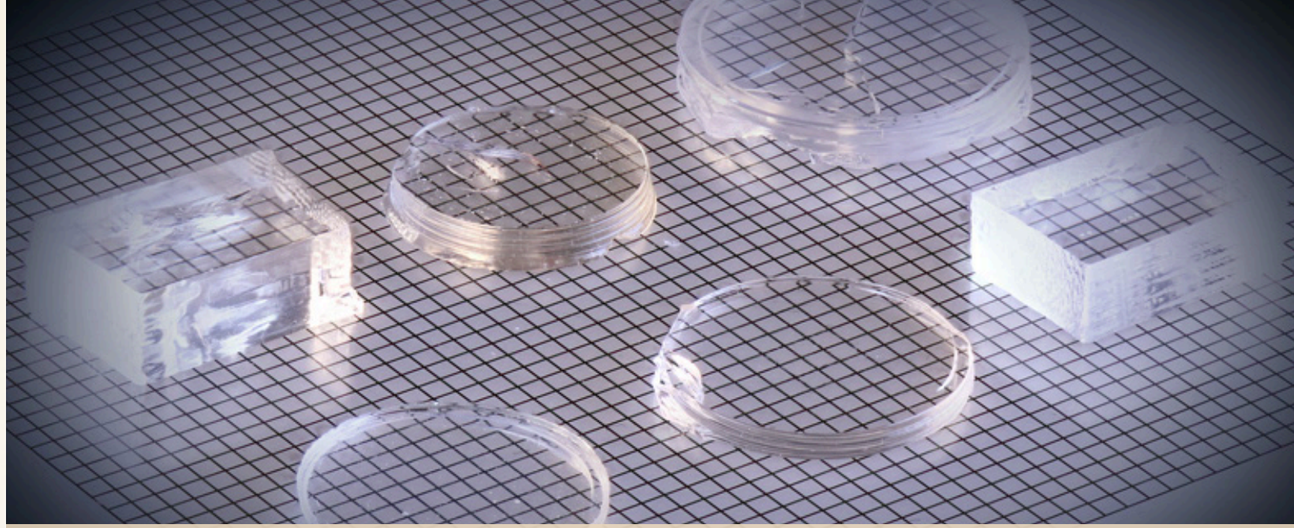


"The collaboration with MilliporeSigma is innovative, addressing the heart of the supply chain for 3D printed functional materials"

—Annemarie Meike
Business Development Executive
Innovation & Partnerships Office
September 8, 2021



DIW prints of a gradient of concentric circles was done using the 70 wt% 3Y-ZrO_2 ink. Clear resolution of features is apparent in the resulting cured and sintered structures.



Investments Spark Innovation

The Lab engages with regional businesses, academia, and federal agencies to match market needs with LLNL's innovative technologies.

LLNL maximizes its technology investments by creating environments that foster collaboration with businesses and train researchers in entrepreneurial skills. DOE supports these endeavors through various programs. Below are some of the activity highlights for the past year.

- The Additive Manufacturing Laboratory (AML) began 2 new thrusts, including a project with Spring Valley California-based FormAlloy.
- Through a new DOE COVID-19 Technical Assistance Program, the Lab provided recommendations to the University of Texas Medical Branch.
- LLNL received 3 national Federal Laboratory Consortium (FLC) awards.
- The High Performance Computing Innovation Center (HPCIC) formed 2 new industry partnerships; HPCIC and the Data Science Institute held its first Machine Learning for Industry forum; and 3 startups are active in the i-GATE incubation program.
- The Innovation Development Fund (IDF) is supporting 5 LLNL projects.
- The Lab Innovation Network Center (LINC) increased the region's awareness of the national labs through sponsored events.
- LVOC added 2 new buildings for 100 scientists and technical staff.
- OTT's Technology Commercialization Fund (TCF) is supporting 5 Lab projects, and its new entrepreneurial program is supporting an LLNL engineering intern.
- LLNL is participating in 5 projects and leading 1 in DOE's Practices to Accelerate the Commercialization of Technologies (PACT) program.
- 56 S&Es participated in the National Labs Entrepreneurship Academy (NLEA); 6 researchers are working with business mentors in the National Lab Accelerator (NLA); and IPO hosted a virtual NLA Pitch Event.

RECOGNIZING INNOVATORS

LLNL has won:

40 national FLC awards to date

FLC Technology Transfer Awards

National Award Winners:

Digital Droplet™ polymerase chain reaction (ddPCR)

Early disease detection can sometimes make the difference between life and death. LLNL developed the ddPCR technology to support the Laboratory's biosecurity mission. Compared to other PCR technologies used to amplify DNA samples for study, the ddPCR test's high degree of sensitivity makes it more effective for identifying individuals in the early stages of infection. ddPCR offers greater ease of use and integration into research workflows; increased signal-to-noise ratio; simplified quantification; and unrivaled precision, accuracy, and sensitivity. In May 2020, Bio-Rad Laboratories announced that its SARS-CoV-2 ddPCR test kit had been granted emergency use authorization by the U.S. Food and Drug Administration.

An analytical technique – known as Droplet™ Digital Polymerase Chain Reaction (ddPCR)– that was developed by LLNL scientists and engineers, has garnered an Impact Award from the Federal Laboratory Consortium. The technology has been commercialized by Bio-Rad Laboratories.

Radiation Field Training Simulator (RaFTS)

A collaboration between LLNL and Argon Electronics has led to the development and commercialization of the RaFTS technology, an ultra-realistic radiation simulator. RaFTS connects directly to radiation detection instruments to provide a signal indistinguishable from a real radiation source so training in a scenario of interest can take place without the risk of radiation exposure. The technology also eliminates the expense and risk of transporting radioactive materials for training purposes.

SuppleVent™ Ventilator

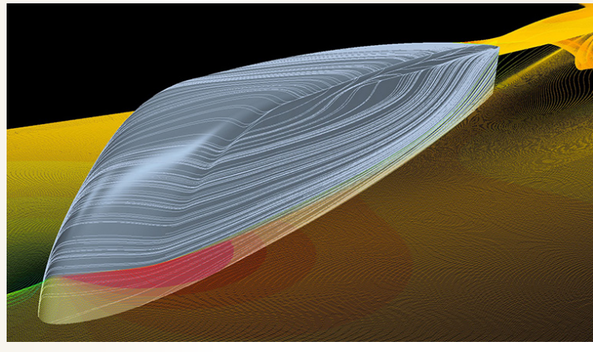
The COVID-19 pandemic revealed a nationwide shortage of ventilators, so LLNL convened experts in engineering, biotechnology, computer modeling, and materials to design a portable, mechanical ventilator to help fill the gap. Within weeks, the team members—many working remotely during the shelter-in-place—invented a ventilator technology that used readily available parts not required by commercial ventilator manufacturers, avoiding impacts to a strained supply chain.

Researchers from LLNL and Argon Electronics Ltd. conduct a test with the Radiation Training Field Simulator (RaFTS). From left: Dave Trombino, Erik Swanberg, and Josh Oakgrove, from LLNL; Phil Dunn of Argon, Greg White of LLNL, and Steven Pike of Argon.

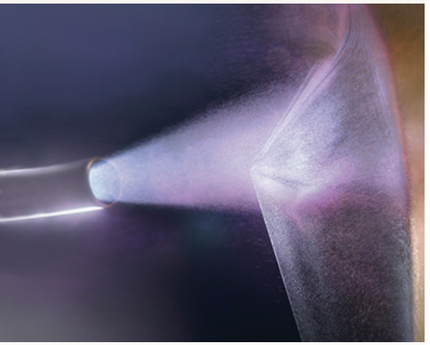
SPOTLIGHT

New heavy vehicle design increases fuel efficiency, cuts carbon emissions

Using wind tunnel measurements and computational fluid dynamics simulations, LLNL engineers demonstrated that aerodynamically integrated vehicle shapes decrease body-axis drag in a crosswind, creating large negative front pressures that effectively "pull" the vehicle forward against the wind, much like a sailboat. Reshaped semitrucks could reduce drag, increase fuel efficiency, and cut carbon emissions.



R&D 100 Awards



A cold-spray chamber is shown during deposition, with the nozzle at the left of the image and a near-full density sample being fabricated in the center. Particles of the brittle thermoelectric bismuth telluride are accelerated to more than 900 meters per second, or almost Mach 3, in inert gas and directed onto a copper surface, laying down the strips that form the basis of a functioning thermoelectric generator to harvest waste heat. Graphic by Jacob Long/LLNL.

In FY20, LLNL researchers garnered one R&D 100 award for an invention recognized as among the top 100 science and technology innovations worldwide.

Versatile Cold Spray (VCS) (Analytical/Test)

The new VCS technique deposits a broad range of brittle and glassy materials, including functional materials such as thermoelectric devices and magnets, onto any substrate. VCS has been developed through a partnership of LLNL and TTEC Thermoelectric Technologies.

In FY19, LLNL researchers garnered four R&D 100 awards and one silver Special Recognition award for being a market disruptor.

IMPEDE Embolization Plug (Analytical/Test)

IMPEDE is a medical device that reduces blood flow to blood vessels outside of the brain to decrease health risks. Researchers from LLNL, Santa Clara-based Shape Memory Medical Inc., and Texas A&M University developed the IMPEDE® Embolization Plug. The device offers 100–1,000 times greater surface area than current technologies to more effectively initiate clotting in the target vessel and divert blood flow away from at-risk regions. To date, more than 100 patients have been successfully treated worldwide with IMPEDE® with no reported adverse effects.

Spack: A Package Manager for HPC Systems (Software/Services) and Silver Special Recognition for Market Disruptor

Spack is an easy-to-use, versatile, and scalable software package management tool for HPC scientific applications. It simplifies and accelerates building and customizing software by automating the build workflow, thus reducing deployment time for large software stacks from weeks to hours. Spack is widely available as open source software and has a large and active community of more than 400 contributors.

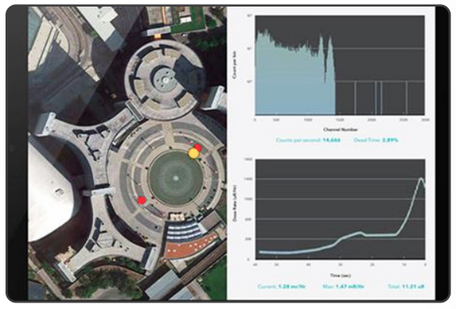
Technology Transfer Working Group Awards

The Technology Transfer Working Group (TTWG) held its annual awards event to recognize technology transfer professionals who shepherd DOE research through the commercialization process. The TTWG comprises technology transfer professional representing DOE's 17 national laboratories. The TTWG awards celebrate the exceptional efforts put forth by the leading technology transfer teams across the DOE Complex.

LLNL received two awards this year. The winning technologies support American competitiveness, national security, and quality of life improvement. Genaro Mempin, Alicera Aubel, Ines Gomez, and Jonathan Celniker received the TTWG Partnering award for their work involving **LLNL's SuppleVent™ Emergency Ventilator.** The team is responsible for the negotiation, coordination, approval, and execution of the CRADA agreements that enabled the successful transfer of the technology to BioMedInnovations, LLC in a matter of weeks.

Annmarie Meike received the Innovative Technology Transfer award for her work with the **Radiation Field Training Simulator (RaFTS) technology.** RaFTS is an ultra-realistic radiation simulator that connects to existing radiation detection instruments and produces a seemingly realistic radiation signal so training scenarios occur without the risk of radiation exposure. Annemarie was instrumental in bringing RaFTS to market through numerous agreements such as the negotiation of multiple NDAs and input for funding proposals including internal development funds and DOE's Technology Commercialization Fund. These activities resulted in a CRADA and an exclusive license agreement with Argon Electronics LTD.

SuppleVent™ Emergency Ventilator



RaFTS demonstration

In this RaFTS demonstration, radioactive sources are indicated as red dots, and the human responder is represented by a yellow dot in the image on the left. Readouts indicate the synthetic spectra of cobalt-60 (top, right), and the personal radiation dosimeter readings (bottom, right) indicate the responder is close to the radiation source.

FOSTERING COLLABORATION

LIVERMORE VALLEY OpenCampus

Open Resources Foster Collaboration

Laboratory Collaboration Zone

The Livermore Valley Open Campus (LVOC) is a 110-acre campus that LLNL and Sandia National labs developed to promote access between the labs and private sector collaborators, businesses, and academic institutions. In August 2021, a new 25,000 square foot facility comprising Buildings 642 and 643 was constructed to provide offices, conference rooms, and support spaces for 100 scientists, engineers, and technical staff. The conference facility (B643) can accommodate nearly 100 people for large gatherings. As part of LVOC, both buildings enjoy a designated General Access Area (GAA) security classification, allowing for improved access for foreign nationals and unbadged scientists invited to work on unclassified projects in support of the Laboratory's mission. The new office building will initially be occupied by tenants from the Innovation and Partnerships Office, High Performance Computing Innovation Center, Predictive Biology Group, and the Center for Engineered Materials and Manufacturing. LVOC Buildings 642 and 643 are the newest in a succession of current and future buildings in LVOC designed to encourage collaboration with external parties in support of LLNL's mission.

Advanced Manufacturing Laboratory

The Advanced Manufacturing Laboratory (AML) was one of the first facilities to restart onsite work after the COVID-19 outbreak. The hands-on nature of the work, ongoing time sensitive activities, and the need for benchtop collaboration made creating a safe environment in the facility a high priority.

LLNL and Volumetric Biotechnologies, Inc. completed a CRADA that transformed LLNL's Large Area Micro Stereo Lithography (LAPµSL) into a large area, large volume, and extremely fast Bio printer. This system, known as the "*Tessel™*," is designed to create biological constructs of unprecedented complexity, including human lungs and livers. The LAPµSL technology allows large bio-structures with tremendous detail to be built quickly. Speed is vital, as the bio parts can require teravoxels (10^{12}) of information to be printed. For example, if printed at 1 voxel per second, one teravoxel would take 317,000 years to print. The system, developed by Volumetric Biotechnologies, Inc., can print this in a little less than a week.

The AML contains approximately 5,000 square feet total with Class II, Division 2 enclosure for processing reactive materials.

The AML has been busy establishing new partnerships and making progress with its existing partners. Through these collaborations, critical advances are being made on new processes and equipment capabilities that are vital to our NNSA program. AML's successes are growing, and space within the facility is in high demand. As a result, space for equipment is being prioritized based on the ability to best foster external partnerships. LLNL's AML advisory committee meets to review applications for facility use and has recently approved two major new thrusts including: (1) development and provisioning of non-destructive evaluation capabilities for new and partner work, and (2) a project with Spring Valley, California-based FormAlloy Technologies, Inc., a metal additive manufacturing systems company. The collaboration will focus on perfecting a new alloy synthesis process.

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 Lab researchers 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.

HIGH PERFORMANCE COMPUTING
INNOVATION CENTER

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, 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 FY21, the HPCIC moved to an all-virtual operation, due to the COVID-19 pandemic. A new strategic partnership with the National Center for Supercomputing Applications (NCSA) was established, as was an international collaboration between Rolls-Royce and the UK Hartree Centre on manufacturing technology. With the anticipation of an enduring virtual outreach model, the HPCIC created the first annual Machine Learning for Industry (ML4I) Forum to bring together expert ML practitioners with industrial representatives who seek to put their data to best use. The HPCIC also continued robust support for the DOE HPC4EI program by fostering ideas, proposals, and staff engagement at LLNL.

This is an exciting year, as the HPCIC staff is moving into a new Livermore Valley Open Campus (LVOC) office complex B642/B643 in late FY21. The move to LVOC will also include the Innovation and Partnerships Office, the Advanced Manufacturing team, and the Predictive Biology team. All have in common a strong theme of outreach to the public and private sectors. This is an example of a vigorous LLNL effort to embrace and recognize outreach and partnerships as a critical and valuable component for all Lab programs.

HPC4 ENERGY INNOVATION

HPC4 Energy Innovation

The High Performance Computing for Energy Innovation (HPC4EI) program comprises two programs, PC4Manufacturing (HPC4Mfg) and HPC4Materials (HPC4Mtls), which leverage the world-class computational resources at the national laboratories to connect with industry to advance the national energy agenda. Companies submit concept papers and if accepted, a laboratory scientist 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 by 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. Eight additional national laboratories participate in the program 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 while reducing the risk of HPC adoption. DOE labs involved in the HPC4Mfg program include LLNL, LBNL, ORNL, SNL, ANL, NREL, NETL, INL, LANL, PNNL and Ames.

HPC4Mtls Program

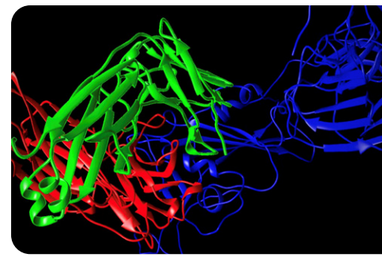
In FY21, DOE announced an opportunity to fund up to $1M in projects related to improving materials exposed to severe or complex environments through the new HPC4Mtls program. The HPC4Mtls program brings together industry partners and DOE laboratory scientists to work on short-term, collaborative projects and focuses on applying HPC to challenges associated with materials in energy technologies.

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. LLNL partners with PPG Industries to increase the understanding of corrosion inhibitors in automobile coatings. LLNL partners with Opus 12 to turn CO_2 into liquid fuel.

Materials Sciences LLC	HPC-enabled Optimization of High Temperature Heat Exchangers
Machina Labs	Advanced machine learning for real-time performance-informed thermo-mechanical processing of sheet metal parts
Toyota Research Institute of North America	Mechanistic understanding of electrolytes that improve processability and performance of solid state batteries
Opus 12 Inc.	Transport analysis and optimization in a MW-scale CO_2 electrolyzer

DOE labs involved in the HPC4Mtls program include:

Lawrence Livermore National Laboratory
OAK RIDGE National Laboratory
Los Alamos NATIONAL LABORATORY EST.1943
NETL NATIONAL ENERGY TECHNOLOGY LABORATORY
Pacific Northwest NATIONAL LABORATORY



LLNL scientists used high performance computers to design antibody candidates predicted to bind with SARS-CoV-2. In just 22 days, they reduced the number of possible designs from a nearly infinite set of candidates to 20 initial sequences predicted to target SARS-CoV-2.

Bay Area Lab Innovation Networking Center (LINC)

The San Francisco Bay Area is a booming technological and entrepreneurial ecosystem. It is the only region in the U.S. where four DOE national laboratories, Lawrence Livermore, Sandia, Berkeley, and Stanford Linear Accelerator Center, are co-located. LINC's goal is to increase the region's awareness of the Bay Area's national laboratories and use the labs' capabilities to participate in the region's innovation ecosystem.

Many regional stakeholders view each national lab as a specialized institution and only reach out to the labs for a limited timeframe when the need arises for specific projects. This collaborative project will develop a unified brand and engagement approach that engages the regional community. LINC aims to change the Bay Area's perception of the national labs as short-term, specialized partners to sustained partners.

The LINC team began outreach efforts in February 2020; however in March, travel restrictions and the shift to teleworking required the project be conducted on a virtual platform. Due to the continued COVID-19 restrictions, stakeholder survey meetings and subsequent events were hosted virtually.

In addition to creating a regional brand and aligning the Center's efforts to the Bay Area's innovation ecosystem, LINC has developed an engagement plan to increase interactions.

The Center has so far carried out two of the three planned sponsored events and is working on their third event. All labs reported approximately 10–12 leads from each event, and saw an increase in LPS activity. LINC shares office space at SLAC, and the Center plans to report to the broader DOE Complex.

Open the Door to Innovation (1st event)

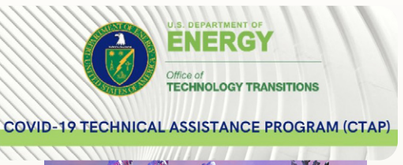
1,224 *registrants:*
- **54%** *as startups,*
- **26%** *as lab/universities,*
- **13%** *small businesses,*
- **6%** *large businesses.*

Open the Door to Partnerships (2nd event)

421 *registrants:*
- **58%** *representing startups,*
- **27%** *as lab/universities,*
- **8%** as small businesses, and
- **7%** as large businesses.

COVID-19 Technical Assistance Program

LLNL is now able to offer limited technical assistance to U.S.-based state, tribal, and local governments, not-for-profit organizations, regional and local businesses, and other private sector entities seeking the Lab's expert technical advice. Subject to available funding provided by DOE's Office of Technology Transfer's COVID-19 Technical Assistance Program (CTAP), LLNL staff can consult on a short-term basis to help overcome particularly challenging technical hurdles brought on by the global pandemic. Launched in summer 2020 to address public health issues, the CTAP program has expanded to address economic consequences stemming from the pandemic. They include investments to strengthen critical American infrastructure and vulnerable supply chains. In its first CTAP project, LLNL assisted the University of Texas Medical Branch by reviewing current practices and suggesting potential improvements aimed at reducing the further spread of COVID-19 within the community, particularly in healthcare facilities.



draft

Innovation and Development Fund (IDF)

The IDF is a mechanism to fund the advancement of LLNL-developed technologies and intellectual property (IP). The IDF, which is managed by the IPO, is funded by fees and royalties from licenses or other income earned or retained by the contractor from the performance of authorized technology transfer activities. The primary goal of the fund is to enhance the likelihood of transferring technologies to the private sector in accordance with the principles and purposes of federal technology transfer legislation. They support technology transfer activities and are typically used for market research, technology maturation/development, demonstration, or similar activities. LLNL inventors or IPO staff can suggest proposals for funding consideration. Each project can be funded up to a maximum of $100,000, and the number of awards per year can change, depending on the availability of funds.

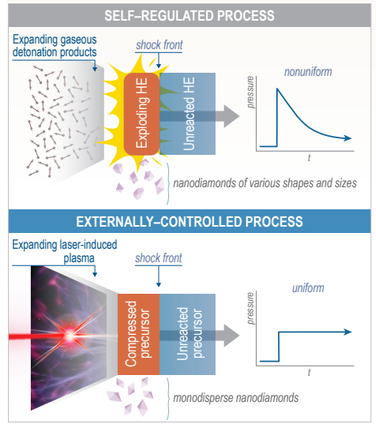
Funding decisions are informed by the IDF Investment Committee (IIC), which comprises members from the IPO, the IP Law Group, and the PADs and AD organizations. IDF applicants must have a relevant record of invention (ROI) or copyright disclosure on file with the IPO for the proposed project. The proposal is submitted as a presentation with predetermined questions and criteria to be included.

In 2021, IPO received and reviewed a record number of 16 IDF proposal applications and selected the top 8 proposals for live (virtual) presentations. After proposals were presented, IIC members had the opportunity to ask relevant questions and scored each proposal according to key criteria. Funding recommendations were forwarded to IPO Director Rich Rankin, who approved awards based on the IIC score and funding availability.

The IPO was able to fund 5 IDF proposals in 2021:

PI	Title
Narine Cherepy	Next-Generation LED Lighting: Based on KSF Transparent Ceramic Phosphor
Fang Qian	Solid-State Bioreactors
Mike Armstrong	High Throughput Nanodiamond Synthesis vVia Laser- Driven Shock Compression
Jason Brodsky	Architected Multimaterial Scintillator Systems
Nathan Ellebracht	Carbon Capture and Utilization: A Winery Application Prototype

The IPO funded **5** IDF proposals in 2021

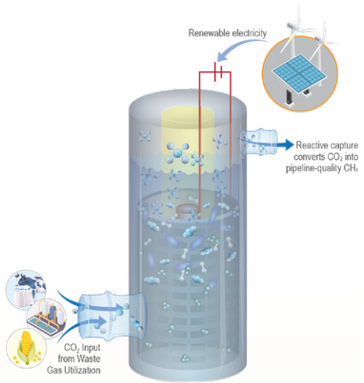


Mike Armstrong's High Throughput Nanodiamond Synthesis vVia Laser- Driven Shock Compression concept figure.

Technology Commercialization Fund

Since 2016, twenty-seven LLNL teams have benefited from the TCF program.

This year, the DOE Office of Technology Transitions announced that it will support five LLNL projects totaling more than $3.1 million through its Technology Commercialization Fund (TCF). The fund helps commercialize innovative technologies from DOE's national labs to spawn new businesses and jobs, while strengthening the nation's economic competitiveness. Below are descriptions of the five projects selected.



High Efficiency Power-to-Gas in a Modular Hybrid Electrobioreactor, $1M

In collaboration with SoCalGas and Electrochaea, Dr. Simon Pang will lead a team to commercialize LLNL's power-to-gas electrobioreactor, which allows excess renewable electricity to be stored in chemical bonds as renewable natural gas (RNG). The RNG can replace fossil-derived natural gas in existing pipeline infrastructure and can be converted back into electricity or heat as needed up to months later. LLNL's electrobioreactors use advanced manufactured 3D electrodes and methanogenic archaea to convert CO_2 and hydrogen into methane and water. By using a hybrid electro-biological pathway, LLNL's process combines multiple steps into a single reactor, reducing energy use for production.

Electron Sensing Diagnostics for Increased Reliability of Metal Additive Manufacturing, $130K

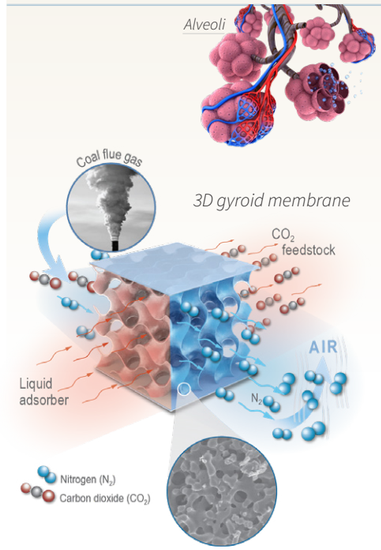
Dr. Aiden Martin and his team are developing an electron-based, in situ sensor and optimization technology that integrates into laser powder bed fusion (LPBF) additive manufacturing systems to provide real-time quality assurance. The sensor operates by measuring the flow of electrical current in the metal component generated by ejection of electrons from the laser-heated metal surface. When integrated into commercial metal LPBF-AM systems, LLNL's electron diagnostic sensor provide component quality analytics in real-time, reducing the current requirement of explicitly testing the fabricated component after it is manufactured, which is a time-consuming process in the traditional process workflow.

Novel Biogas Bioreactors for Energy Recovery at Small-Scale Wastewater Treatment Facilities, $250K

An LLNL team led by material scientist, Fang Qian, in partnership with National Renewable Energy Laboratory (NREL), has developed Biocatalyst-Integrated Units (BIUs) for efficient conversion of methane into fuel and chemical intermediates. The BIU features superior gas mass transfer and high catalyst loading, which result in a volumetric productivity improvement of more than ten times relative to liquid phase bioreactors. The LLNL and NREL teams will partner with nearby wastewater treatment plants and companies to increase the commercialization potential of BIU-based bioreactors. This first-of-its-kind technology will benefit a broad range of small biogas producers, including wastewater treatment plants, agricultural facilities, and landfills, who will realize additional revenue without having to reconstruct their current infrastructure.

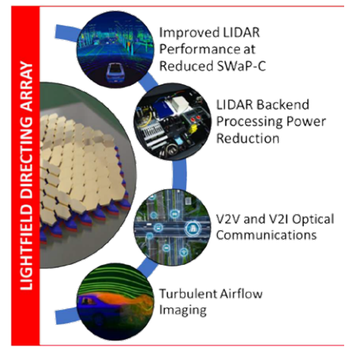
Enhanced Biomimetic Three-Dimensional Nanoporous Gyroid Membrane for High Efficiency Carbon Dioxide Absorption, $250K

A team from LLNL and collaborators from the University of Illinois will fabricate and test a 3D gyroid membrane contactor (3D-GMC) based on LLNL's proprietary photoresist and ink technologies to improve the energy efficiency of CO_2 capture. The 3D-GMC technology, which mimics the functional architecture of human lungs, has ten times higher gas/liquid interfacial area and up to 95% porosity compared to the 20–70% achievable by current designs. The gyroid flow channel architecture also increases the concentration gradient-driven CO_2 diffusion, and thus, capture rate, while reducing system size. The new approach is more robust, cost effective, and environmentally sustainable than other commercially available CO_2 "scrubbing" technologies.



Lightfield Directing Array Commercialization, $1.5M

Dr. Robert Panas and his LLNL team are commercializing their Lightfield Directing Array (LDA), a silicon MicroOptoElectroMechanical Systems chip that uses solid-state optical beam control. The chip's unique architecture enables previously unachievable combinations of high-speed, large field-of-regard, and precision control in harsh environments, all in a package smaller than a cubic inch and a cost of less than $100/device. LLNL is partnering with Bright Silicon Technologies, Inc. to produce commercial prototypes for end-use transportation companies. The LDA will be leveraged to achieve significantly improved vehicle system sensing, communications, and safety platforms.



ENGAGING ENTREPRENEURS

Entrepreneurial Programs

Laboratory solutions to problems important to the U.S., such as energy challenges, are implemented through the business sector; therefore, it is important that LLNL researchers have some knowledge in working with businesspeople and how technology transitions to the private sector. LLNL's IPO sponsors and manages various entrepreneurial programs to enhance the skills of the LLNL workforce, spurring innovation and seeding commercialization of LLNL intellectual assets. With a focus on ecosystem understanding and network curation, these programs are truly impactful for the participating scientists and engineers for commercialization and day-to-day research goals. Programs offered are matched with interested scientists and engineers and the skill level and technology readiness level of LLNL intellectual property.

National Labs Entrepreneurship Academy

- 3-day classroom-based training developed and taught by UC Davis
- 8 academies hosted since 2015
- >300 researchers trained in entrepreneurial skills

National Labs Accelerator

- 6-9 months individualized training & mentoring from investors
- Focused value proposition and business model development for specific technology
- 3 Accelerator programs since 2017

FedTech

FedTech™

- Trains Lab entrepreneurs to develop business models for their technologies
- 6 LLNL technologies chosen to participate since 2018
- 2 companies currently formed and pursuing commercialization

Energy I-Corps

ENERGY I-CORPS
U.S. Department Of Energy

- Lab entrepreneur partners with industry mentor to focus on customer discover & business model canvas
- 8 weeks; $75k
- 7 teams, 13 S&Es since 2015

National Labs Entrepreneurship Academy

NLEA is a three-day classroom-based training opportunity featuring a curriculum developed and taught by professors in the UC Davis Graduate School of Management focusing on technology value proposition development.

National Lab Accelerator

The Accelerator program is a 6–9 month individualized training and business mentoring program focusing on business model development and communication, and culminating in a DOE-wide pitch competition.

Energy I-Corps

The I-Corps curriculum provides an intensive 8–10 week opportunity for scientists and engineers to focus on customer discovery and business model development with DOE funding and support.

ENERGY I-CORPS
U.S. Department Of Energy

FedTech

FedTech is a startup studio that recruits and trains external entrepreneurs in business model development for federally developed and owned technology.

FedTech™

National Labs Entrepreneurship Academy (NLEA)

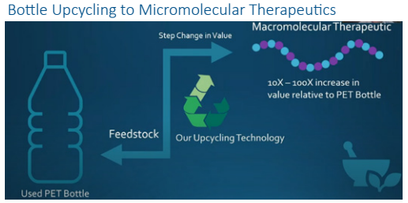
Fifty-six S&Es participated in the Academy in November 2020, bringing the total trained to greater than 300 since 2015. Due to COVID-19 impacts, the 2020 program went virtual for the first time. The curriculum was modified for a five-day virtual learning delivery.

Since 2015, LLNL's IPO has partnered with the UC Davis Graduate School of Management to host seven academies teaching LLNL and Sandia-California 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.

LLNL competitors included:

- **Greg Nyce**
  Antimicrobial Therapeutics from Plastic: Reimagining the Value of an Empty Plastic Bottle
- **Teresa Berry & Colin Yamaoka**
  Moonquake (now available under the name Lunar R3BUILD)
- **Randy Roberts**
  Geovisipedia
- **David "Scott" Andrews**
  Clean Cash™

Bottle Upcycling to Micromolecular Therapeutics



Greg Nyce was the LLNL winner with his pitch, "Antimicrobial Therapeutics From Plastic: Reimagining the Value of an Empty Plastic Bottle."

National Lab Accelerator

The 2020 Accelerator program saw five LLNL researchers working with business mentors to develop business models and pitches applying LLNL technologies to a market need. Four went on to compete in the LLNL pitch event for the opportunity to represent LLNL in the DOE-wide pitch event. Greg Nyce was the LLNL winner with his pitch, "Antimicrobial Therapeutics From Plastic: Reimagining the Value of an Empty Plastic Bottle." His fellow LLNL competitors included Teresa Berry and Colin Yamaoka pitching Moonquake (since rebranded as Lunar R3BUILD), the immersive and fun multi-modal learning game that fosters an inclusive culture in companies; Randy Roberts pitching Geovisipedia, a satellite imagery-fueled visual database with potential impact in industries from economic forecasting to insurance claim estimation; and David "Scott" Andrews pitching "Clean Cash™," an automated paper money ultraviolet-sanitizing machine.

On December 2, 2020, IPO hosted a virtual National Lab Accelerator Pitch Event, a competition format and a rare opportunity for the business community to learn firsthand about the diverse science and technology across the DOE national laboratory complex. With 10 national labs represented, investors and entrepreneurs evaluate the commercial potential of innovations for transfer to the private sector. Other national labs that sent researchers to the national pitch event included BNL, LANL, SNL, LBNL, PNNL, INL, ANL, NREL, and ENTL. The winner of the 2020 National Lab Accelerator Pitch Event was Curtis Larimer of PNNL. He presented "ElastiDry Protective Coating," a groundbreaking liquid repellent material that, when applied to personal protective equipment such as gloves, face shields, shoes, or protective suits, reduces infection and contamination in healthcare settings.

The LLNL-hosted National Lab Accelerator is a DOE Office of Technology Transitions-funded program designed to train national laboratory researchers in optimizing the flow of laboratory-developed technologies into the private sector to create value for the U.S. economy. With a stronger understanding in business, researchers are able to better communicate a value proposition with business-people. 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 researchers the opportunity to work with experienced external business mentors who help them develop a value proposition and business concept around a market need and a technology. Their work culminates in a pitch competition in which their knowledge and business model communication are judged by Bay Area and Silicon Valley investors.

IPO has hosted the National Lab Accelerator program since 2017.

I-GATE

i-GATE Innovation Hub and Daybreak Labs

i-GATE manages a life sciences and deep tech incubator called Daybreak Labs. Daybreak Labs provides biological research facilities and prototyping equipment to help life sciences and deep tech startups get started and grow quickly. i-GATE's incubation programs have supported a number of high-tech startups that are commercializing technologies originally developed at LLNL. Three startups with ties to LLNL (Savion Aerospace, Metal Monomers, and New Frontier Aerospace) are currently incubated in the facility. 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.

SafeTraces recently expanded its offices to an 8,000 ft^2 laboratory/office in Pleasanton, California and relocated its research and development facility to Livermore, further contributing to the regional economy. 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.

Since 2010, iGATE's incubation programs have provided a network of resources to budding entrepreneurs. (Image was taken prior to COVID-19 indoor spacing and mask mandates)

EXPLORING OPPORTUNITIES

Machine Learning for Industry

The High Performance Computing Innovation Center (HPCIC), together with the LLNL Data Science Institute, recently held the first annual Machine Learning for Industry Forum (ML4I) August 10–12.

ML4I was created to foster the free exchange of ideas and best practices in applying machine learning (ML)/artificial intelligence (AI) methods for solving practical industrial problems. Industry participants work with the broader research community and solution vendors to identify the most promising solution strategies and demonstrate methods of data analytics that can achieve actionable outcomes. The industrial participants learn solution strategies for their own needs while the research community gains a broader perspective of ultimate use cases for ML/AI methods. All participants benefit by a tighter community bond between research and application of data analytical methods.

This virtual event brought together more than 500 participants from the Department of Energy complex, commercial companies, professional societies and academia. Industry sponsors included ArcelorMittal, Cerebras Systems, Ford Motor Company, IBM, Intel, SambaNova Systems, NVIDIA, Intersect360 Research and Rhino Health. Each day featured a theme, with Day 1 devoted to Industrial Applications, Day 2 to Tools and Techniques, and Day 3 to Special Topics. Keynote speakers included Devesh Upadhyay, Leader of AI-ML at Ford Motor Company, Prof. Pieter Abbeel, Director of the UC Berkeley Robot Learning Lab, and Pamela Isom, Director of the DOE Artificial Intelligence & Technology Office. Panels of experts discussed workforce development, resources for ML tool development, and dataset sharing and security. The bulk of each day was devoted to topical sessions with speakers presenting on a variety of subjects that examined each day's theme. Response to the forum has been overwhelmingly positive, showing the strong traction for the ML4I charter. Work on ML4I 2022 will begin soon.

The Office of Technology Transitions' (OTT) Entrepreneurship Program

LLNL benefited from an exciting new internship opportunity for undergraduate students looking to experience DOE's world-class national laboratory system, boost entrepreneurial thinking, and explore market opportunities. In this year's pilot program, LLNL welcomed intern QuoVadis Savoy, a recent electrical engineering graduate from Southern University and A&M College. QuoVadis provided a commercialization assessment for LLNL's sense-and-avoid navigation technology as applied to the small, unmanned ground vehicle market. She also led a team of fellow interns in presenting the plan as an investment opportunity for a new company—a key skill for budding entrepreneurs.

LLNL welcomed intern QuoVadis Savoy, a recent electrical engineering graduate.

Engaging Silicon Valley

Entrepreneurial Outreach

LLNL is fortunate to be located near Silicon Valley's many entrepreneurs and investors. IPO regularly interacts with this community and attends angel investor meetings such as the Keiretsu Forum, Band of Angels, Venture Capital Roundtable, TriValley Ventures, and many others. Closer to home, IPO supports the entrepreneurs at the Livermore-based incubator, Daybreak Labs. The Lab is also an active member of the TriValley Innovations Group, comprising companies within the TriValley region. In addition, IPO spearheads an informal group called the Entrepreneurs in Readiness, whose members freely give their time to help LLNL scientists and engineers understand the business world to improve their technology transfer efforts. This same group mentors LLNL scientists participating in our National Lab Accelerator program and the National Lab Entrepreneurship Academy.

Society for Brain Mapping and Therapeutics (SBMT)

IPO is a member of the Scientific Board of the SBMT with the goal of bringing the DOE national labs and the neuroscience R&D communities together to conduct joint research for mutual benefit. SBMT leadership strongly believes that progress in understanding how the human brain works can only be achieved through multidisciplinary research. IPO helped plan and create two R&D speaker sessions for the SBMT World conference held in July 2021. One session showcased speakers from three national labs offering an overview of each lab's research in neuroscience R&D. A second session involved national labs and private companies presenting their work on neuromorphic computing under the title, "The Brain as a Computing Machine."

Promoting Technology Commercialization

LLNL is participating in five PACT projects and is leading one

- Open Source Software
- Lab Innovation Networking Center
- Technology Transfer Researcher Liaison Program
- Accelerating Commercialization by Connecting Inventions to Maturation
- Diversity and Inclusion in InVentorship and EntrepReneurship Strategies and Engagement – Women

In an effort to lower barriers to technology innovation, the DOE selected 12 projects as part of its Practices to Accelerate the Commercialization of Technologies (PACT) program. Each PACT project is designed to enhance the potential for commercialization of national laboratory technologies and increase collaboration between industry and lab researchers. The program, originally developed by the DOE's Office of Technology Transitions (OTT), provided $2.5 million for the 12 projects. These PACT projects engage all 17 national labs, one National Nuclear Security Administration (NNSA) facility, and six external partners, for a total of 24 participating entities.

Open Source Software (OSS): Seeds of Commercialization

LLNL leads the Open Source Software (OSS) Seeds of Commercialization project, which seeks to identify and validate value propositions for OSS developed and released by LLNL, and by extension, all of the DOE national laboratories. The project team continues to work with LLNL's open source developers to identify and test methods for increasing and tracking OSS projects. The areas of focus include user community development, cloud computing access strategies, software foundation model investigation, and streamlined access coupled with user attribution.

Lab Innovation Networking Center (LINC)

The Lab Innovation Networking Center (LINC) serves as a portal to the four DOE national laboratories (LLNL, Sandia National Laboratories, SLAC National Accelerator Laboratory, and Lawrence Berkeley National Laboratory) in the San Francisco Bay Area, connecting corporations, startups, and investors to DOE's world-class research and unique facilities, to accelerate innovation in the region. LINC has aligned individual laboratory efforts and created a single LINC brand. A LINC website (bayarealabs.org), informational material, and a video were created, along with shared office space at SLAC. LINC conducted three virtual events to inform private industry about the tools and expertise that could be leveraged to help drive their business goals.

Technology Transfer Researcher Liaison Program

The Technology Transfer Researcher Liaison program's goal is to improve communication between research organizations within the 12 participating DOE laboratories and their respective technology transfer office. To meet this goal, DOE scientists representing different organizations and various disciplines were recruited to become technology liaisons. They serve as advocates for the patenting and commercialization of newly developed DOE technologies within their specific laboratory. Seven technology liaisons were recruited from across LLNL and have reinvigorated a similar program within the Laboratory.

Diversity and Inclusion in InVentorship and EntrepReneurship Strategies and Engagement–Women (DIVERSE-W)

The project goal for DIVERSE-W is to increase female participation within the national laboratories' tech transfer programs to spur innovation and enhance the potential for commercialization of lab technologies. The inclusion project seeks to better understand and frame diversity and inclusion (D&I) issues. DIVERSE-W will address: low participation rates for women in inventorship and entrepreneurship; D&I best practices from both inside and outside of DOE that are yielding results; and development strategies for new and innovative inclusion programs that can be piloted. The DIVERSE-W team partnered with FedTech to roll out a four-part virtual speaker series. The July event featured Audrey Sherman, a 3M Company division scientist. The August event speaker was Phoebe Suina, CEO of High Water Mark. The final two events are scheduled for the first quarter of FY22. The goal of this speaker series is to educate and inspire women to engage with resources for professional and personal development.

Accelerating Commercialization by Connecting Inventions to Maturation (ACCLAIM)

ACCLAIM seeks to align national laboratory-developed technologies with federal government accelerators that identify, mature, and support technologies for national security applications. ACCLAIM serves as a vehicle for DOE labs to understand the goals and interests of the different federal technology accelerators and technology maturation programs, identify potential roles and pathways for contribution from DOE national laboratories, and define a path forward for strategic alignment. The project participants examined approximately 60 organizations and programs across the federal government and identified those with goals that align with national laboratories. The team determined that existing funding opportunities are limited (with most programs eligible only to industry), but there is potential for access to new resources.

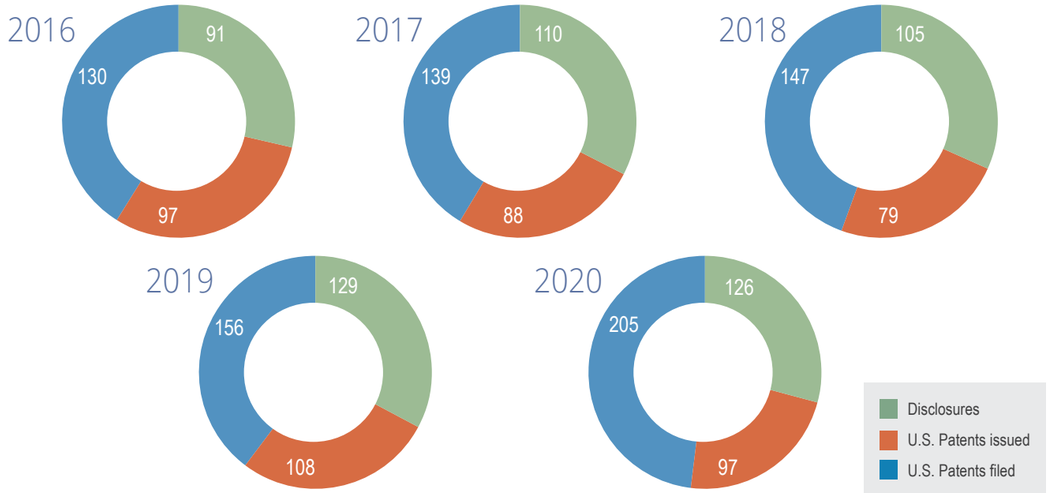
Among the project's findings was that benefits could be achieved through more consistent sharing of best practices and with the development of consistent metrics for measuring outcomes.

METRICS

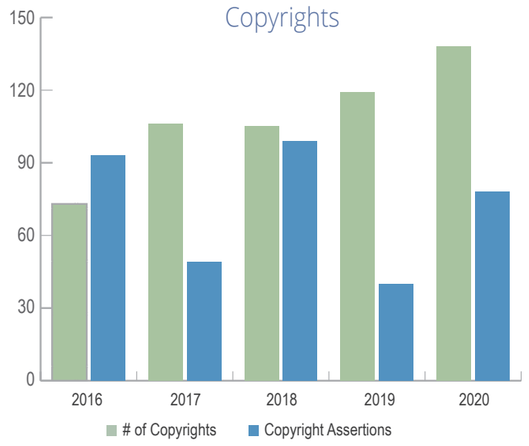
While narratives that describe scientific discoveries at LLNL provide evidence of innovation in action, they do not tell the whole story. Here, we share metrics that serve as quantitative indicators of our success in transferring technology from LLNL to commercial partners.

Intellectual Property

LLNL-based inventions were protected by more than 1,000 issued patents and patent applications, including provisional patents, from 2016 to 2020.

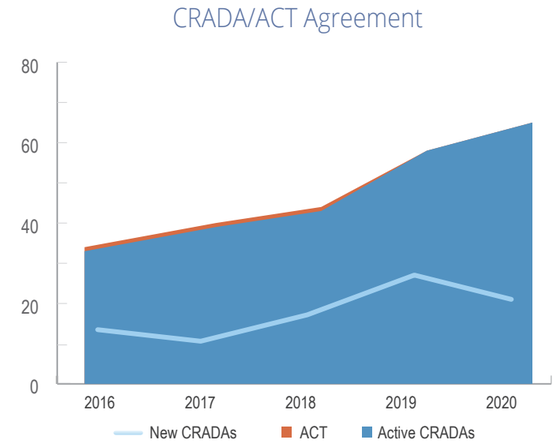


LLNL obtained more than 300 copyright assertions, helping protect our scientists' intellectual property from 2016 to 2020.

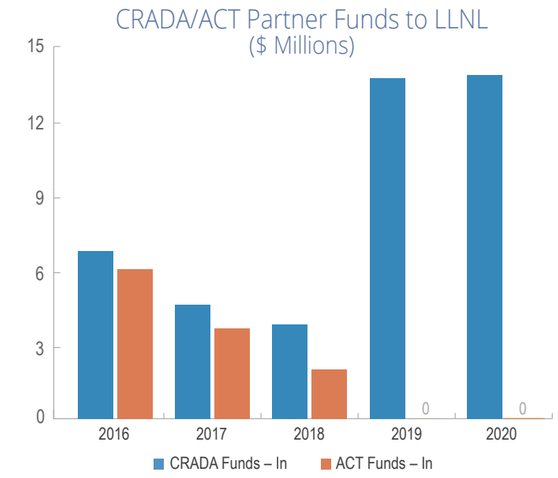


Industry Agreements

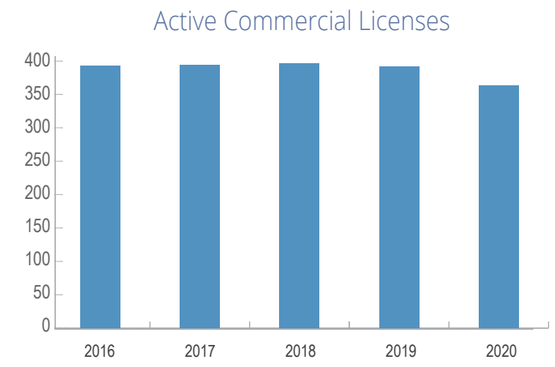
LLNL has maintained nearly 50 active CRADAs annually from 2016 to 2020, which helped our scientists transform promising technology into marketable products.



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



LLNL has maintained nearly 400 active commercial licenses annually from 2016 to 2020.



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-779 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
Quaiterandal1@llnl.gov, 925.423.7302

Alicera Aubel, Lead, Business Development Associate,
Aubel1@llnl.gov, 925.422.3041

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

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

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

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

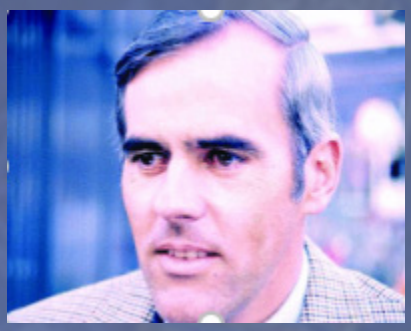
Genaro Mempin, Business Development Executive, Advanced Manufacturing, Instruments/Sensors/Electronics
Mempin1@llnl.gov, 925.423.1121

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

IN MEMORIUM



Gerald "Jerry" Burke

Former LLNL Engineer, Gerald "Jerry" Burke, a leading antenna modeling and design innovator, passed away in February. Burke and his colleagues created the Numerical Electromagnetic Code (NEC), an antenna modeling system for wire and surface antennas that became a game-changer for antenna mapping and significantly improved radar and communication systems. NEC's ability to calculate currents more accurately along the antenna wires, and the junctions between them, offered a significant improvement over the Antenna Modeling Program (AMP2) that was being used at the time. It gave the Navy insight into how a ship's structure would affect an antenna's performance and inform modifications to both ship and antenna designs. The result was significantly improved radar and communication systems that saved time, money, and resources. An early version of NEC was released to the general public for free, which helped to build the user community. More sophisticated proprietary versions eventually followed. Just prior to his passing, Jerry modified the NEC-4 code and created NEC-5.

Jerry received B.S. and M.S. degrees in electrical engineering from the University of California, Berkeley, and he lectured at short courses and workshops in a variety of locales around the world. Quiet and unassuming, Jerry was a gifted numerical analyst and an outstanding programmer. But, most of all, he was a valued colleague and friend to many. He is missed.

Lawrence Livermore National Laboratory