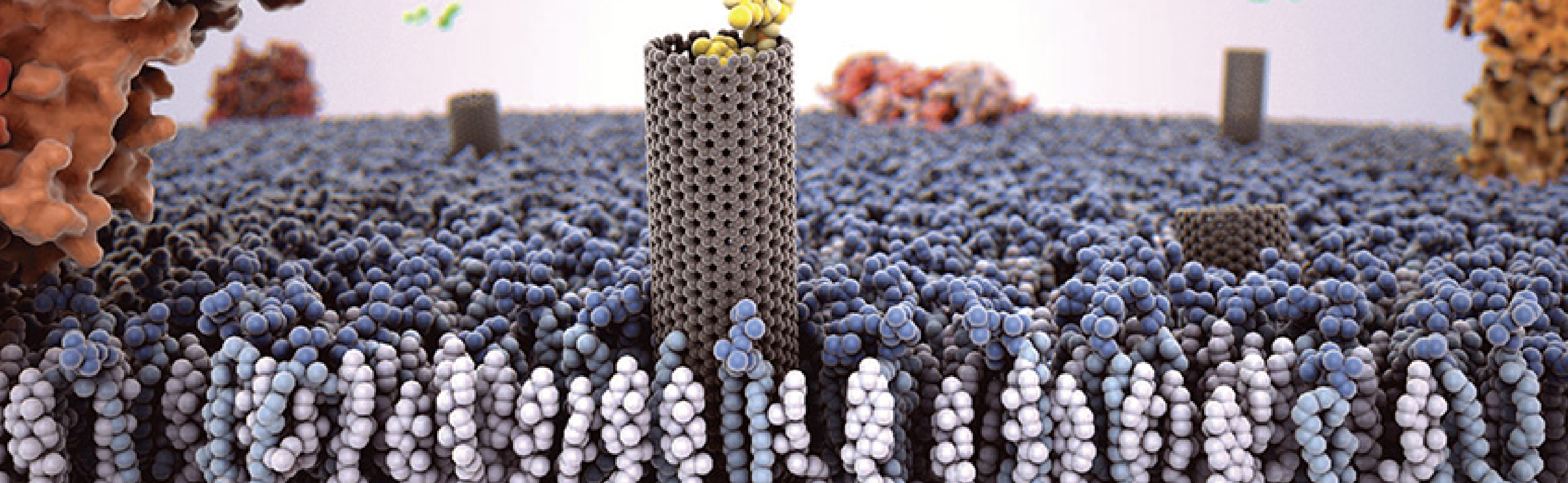
Lawrence Livermore National Laboratory

2018
Technology Transfer Report

Innovation in Action



Scientific Discoveries
Change Lives and Fuel Economic Growth

LLNL's mission is to make the world a safer place. As such, the Laboratory is a leader in delivering innovative solutions for the nation's most challenging security problems. In this context, the Innovation & Partnerships Office provides scientists and engineers with the tools they need to shape their ideas, protect their intellectual property, and tap into a network of investors and mentors who can help them transform promising ideas into marketable products and ground-breaking industrial partnerships.

During 2018, we saw significant growth in our partnerships, across a wide spectrum of industry sectors. Notable partnerships were started in areas as diverse as cancer treatment, high-performance computing applications in the manufacturing industry, and oil and gas applications of subsurface science research.

Laboratory licensees saw success this year as well. Licensed technologies are making their way into commercial systems employed for high-fidelity imaging, low-dose radiography, medical products, food safety, and state-of-the-art manufacturing.

As you browse this report, I hope you better understand our initiatives to foster successful technology commercialization by providing budding entrepreneurs with the support they need to change the world with their inventions. We are proud to be part of the Department of Energy's efforts to increase the commercial impact of innovative technology developed at DOE National Labs.

—Richard A. Rankin

Director,
Innovation & Partnerships Office

IPO
INNOVATION & PARTNERSHIPS OFFICE
COMMERCIALIZING LLNL TECHNOLOGY

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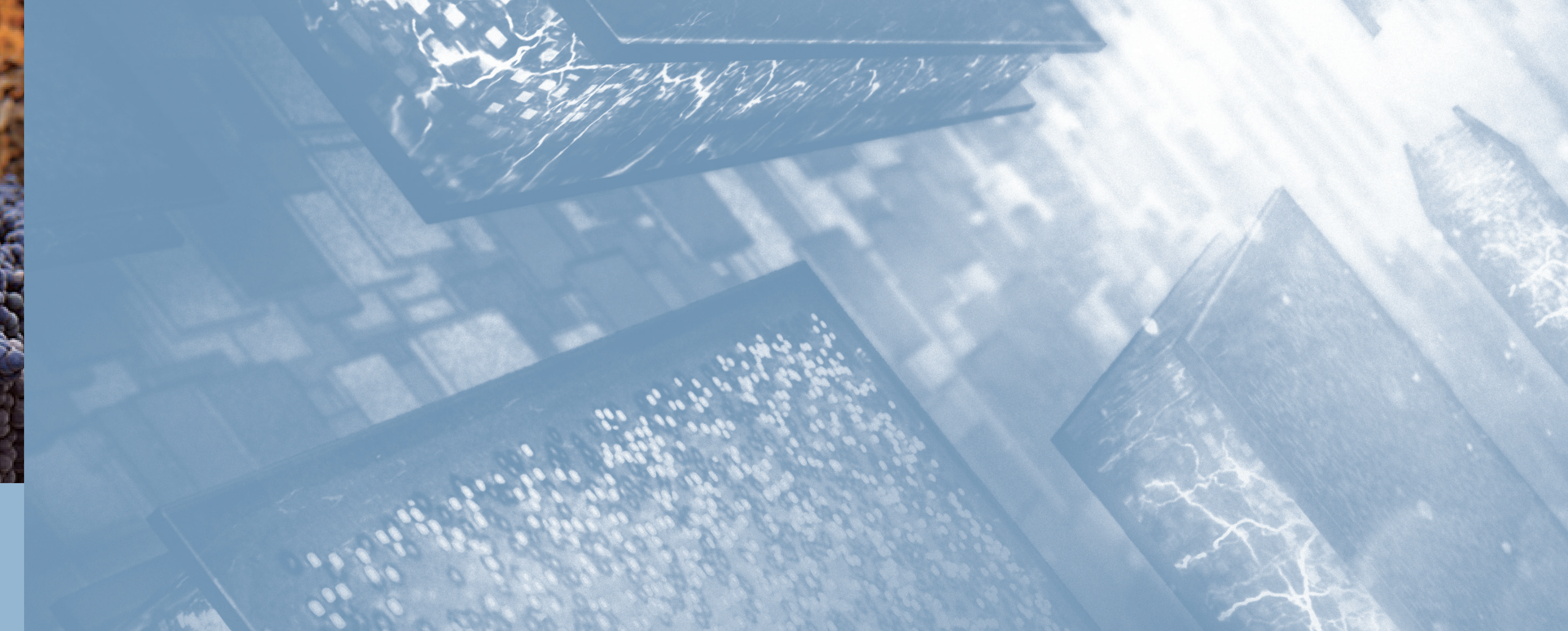

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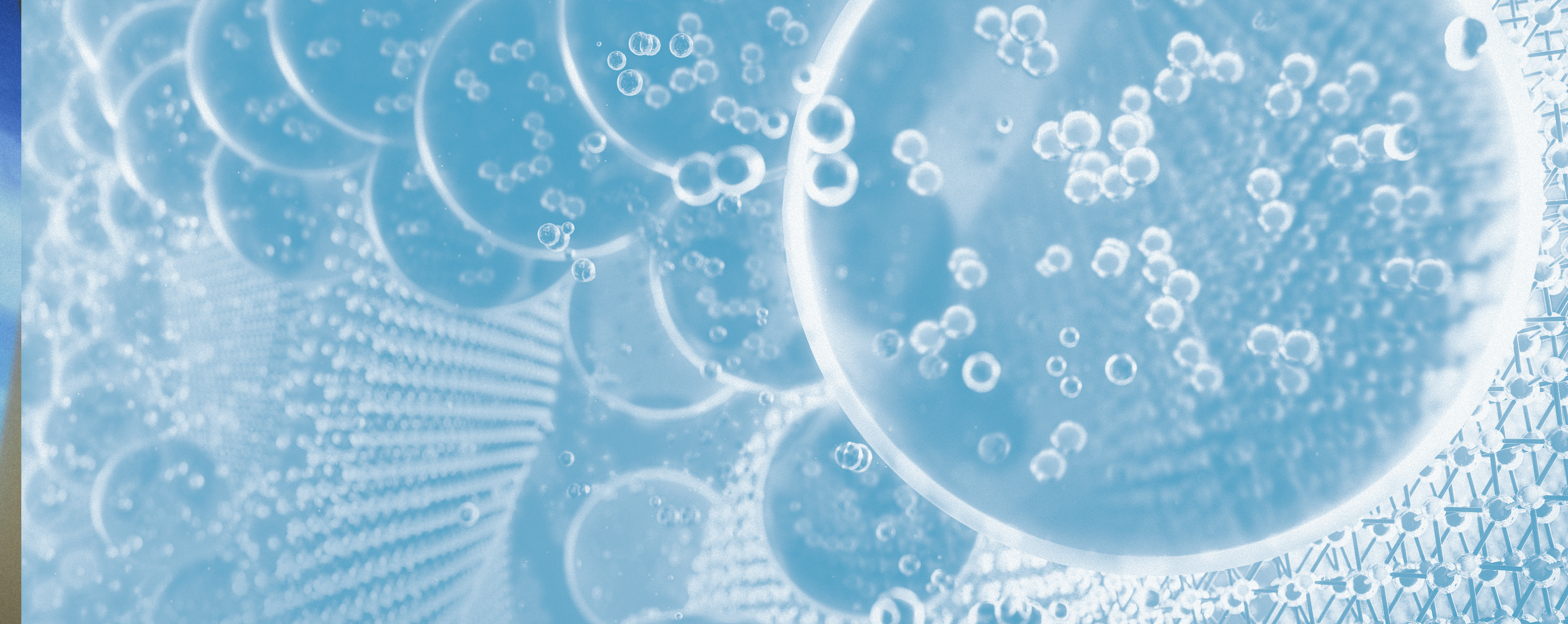
From the Laboratory to the **WORLD**

Desalination technology developed at LLNL in collaboration with Northeastern University—carbon nanotube pores, which can form a synthetic water channel that excludes salt from seawater. The technology has clear implications for the next generation of water purification technologies and efforts to address water scarcity.



EXECUTIVE SUMMARY

Lawrence Livermore National Laboratory (LLNL) is proud to play a role in transforming promising ideas into products that can drive economic growth and foster healthier communities.

Inside LLNL's gates, our scientists and engineers create the spark, which moves onward, beyond LLNL, to startup companies in nearby Silicon Valley, and across the nation, where entrepreneurs and investors adapt our technology to solve a broad range of challenges.

With this year's report regarding LLNL's technology transfer activities, we highlight many of these exciting initiatives. For example, we are pioneering new advanced manufacturing techniques that can produce precisely calibrated optics for lasers, microscopes, and cameras. We are collaborating with industry to test new solutions to our nation's energy challenges, such as a large-scale, subsurface energy storage system that can dispatch stored energy to the power grid whenever it's needed. Our innovators are leveraging their expertise in optics to transform the safety of self-driving cars, using thousands of tiny mirrors to spot potential hazards.

Our licensed technology is also being transformed into products that can make people healthier. In this report, we feature our work with the American Heart Association to accelerate drug discovery. We also highlight a next-generation imaging technology, being commercialized by Lumitron Technologies, to provide x-ray imaging at the cellular level.

Recognizing that innovative ideas will be needed well into the future, we also invest in initiatives to train tomorrow's entrepreneurs. We help our scientists and engineers understand the commercial potential of their ideas and promote their discoveries to investors. We host online and on-site events that bring together experts from academia and industry to mentor our scientists and inspire the next generation of innovators.

Hot Technologies Transforming our World

Our multidisciplinary teams of scientists and engineers work in a unique environment, where they can leverage world-class research and development resources. Yet we have found that some of the best ideas come from our growing engagement with industry collaborators, as we explore how technology developed at LLNL can be adapted to solve a broad range of challenges.

In this section of our report, we highlight several recent collaborative efforts, which demonstrate the impact of our technology transfer activities, including:

- An innovative additive manufacturing approach that will revolutionize the field of glass optics by enabling production of precisely calibrated optics for lasers, microscopes, cameras, and other technologies.
- An automated energy audit process that provides data regarding real-time energy use, making it possible to rapidly identify the optimal approach to reduce energy use in commercial buildings.
- An array of thousands of miniature mirrors that may transform the safety of self-driving cars by capturing clear, telescopic images of potential hazards, allowing the vehicle's autonomous controls to quickly respond to changing road conditions.
- Technology that will enable more realistic training exercises for first responders who need to rapidly locate radioactive materials—using a training simulator that is attached to the trainee's own device, providing a more realistic training experience.
- A software code that can simulate advanced manufacturing processes, helping manufacturers analyze how their processes affect the quality and safety of their products.

OPENING UP A NEW DESIGN SPACE FOR NEXT-GENERATION GLASS OPTICS

3D-Printed Glass Optics Using Direct Ink Writing Technology

Challenge:

The ability to produce precisely calibrated optics allows lasers, microscopes, telescopes, and other instruments to offer high performance at a reasonable cost. However, conventional glass-processing techniques often fall short of the performance needed by next-generation optics that feature high-resolution architectures made without a mold.

Today, optical glass is typically produced via heat-based printing, where silica powders are melted and fused to generate forms. Unfortunately, the forms are vulnerable to thermal stress, and the process can result in non-uniform structures, as well as forms that cannot withstand polishing. The goal is to avoid issues such as cracking or bubbles. Engineers need to be able to produce strong optics with complex geometric structures, as well as the refractive properties needed for a range of applications.

A multidisciplinary team at LLNL, made up of experts in laser technology, optical engineering, materials science, and additive manufacturing, searched for a solution. Their aim was to revolutionize how optical components are made.

The LLNL team, led by chemical engineer Rebecca Dylla-Spears, explored new optical designs and new fabrication methods. They wanted to develop optical components by changing the optic's composition or structure, rather than its shape. They also wanted to produce gradient refractive index lenses that could be polished flat, replacing more expensive polishing techniques used for traditional curved lenses.

Solution:

To achieve this objective, the research team explored use of an additive manufacturing process known as Direct Ink Writing (DIW) to produce glass optics. DIW is a three-dimensional (3D) printing approach selected by the team because it provides the most control during fabrication.

A key part of the team's efforts was to develop custom "inks" that would make it possible to form silica and silica-titania glass, and tune the optical, thermal, and mechanical properties of the glass. Because the refractive index of glass is sensitive to its thermal history, it can be difficult to ensure that glass printed from the molten phase will result in the desired optical performance.

The LLNL team developed a glass-forming sol-gel ink, which enabled them to generate a 3D paste form or "green" body. They demonstrated that heating the form results in a glass optic with a uniform refractive index, eliminating optical distortion that would degrade its function.

According to Dylla-Spears, components printed from molten glass often show texture from the 3D-printing process. Even after polishing the surface, there is still evidence of the printing process within the bulk material. In contrast, the new DIW technique makes it possible to obtain the homogeneity needed for optics.

A 3D-printed helical glass structure created by LLNL engineer Du Nguyen demonstrates the capability to preserve fine features and sharp edges.

Collaboration:

Proof-of-concept experiments demonstrated the viability of the DIW 3D-printed optical component technology. LLNL filed a patent on the technique, and the inventors are now working on mixing and patterning various material compositions to refine control of material properties.

Academic research partner Creighton University executed a non-commercial technology license to support development of new rheologically-tuned inks. In addition, optical component manufacturers are already expressing interest in partnering with LLNL to commercialize the revolutionary new DIW 3D-printing process, which allows free-form fabrication of graded index glass optical components.

Impact:

Advanced optical components, such as precision compound lenses and prisms, are essential for today's cameras, telescopes, binoculars, and microscopes. These optical components represent a multi-billion-dollar global industry, which currently relies on costly and time-consuming subtractive manufacturing processes.

DIW 3D-printing is a paradigm shift, expected to revolutionize how optical components are made. It will open up a new, free-form design space, where scientists can design the shape and optical properties of the material.

SHRINKING THE COST TO HEAT AND COOL COMMERCIAL BUILDINGS

Commercial Building Energy Saving Technology (C-BEST)

Challenge:

Commercial buildings consume nearly half of all electricity used worldwide. Improving the energy efficiency of buildings can save energy, while reducing operating costs and harmful gas emissions.

Although building owners recognize the benefits of improving the efficiency of a building's heating, ventilation, and air conditioning (HVAC) system, energy audits and building retrofits are expensive, and they typically lead to only marginal cost savings. It can take a long time to achieve a return on investment.

To address this need, LLNL scientists investigated new options for HVAC optimization technology, exploring how to provide a more automated energy audit process that is easy to use and affordable. In addition, they wanted to design a system that avoided expenses associated with HVAC system retrofits.

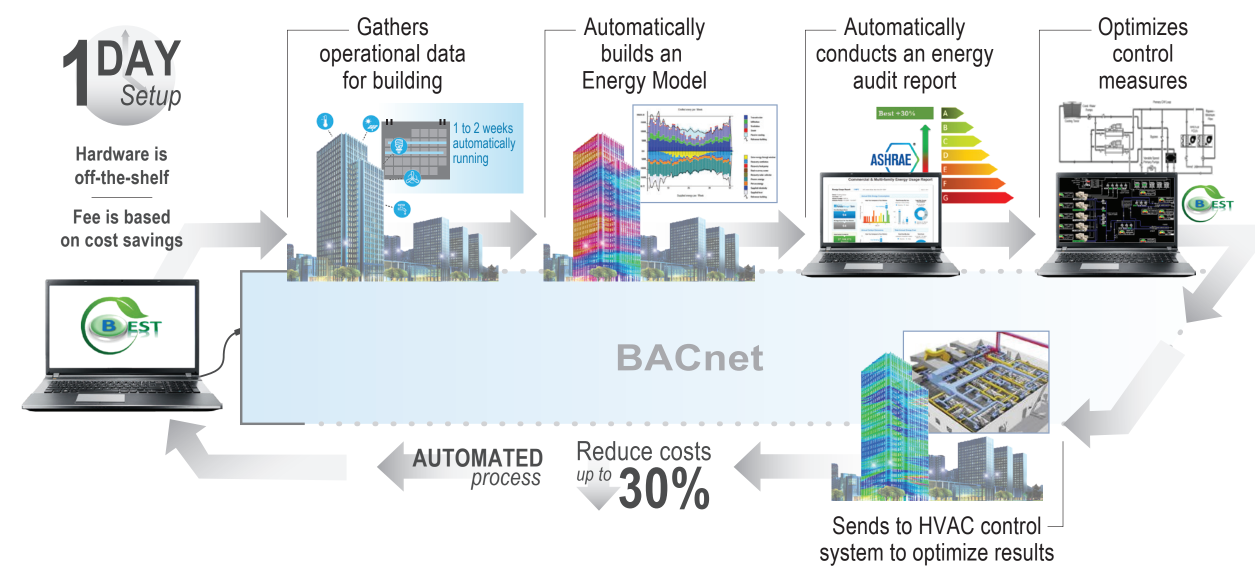
Solution:

LLNL scientists developed an optimization and control system that can easily integrate with existing building management systems and produce results in just one week. The system includes Commercial Building Energy Saving Technology (C-BEST) and an intelligent Software as a Service (SaaS) solution.

After collecting data on a building's energy consumption patterns for two or three weeks, the C-BEST software package develops an optimization model tailored to the building's needs. The model is an algorithm that determines optimal control points for a range of HVAC components, such as water flow, static air pressure, and heating. C-BEST uses deep learning—a type of artificial intelligence—to consistently improve the model as it receives a constant stream of building performance data.

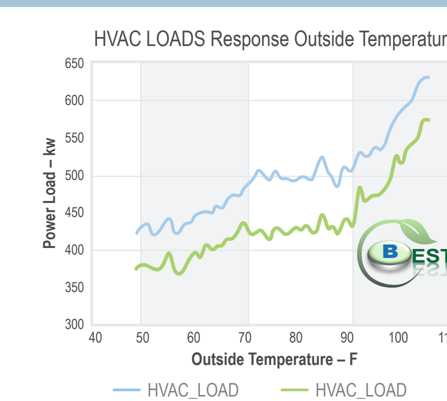
Novel Features of the C-BEST Optimization Software

- An automated energy audit process.
- Advanced controls that can optimize savings based on real-time performance data

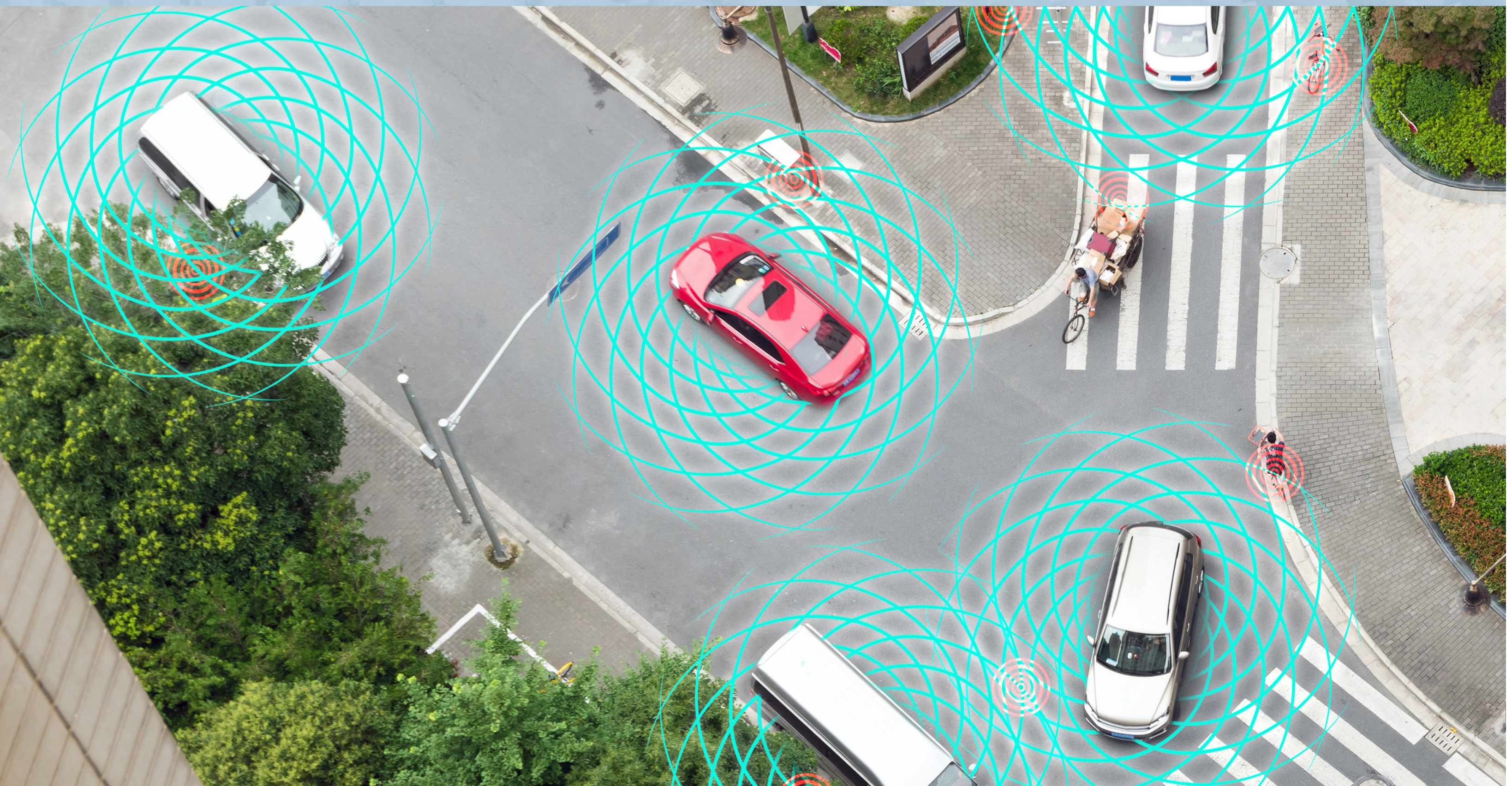


Impact:

During tests in buildings at LLNL, the C-BEST system provided up to a 30% savings on heating and cooling costs, over a range of outside temperatures. The system can self-audit and provide data regarding real-time energy use. Installation of the system is quick, as it easily plugs into existing HVAC systems, operating equally well in modern and older HVAC systems.



During testing, C-BEST optimized energy savings over a range of temperatures.



IMPROVING THE SAFETY OF SELF-DRIVING CARS

Steering Light with Thousands of Tiny Mirrors: The Lightfield Directing Array

Challenge:

Self-driving cars require onboard technology that continuously scans the vehicle's surroundings and collects data used to steer the vehicle. Current technology, known as a light detection and ranging (LIDAR) system, uses a pulsed laser to measure distances and generate high-resolution maps. However, existing LIDAR systems are not able to focus on specific objects of interest, and they are often slow to sift through the massive amounts of data they collect to identify hazards. An innovative technology developed by LLNL scientists to control and direct light, known as a Lightfield Directing Array (LDA), may be the perfect solution.

The Lightfield Directing Array, which consists of miniaturized mechanical and electromechanical components measured on the micrometer scale, is the culmination of a decade of research at LLNL. Laboratory experts in precision engineering and additive manufacturing developed LDA to provide compact, accurate, and robust solutions to steer a light beam to its intended target, addressing needs in a range of applications, including optical communications and optical sensors used in manufacturing.

LDA is a micro-electromechanical system (MEMS) that uses microscale structures to control arrays of miniature mirrors that are constantly moving. This approach promises motion that is faster, covers a larger range, and is more accurate than current commercial technologies.

Solution:

Leaders of the Laboratory's LDA program recognized that the technology could improve the speed and accuracy of LIDAR systems used to steer light beams—and could offer a more effective approach to steer self-driving cars.

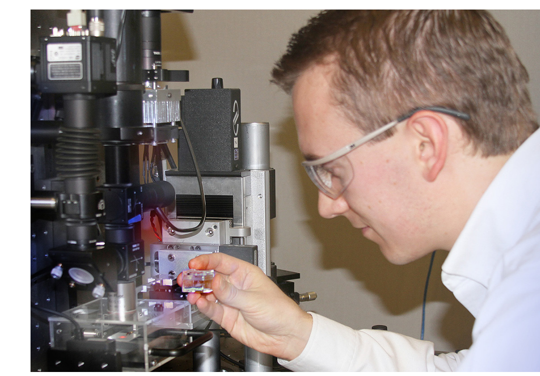
LLNL's patented design offers dramatically enhanced performance compared to existing light-guiding techniques—approximately 100 times greater than other tip-tilt mirror array designs, as measured by the speed and range of the mirrors. The array is composed of identical miniaturized hexagonal units, each consisting of a mirror, three microscopic decoupling fixtures, and three 2-layer actuator paddles. These components are fabricated at LLNL using a combination of microfabrication, micro-assembly, and micro-additive manufacturing techniques. The LDA team at LLNL envisions a system made of thousands of these hexagonal-element units, each measuring 1-mm^2 square, and together covering a roughly 10-cm^2 surface.

Moving in unison, the tiny mirrors operate like a single, large-area reflecting device, with each mirror controlled independently to create the exact configuration needed. Fast and precise motion control achieves the exact tip, tilt, and piston-like (up-and-down) movements required. With this degree of control, light can be reflected in any direction. The array can even split the outgoing beams in different directions to map large areas in parallel, or quickly focus on an object of interest.

The array's design makes it possible to perform effectively even in noisy, vibration-rich environments, such as moving vehicles—achieving the cleanest possible control for capturing clear telescopic images.

Collaboration:

Initially funded by the Laboratory Directed Research and Development (LDRD) program, the current R&D effort includes contributions from Jonathan Hopkins, an assistant professor at the University of California, Los Angeles, whose research focuses on the design and fabrication of flexible structures and materials. In addition, the effort includes experts from A.M. Fitzgerald & Associates, a MEMS microfabrication consulting firm in the San Francisco Bay Area.



Robert Panas inspects the micromirror array, designed and being prototyped at LLNL.

Impact:

The most immediate application of LDA technology is improving LIDAR systems, where the LDA can significantly reduce the size and cost of bulky LIDAR units being considered for the autonomous vehicle industry. The LDA-based LIDAR system onboard self-driving vehicles can locate and avoid objects more rapidly, from a greater distance, allowing the vehicle's autonomous controls to respond to road conditions sooner than is possible with existing LIDAR technology.

Beyond self-driving cars, LDA technology promises to improve capabilities in a range of applications, such as secure laser communications and high-resolution telescopes. The microarray's capabilities will be particularly useful in advancing the use of lasers in additive manufacturing and nanomanufacturing, where the array's precision and bandwidth can be used like "optical tweezers" to stabilize optics, adjust for misalignment, and guide laser beams to sinter nanoparticles.

TRAINING FIRST RESPONDERS TO FIND RADIOACTIVE HAZARDS

Radiation Field Training Simulator (RaFTS)

Challenge:

Radioactive materials can't be seen, smelled, or felt. Our nation's first responders, who would be called upon to locate hazards in the aftermath of a radiological or nuclear incident, will only have their equipment to guide them.

The United States has invested billions of dollars fielding radiation detection equipment at borders and ports, and in urban environments, to protect against radiological or nuclear terrorism and be prepared to rapidly respond to incidents. Agencies also spend millions of dollars training first responders to operate radiation detection equipment.

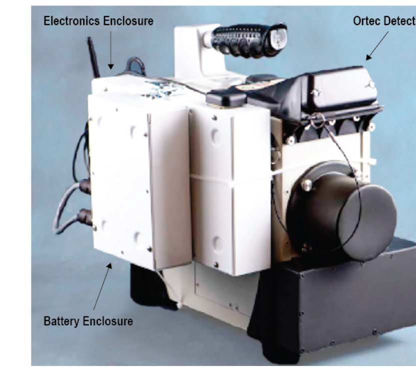
To be effective, first responders need to train for these emergencies under realistic conditions, which can be difficult to safely simulate. Law enforcement agencies charged with preventing nuclear smuggling also need this type of training. However, current training exercises do not provide a fully realistic experience for trainees, limiting the ability to adequately train first responders for a real event, when time is limited and accuracy is essential.

Solution:

LLNL developed the Radiation Field Training Simulator (RaFTS) to provide more realistic training for first responders. The device generates realistic signals for hazardous sources that first responders may encounter during an actual incident, without such sources being present during training exercises. The simulator precisely and realistically replicates the physics of real, hazard-level radiation sources.

RaFTS hardware is attached to the exterior of a radiation detector—allowing trainees to use their own equipment during the exercise. Using RaFTS, trainees can see how their equipment responds to simulated radiation signatures associated with a specific, pre-determined training scenario that is programmed into RaFTS.

As trainees move throughout the training site, RaFTS injects signals into the detector's circuitry (instead of the active detection element). The RaFTS module injects a dose-rate response, and it feeds location-appropriate energy spectra, pulse-by-pulse, based on the trainee's distance from the source, shielding, and the statistical randomness of radioactive signals. With this input from RaFTS, the detector responds as if real sources are present. After training, RaFTS is detached from the detector, returning the instrument to its normal function.



Example of how RaFTS is attached to an Ortec radiation detector, with signals injected through a port on the detector's exterior. RaFTS is detector-agnostic, enabling it to work with each trainee's specific type of detector, providing a more realistic training experience.

Collaboration:

LLNL researchers successfully demonstrated RaFTS in the field using two different detectors in widespread use. The first was an LLNL-developed radiation detector licensed to Ortec, Inc., and marketed as the *Detective.* This detector, used to characterize complex radiation sources, is based on high-purity germanium. The second detector was a sodium-iodide-based instrument commonly used by law enforcement in backpack-based or handheld devices to search for radiation sources.

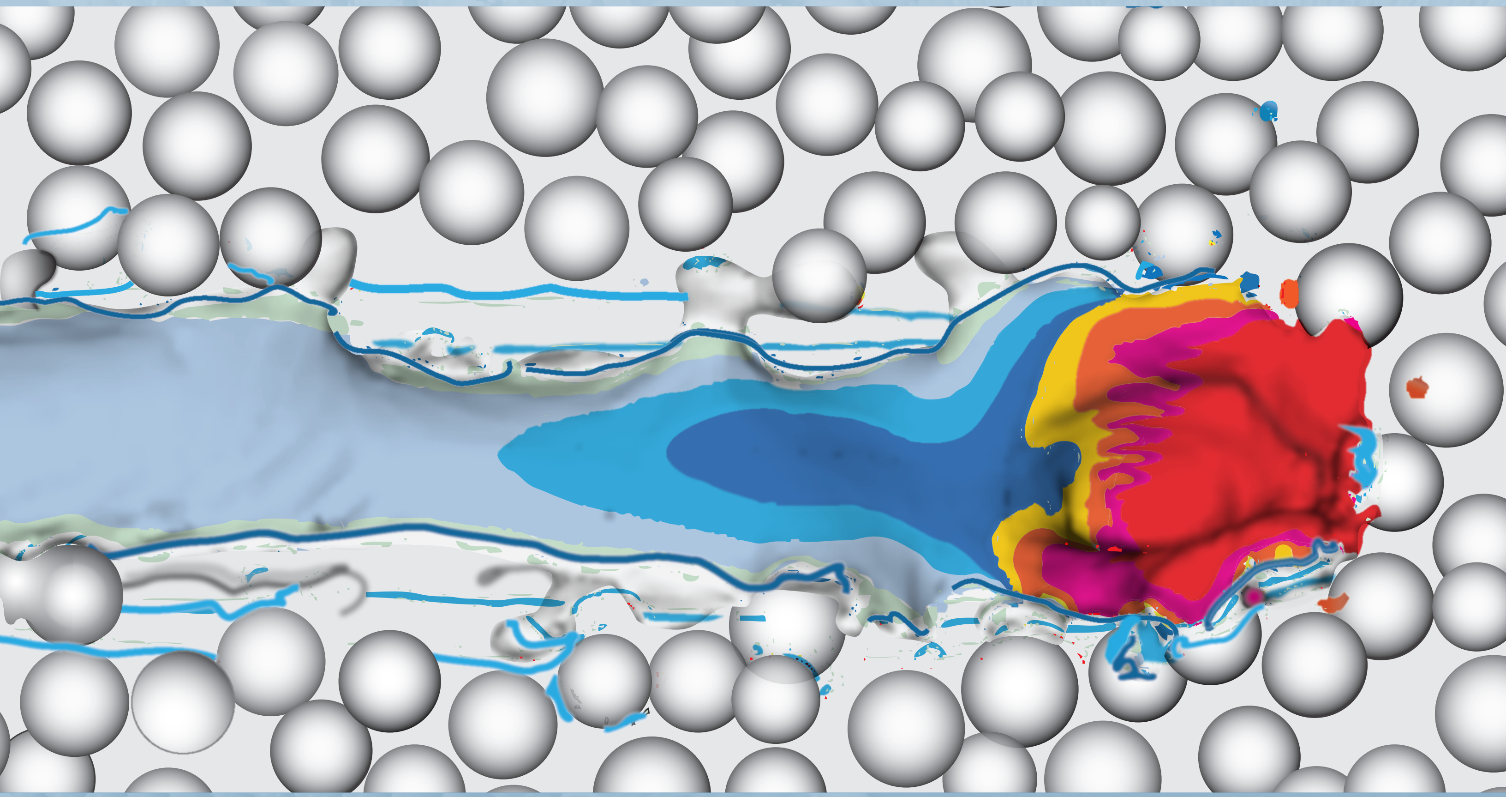
The RaFTS technology won a 2017 R&D 100 award from *R&D Magazine,* designating it as one of the 100 best technologies of that year.

Impact:

RaFTS can be used by all types of radiation detectors, from large-scale spectroscopic radiation detectors mounted in vehicles, to hand-held spectroscopy-capable radiation detectors. The training simulator can also be used with more expensive technologies, such as radioisotope identifiers and high-resolution detectors.

As the technology is refined, developers at LLNL envision a USB-like interface, enabling RaFTS to plug into a standard port on detectors. A single, miniaturized RaFTS box could be used with multiple types of detection instruments, ensuring that all detector types will respond with consistent physics.

RaFTS enables integrated communications for command and control during training scenarios, along with a variety of uses, including survey, sample collection, and field and laboratory analysis. In addition, RaFTS technology can be modified to provide other types of simulations, such as chemical weapons or biological hazards.



SIMULATING INNOVATIVE SOLUTIONS TO ADVANCED MANUFACTURING CHALLENGES

A Multi-Physics Simulation Code Expands Industry's Ability to Address Manufacturing Challenges

Challenge:

Advanced manufacturing is revolutionizing how industry is solving the world's manufacturing challenges. Still, it can be difficult for industry to analyze risks, such as the failure rate of parts. For example, some companies are hesitant to use metal additive manufacturing to produce critical parts for automobiles and airplanes because they lack confidence in the quality of the resulting part.

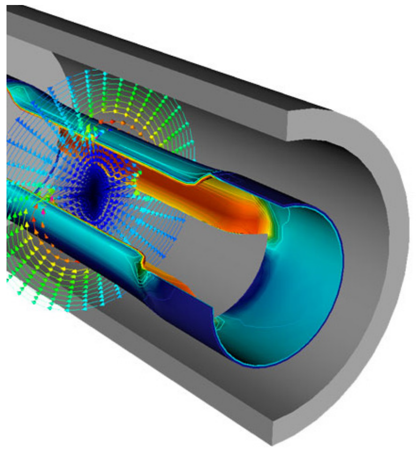
Manufacturers need to be able to analyze their manufacturing process and better understand its effects on their products before they invest significant resources implementing new manufacturing techniques. Yet many companies do not have the capabilities in-house to study the increasingly complex processes used in advanced manufacturing, and they are seeking tools that can help them conduct these critical assessments.

Solution:

For over 30 years, LLNL has developed and utilized Arbitrary Lagrangian-Eulerian 3D (ALE3D)—a unique multi-physics software code used by researchers to predict how materials will perform in a variety of environments, enabling them to solve various engineering and physics problems. The simulation code runs on powerful supercomputers, such as those at LLNL, with hundreds of thousands of processors that work in tandem. Until recently, the highly versatile ALE3D simulation code has been limited to work on mission-relevant applications that are important to national security.

A team led by LLNL computational engineers recently developed a version of ALE3D called **ALE3D for Industry,** which can be used with research partners who are interested in a much broader range of applications. With ALE3D for Industry, manufacturers can use the multi-physics simulation code on LLNL's high performance computing resources to identify ways to make their operations more productive and their products more cost-effective.

The code can capture the behavior of both solids and fluids. Users can select from a range of physics "packages" that make it possible to study multiple phenomena, such as heat conduction, chemical reactions, kinetics, and hydrodynamic flow. Additional features include species diffusion, incompressible flow, multi-phase flow, magnetohydrodynamics, and a wide range of material and chemistry models. The simulation tool can be used in applications involving both long and short timescales.

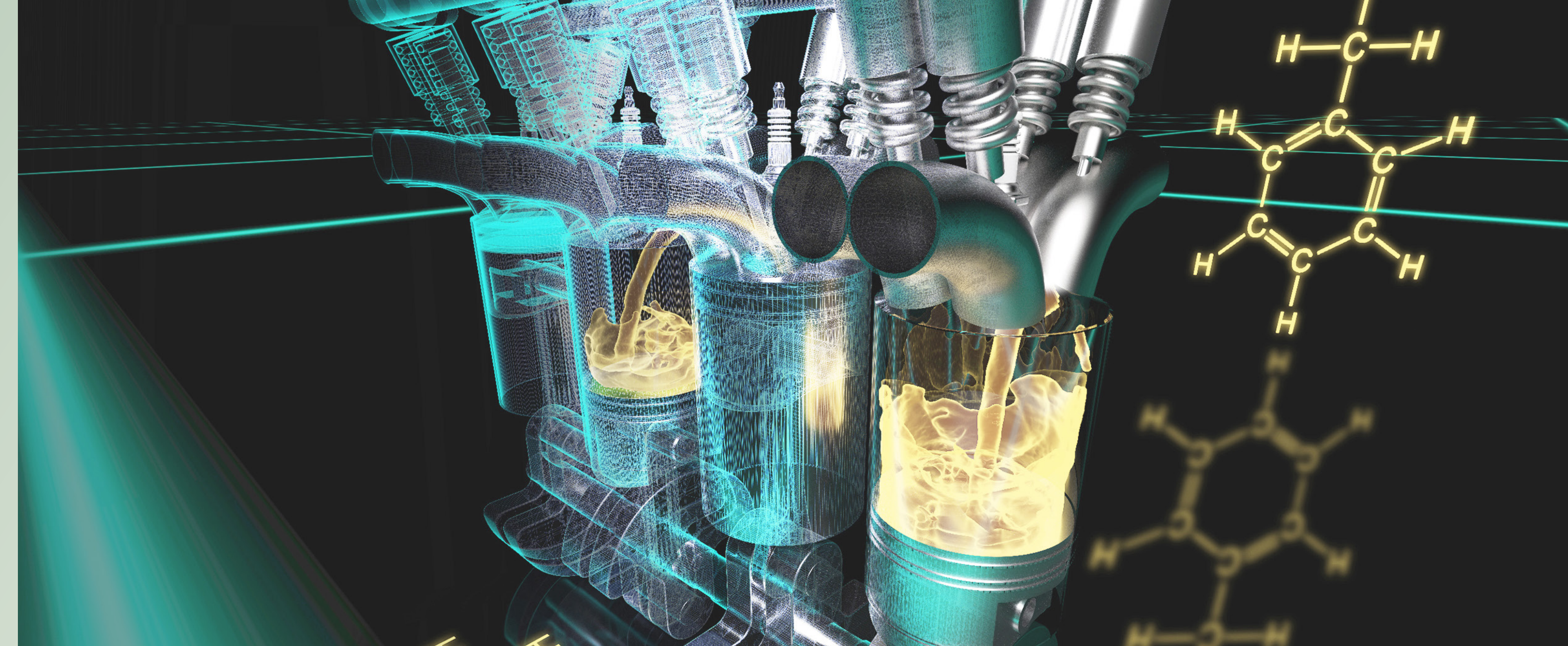


The ALE3D simulation shown depicts powerful magnetic fields generated by a large pulse of electrical current running through an outer conductor. The magnetic fields crush a thin-walled metal cylinder located inside the larger conductor. The inner cylinder is slotted to break the axial symmetry, making this a fully 3D problem.

Impact:

In partnership with LLNL, manufacturers can access LLNL's high-performance computers and specialty software, including the ALE3D for Industry code, to simulate production processes for a range of advanced manufacturing techniques. In this rapidly growing field, commercial collaborators can use LLNL's simulation tools to understand the physics involved in the additive manufacturing process, building confidence in the quality of parts, as well as the process itself.

For example, the software code can be used to predict the characteristics of a metal powder that is melted by a laser—a key part of laser-based additive manufacturing. The code's simulations take into account factors such as the recoil force of vaporizing metal, changing surface tension, spattering, and cooling by evaporation, enabling users to predict engineering and physics problems that can degrade part quality.



Partnering to Boost Economic Development

Our partners are a critical part of LLNL's efforts to transform promising ideas into marketable products and game-changing innovations. Our licensed technologies are being transformed into products that can make people healthier, address our nation's energy problems, and expand use of super-computers to solve complex problems.

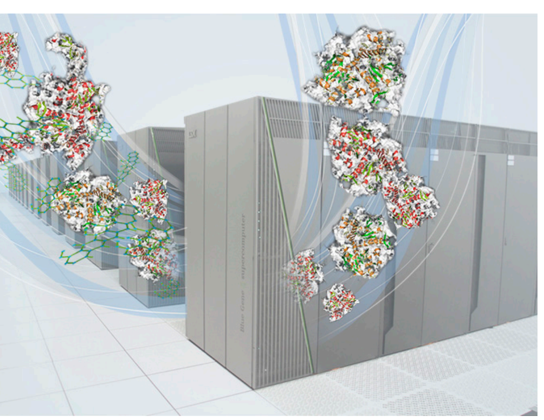
LLNL helped launch new businesses that are driving economic growth. In this section, we feature new collaborations that will:

- Create a healthier world through accelerated drug discovery, next-generation imaging technology, and use of DNA "barcodes" to reduce foodborne illnesses. Our partners include the American Heart Association, Lumitron Technologies, and SafeTraces.
- Address energy challenges through large-scale, underground carbon dioxide (CO_2) storage, in partnership with TerraCOH.
- Boost use of high-performance computing resources by developing an open-source packaging software for supercomputers, as well as an open-source simulator to model subsurface business operations, in collaboration with Total American Services and Stanford University.

COMMERCIAL PARTNERSHIPS

American Heart Association partners with LLNL to Accelerate Drug Discovery

In November 2017, the American Heart Association (AHA) and LLNL formed a strategic business partnership aimed at overcoming the burden of drug discovery, reducing costs and improving access for patients with heart disease and other chronic conditions. The three-year, $6.9 million Cooperative Research and Development Agreement (CRADA) demonstrates both institutions' commitment to accelerate drug discovery.



A collaboration between the AHA and LLNL will leverage the Lab's supercomputers and drug discovery algorithms to accelerate discovery of new therapies.

The Association's CEO, Nancy Brown, underscored the problems associated with the current drug discovery process. "It takes 10 years, on average, for a new medicine to be commercialized in the marketplace and an average cost of $2.6 billion. Imagine if we could reduce the time to market by half." The goal of the strategic partnership is to do just that—reduce the time to market by leveraging AHA's leading science combined with LLNL's supercomputers and drug discovery algorithms.

AHA-funded scientists will collaborate with LLNL investigators to create a simulated environment that rapidly and precisely predicts how drugs bind to target proteins, and then test these predictions in experimental systems to explore the safety and efficacy of potential new therapies. According to Felice Lightstone, LLNL's principal investigator on the project, LLNL's computing infrastructure will enable machine learning approaches and ultimately get safe drugs to the marketplace faster. "By bringing world-class, leading-edge engineering and high-impact biological fields together, we can develop a comprehensive reference atlas of cell-protein targets to accelerate and hone drug discovery."

This collaboration is part of the AHA's newly formed Center for Accelerated Drug Discovery, reinforcing the Association's commitment to improve health by accelerating the pace at which drug-protein interactions are identified and documented before clinical trials begin. "The AHA's leading science, combined with LLNL's leading-edge computational engines, will speed progress and give rise to high-value treatments, making therapeutic innovations more readily available and more affordable," says Brown.

Work under the CRADA will integrate machine learning approaches into the drug discovery pipeline. This integrated approach will address a critical gap in the ability to predict drug safety and efficacy ultimately driving down the cost and the time it takes to get safer drugs to patients.

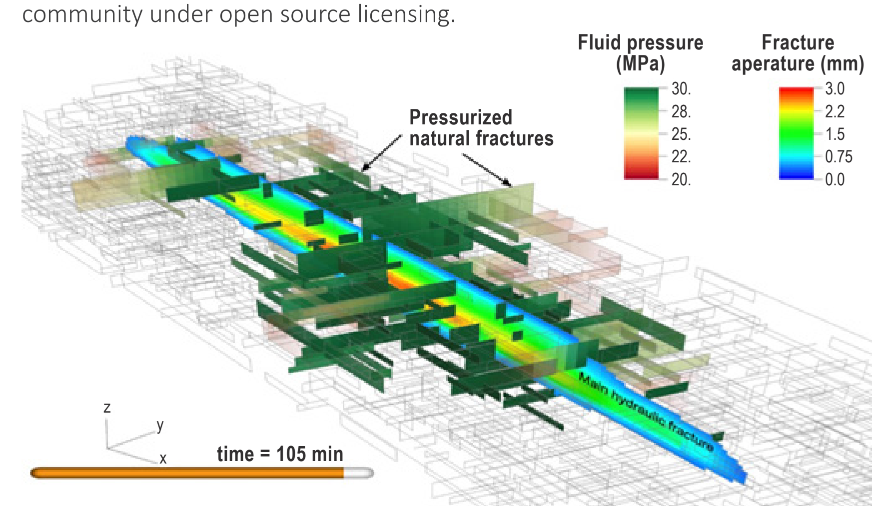
High-Performance Simulators Help Model Subsurface Operations

In 2018, Total—a multi-national energy company and major oil and gas corporation—sponsored a research collaboration with LLNL and Stanford University's School of Earth, Energy & Environmental Sciences (Stanford Earth). The collaborative initiative will focus on developing high-performance algorithms and numerical methods for next-generation supercomputer architectures to model subsurface operations.

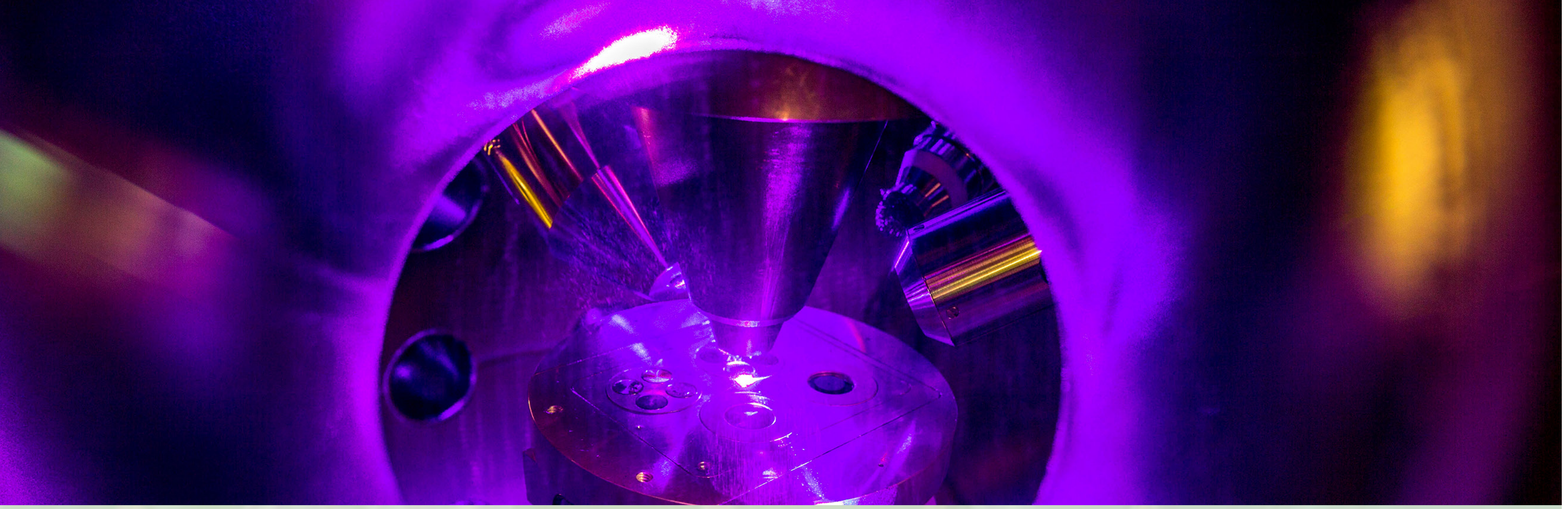
"The spectrum of applications for the new simulation tool is very broad and corresponds to any business operation that impacts the subsurface," says Philippe Cordier, who leads Total's Scientific Computing, Data Science and Artificial Intelligence R&D program. One of the first identified applications of this research is geological CO_2 storage at the gigaton scale.

This joint effort—involving an industry leader, along with two world-class research institutions—will provide a unique opportunity to tackle this critical research area. It will leverage the institutions' high-performance computing resources, dedicated simulators, and research expertise. The project is part of Total's efforts to be a leader in carbon capture, utilization, and storage technologies—a research area that is also a key emphasis at LLNL and Stanford Earth.

Another key objective of this collaboration is to support development of research scientists and engineers with core competencies in applied computational science. A large portion of the simulator will be available to the community under open source licensing.



Total will invest more than $20 million over 5 years in this collaborative project, aimed at developing a research simulator for modeling subsurface operations



TECHNOLOGY IMPACTS

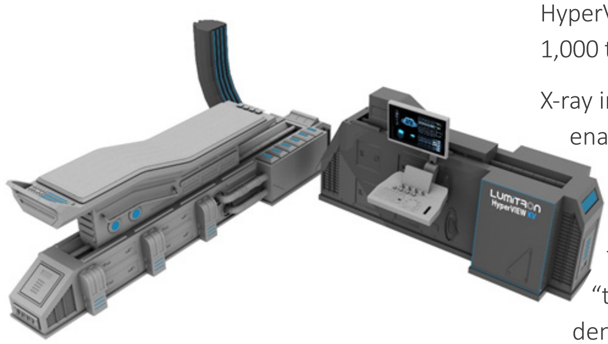
Lumitron Technologies and X-ray Imaging at the Cellular Level

LUMITRON TECHNOLOGIES

Lumitron Technologies, Inc., an x-ray systems company founded in 2013, plans to develop and market a new generation of advanced x-ray and gamma-ray radiography systems. The technology holds the potential to transform how we diagnose and treat diseases at the cellular level.

In 2017, Lumitron acquired key licenses to LLNL's Laser-Compton IP portfolio. Unlike conventional radiography and photodynamic therapy, Laser-Compton-generated x-rays can be tuned to cancer markers, enabling treatment of a tumor using precision radiotherapy, at ultra-low doses.

Conventional clinical x-ray systems are generally limited to a resolution of just under 1mm, which is insufficient to diagnose early-stage cancer. By contrast, Lumitron's HyperVIEW KV x-ray imaging system is capable of imaging objects that are up to 1,000 times smaller, and it can capture motion down to the picosecond timescale.



An artist's impression of Lumitron's HyperVIEW KV x-ray radiography system, which is based on LLNL's Laser-Compton technology. It operates at up to 1,000 times the resolution of traditional x-ray machines, and is capable of high-fidelity, hyper-precision imaging , making it possible to conduct x-ray imaging at the cellular level.

X-ray imaging at the cellular level is a game-changer for the medical field. It will enable cellular changes to be detected much earlier. It will also allow use of small animal models for drug discovery, potentially lowering costs and shortening clinical trials.

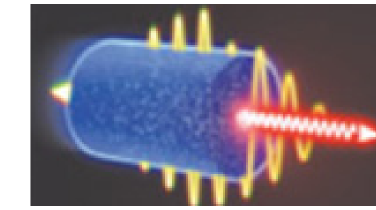
The HyperVIEW technology presents the potential to create the first true "theranostics" machine, capable of simultaneously providing unprecedented imaging detail (diagnostics) and cellular-level treatment (therapy), according to Lumitron's Chief Technology Officer Chris Barty. This former LLNL leader is now a professor at the University of California, Irvine (UCI), and part of UCI's Convergence Optical Sciences Initiative.

Lumitron has already raised more than $20 million in capital, and in July 2018, the company opened its new R&D and manufacturing facility at the UCI Research Park, in close proximity to UCI's Beckman Laser Institute and Medical Clinic.

The company is collaborating with some of the world's leading manufacturers of x-ray systems, moving closer to its vision of a next-generation imaging technology that offers precise, non-invasive cancer treatment.

A CLOSER LOOK AT LASER-COMPTON TECHNOLOGY

Laser-Compton light-source technology enables production of mono-energetic gamma rays and x-rays, which are created by Compton scattering of short-duration laser pulses from relativistic electrons (moving at close to the speed of light).



Open-Source Packaging Software for Supercomputers

Large-scale supercomputer simulations often contain millions of lines of code and rely on hundreds of external software packages. Users of high-performance computing (HPC) systems frequently need different versions and configurations of these software packages to test the performance and compatibility of their code. Efficient packaging tools are critical in HPC environments, but traditional package managers cannot manage simultaneous installations of multiple versions and configurations. Consequently, users, developers, and HPC support staff spend many hours building codes and libraries by hand.

In 2013, this frustrating challenge led LLNL computer scientist Todd Gamblin to develop the first prototype of a package manager he named Spack (Supercomputer PACKage manager). Spack is a flexible, configurable HPC package manager, automating the installation and fine-tuning of simulations and libraries. It operates on a wide variety of HPC platforms and enables users to build many code configurations.

The key benefit of this open-source package manager is that it allows developers to build software for many combinations of compilers, architectures, dependency libraries, and build configurations, all with a friendly, intuitive user interface. According to Gamblin, Spack allows developers to easily leverage the millions of lines of code that others have written.

Spack is a successful example of how LLNL actively engages with open-source communities to enable the Laboratory to stay at the forefront of HPC advances, save time and effort, recruit and retain top computer scientists and engineers, and collaborate with organizations around the world.

Spack is available via open source licenses, and can be found online at the community's public repository: github.com/spack

Spack

400-500 downloads per day

8,000 views per week by 3,000 unique visitors

2,800 packages contributed by external users

"Active participation within the open-source community creates a symbiotic relationship in which staff can collaborate with external users, including other government agencies, to produce cost-effective solutions to complex problems and bolster software to its full potential."

— Bruce Hendrickson, LLNL's Associate Director for Computation

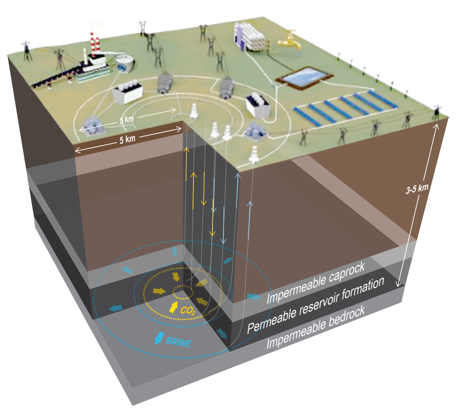
TerraCOH and the Earth Battery

What are the biggest challenges associated with increasing use of renewable energy? To completely replace coal and gas power generation in the electric grid, renewable technologies such as wind and solar must be able to ensure that electricity is available 24 hours a day. However, with the intermittency of the wind and times when the sun doesn't shine, these renewable energy sources are only available 25 – 35% of the time, making it difficult to replace traditional power-generation facilities.

Researchers at LLNL, along with colleagues at The Ohio State University, the University of Minnesota, and TerraCOH think they've found an answer to these problems with a large-scale system called the Earth Battery. The subsurface energy system is designed to tap into geothermal energy (a renewable energy resource), and store energy obtained from above-ground sources. The massive underground "battery" can then dispatch stored energy to the power grid whenever it's needed. At the same time, the Earth Battery's design would enable it to store carbon dioxide (CO_2) emitted by fossil-fuel power plants.

"If you want to store the large quantities of renewable energy necessary to balance seasonal supply-demand mismatches, we believe the best way to do that is underground," says Thomas Buscheck, an Earth scientist at LLNL. "We believe this is a cost-effective, efficient way to store the energy long enough, so it can be used later, when it's needed."

The Earth Battery's approach involves injecting compressed, liquid-like CO_2 into underground reservoirs located in sedimentary rock, creating a pressurized plume that pushes brine through wells up to the surface. The brine could be heated and reinjected into the reservoir to store thermal energy, and the resulting pressurized CO_2 would act as a shock absorber, enabling the system to be charged or discharged depending on supply and demand. When there's insufficient renewable energy, the pressurized CO_2 and heated brine could be released and converted to power.



The Earth Battery system would store CO_2 in an underground reservoir, with concentric rings of horizontal wells confining the pressurized CO_2 beneath the caprock. Stored CO_2 displaces brine, which is pushed through wells up to the surface, where it is heated by thermal plants (e.g., solar farms) and reinjected into the reservoir to store thermal energy.

Buscheck's research connected him with Jimmy Randolph, who at the time was a postdoc at the University of Minnesota. Randolph went on to establish TerraCOH, Inc., a geothermal energy startup company based in Minnesota, in 2014. Two years later, Buscheck and Randolph, along with other colleagues, published a paper in *Geosphere Journal* that was the foundation of the Earth Battery concept.

Realizing the complementary nature of their technologies, TerraCOH signed an agreement with LLNL in 2017 to secure the option to license LLNL's technology.

In August 2018, LLNL obtained funding from DOE's Technology Commercialization Fund, enabling Lab scientists to collaborate with TerraCOH, Echogen Power Systems, and Enviro Ambient to mature this promising energy technology. The future of renewable energy is unknown, but LLNL and TerraCOH are joining forces to charge the Earth Battery.

SafeTraces and DNA Barcodes for Food Safety

The annual cost of foodborne diseases in the U.S. is estimated at $150 billion. SafeTraces, Inc., a startup company, aims to address concerns related to food safety, including contaminated and counterfeit food. The company licensed a DNA-based barcode technology developed at LLNL that has a broad range of applications, ranging from securing the food supply chain, to tracing the outbreak of foodborne illness to its source in just minutes.

SafeTraces uses unique DNA barcodes (SafeTracers™) for labeling food ingredients or products. The odorless, colorless, and tasteless barcodes are applied directly to food, or blended into oils or other liquids. When used with most commodities, the barcodes are stable for more than two years. By scanning DNA barcodes with a reader that uses real-time polymerase chain reaction, it takes only 15 minutes to reveal counterfeit products or trace the food's source. The U.S. Food and Drug Administration (FDA) recognized the DNA-based barcodes as Generally Regarded as Safe (GRAS).

The technology is an offshoot of defense research at LLNL. George Farquar, a lead inventor of the technology, received $3 million in funding from the Department of Defense to develop biodefense tools to track pathogens in air. Anthony Zografos, an entrepreneur, founded SafeTraces in 2013, and licensed the technology from the Lab. The company markets commercial solutions in the food, agriculture, and healthcare industries.

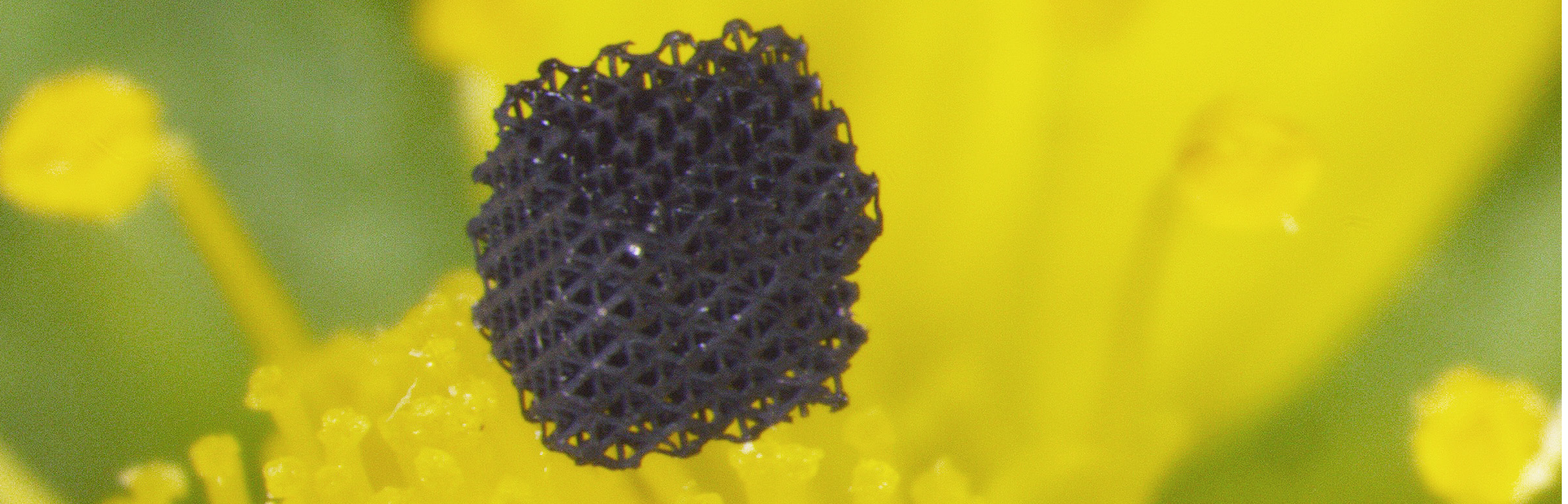
SafeTraces completed a $6.5 million Series A financing round in October 2017, bringing the total investment to $8.5 million. Additionally, the company recently received a multi-year FDA grant to advance commercialization of SaniTracers™—a technology that focuses on verifying the sanitation of fresh produce.

Key benefits:

- Brand protection and reduced recall and inventory costs for producers, processors, and wholesalers.
- Maintenance of supply chain integrity and transparency of importers, processors, and wholesalers.
- In-house control over food safety during food processing and sanitation.
- Source verification at the retail level to maintain consumer confidence.

TRACKING FERTILIZER

Illegal diversion, tax evasion, and misuse plague many global commodities, including fertilizers. In 2018, SafeTraces delivered the world's first DNA-based traceability system (D-ART 3000) for fertilizers to 20 manufacturers. Coupled with a blockchain-based or centralized code registry system, SafeTraces DNA barcodes create unbreakable links between physical objects and their digital certificates, enabling transaction recording and rapid verification at any point in the supply chain. The company is expanding use of the D-ART 3000 system to traceability and source assurance in sustainable commodities such as palm oil, oil seeds, and beans.



LEGACY INVENTIONS STILL SPARK INNOVATION

Chromosome Painting Improves Molecular Diagnostics

Abbott

VYSIS IntelliFISH SOLUTION

A technology developed at LLNL more than 30 years ago is still hard at work, changing the way cancer and other genetic diseases are diagnosed. During the 1980s, two LLNL scientists were tasked with finding a way to detect radiation damage to DNA—a first step toward early detection and improved treatment for individuals suffering from radiation-related illnesses. Today, the commercialized technology is used to identify genetic abnormalities that can lead to life-threatening diseases, a challenging undertaking when looking for a single abnormality among roughly 20,000 genes and 3 billion DNA base pairs in the human genome.

Three decades ago, LLNL scientists Daniel Pinkel and Joe Gray studied one of the distinguishing effects of radiation damage to DNA, known as "reciprocal translocation," where the ends of two chromosomes break off and trade places with each other. These mismatched chromosomes can result in serious illnesses, so identifying the exact mismatch can lead to improved treatment.

Pinkel and Gray invented a way to identify these translocations by highlighting the desired gene sequence on specific chromosomes with fluorescently-labelled probes (short DNA fragments), a technique they dubbed "chromosome painting." These bright probes enabled them to visualize chromosomes with mismatches. Chromosome painting allowed detection of radiation exposure 10 to 100 times more rapidly than methods available at that time, while also improving the accuracy of detection efforts. Chromosome painting has evolved and expanded such that the technique is now referred to as fluorescence in situ hybridization, or FISH.

Reciprocal translocation is also a hallmark of certain cancers, such as chronic myelogenous leukemia. Pinkel and Gray quickly realized that chromosome painting technology could be used to diagnosis these types of cancers. In addition, they

recognized that their technology could make it easier to detect chromosomal abnormalities associated with inherited diseases.

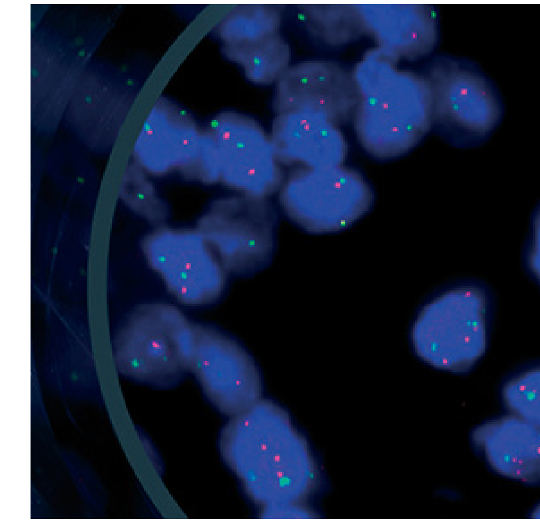
Seeing the technology's broad clinical potential, the two LLNL innovators started exploring commercialization opportunities. They connected with a small company called Imagenetics, Inc., who licensed the technology and later became Vysis, Inc., a genomic disease management company. Vysis implemented chromosome painting into its products, and by 1992, the products started bringing royalty income for LLNL.

In 2001, the impressive sales caught the eye of biopharmaceutical giant Abbott, who was looking to expand the company's molecular diagnostics portfolio. Abbott acquired Vysis and integrated it into a new molecular diagnostic division.

Abbott leveraged its expansive research and development capabilities to bring molecular diagnostic tests to market that use FISH. For example, Abbott developed HER-2 gene amplification detection for a subset of breast cancers. Today, Abbott sells products based on FISH technology that are used for genomics-based molecular diagnosis of cancer, as well as other genetic diseases.

As of 2017, sales of the licensed technology brought in more than $47 million in royalties for LLNL, resulting from total sales of just over $1 billion. FISH continues to be one of the most profitable assets in LLNL's intellectual property portfolio—all because two LLNL scientists had a hunch that their technology could have an impact far beyond its original application.

The technology's pioneering inventors eventually moved on to work in academia. Pinkel currently holds positions as associate director and professor emeritus at the University of California, San Francisco, and Gray holds leadership positions at Oregon Health and Sciences University.



Chromosomes in human cells can be 'painted' with fluorescent probes that bind specific genes to detect aberrations diagnostic of disease. Different fluorescent dyes (red and green) enable detection of unique genes as well as translocations or gene fusions that would appear yellow. FISH technology can also be used for monitoring response to treatment. Abbott Molecular recently improved the hybridization chemistry to make a more rapid assay with equal or improved quality of results.

Optical Communications and Global Internet Access

Internet for all. No boundaries. No "out of service" locations. It's an amazing idea, and a technology initially developed at LLNL may play a key role in plans to turn the idea into a reality.

Google X, a subsidiary of Alphabet Inc., hopes to bring high-speed wireless internet access to people in rural and remote locations across the globe. To achieve this objective, Google X is using free space optical communications (FSOC), where lasers deliver fast and reliable connectivity over long distances, similar to a fiber optic cable, but without the cable. The solution would make digging ditches and laying cable a thing of the past.

Google X

FSOC technology was originally used by Google X for Project Loon, where the company deployed the technology onboard specially designed balloons. For example, they used the technology to provide emergency connectivity following disasters in Puerto Rico and Peru. The optical communication technology, over two decades in the making, is now being integrated into the internet's infrastructure.

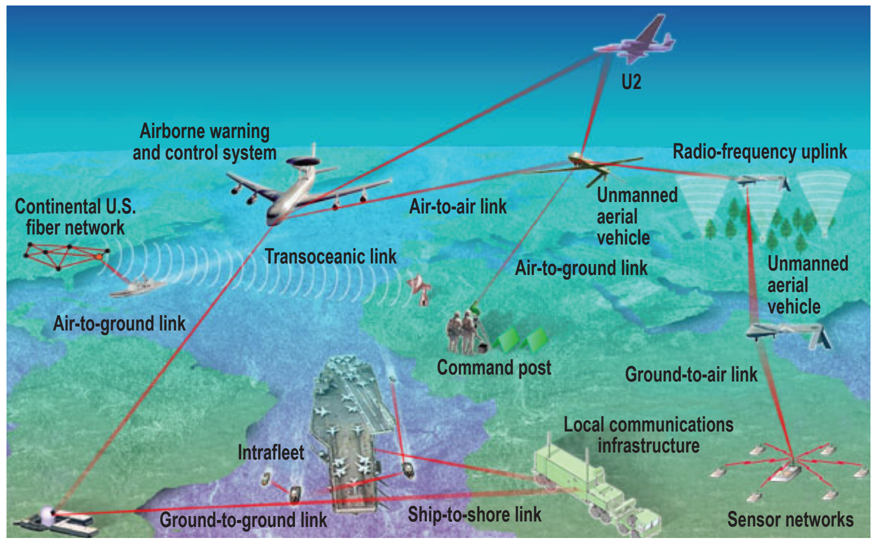
Fast Facts on LLNL's FSOC Technology

12 inventions

8 patents granted

6 projects funded by LLNL internal investments (LDRD)

To understand LLNL's connection to FSOC technology, we must go back to 1993, when Tony Ruggiero and his colleagues explored how to transmit large volumes of information rapidly and securely over long distances. Ruggiero and his team investigated optical communication as a possible solution, and over the next decade, the team moved through multiple iterations of the technology, with an initial focus on enabling more effective communication for the U.S. military.



During 2002, the team demonstrated the first laser communication link between LLNL and Mount Diablo, a mountain 915 meters high and 28 kilometers away. The technology transmitted data at 2.5 gigabits per second on a single laser channel.

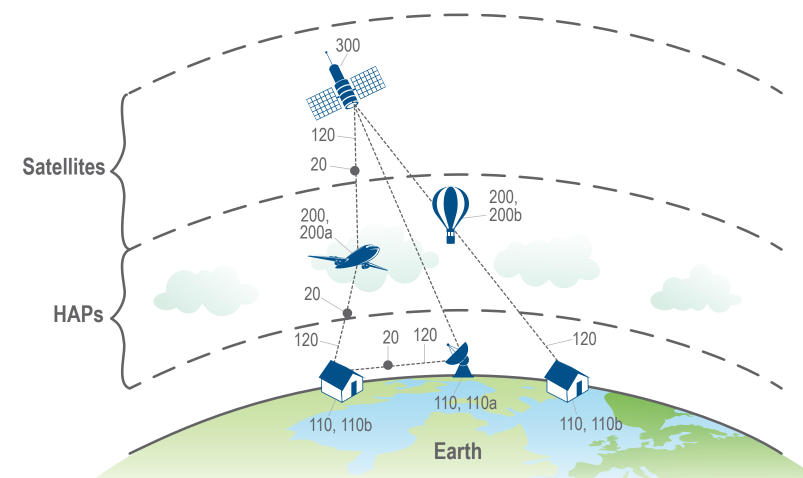
After their initial success with ground-to-ground communications, the team started working on ground-to-air communications. After investing 14 years to refine the technology, the team resolved the technical challenges, and the technology had matured to the point that it outgrew LLNL's mission space. But, like so many other early stage technologies, the market was not yet ready for FSOC technology. Without a Laboratory need and a commercial partner, the technology could have floated away.

However, Ruggiero met entrepreneur Bob Tillman, and in 2009, the two co-founded Sierra Photonics, Inc. Several members of the original LLNL research team joined the company to continue the journey to develop cutting edge communication technologies. Their efforts led to successful ground-to-air communication at 70,000 feet—twice the cruising altitude of a commercial airplane.

Sierra Photonics' achievements led to its acquisition by Google in 2014, and some of the company's employees went to work for Google, including Bobbie Steinkraus, a former LLNL scientist. His work at Google focused on addressing some of the remaining technical challenges of using FSOC technology to provide worldwide internet access.

This research resulted in a patent in March 2018 for ground-to-satellite optical communication technology using an airplane or a Google X box as an intermediate communicator. The patented technology uses a high-power laser beam to send optical data from the ground to the air by optimizing the laser's pointing and acquisition tracking.

The technology that started at LLNL, moved onward to a startup company, and was acquired by Google now serves as the foundation for efforts to provide worldwide internet access. According to Steinkraus, the technology could only have been developed at LLNL due to the Lab's expertise and world-class facilities. Global internet access may be in our future, thanks to 25 years of development by a visionary team at LLNL, along with help from an entrepreneur and funding from the government and private sector



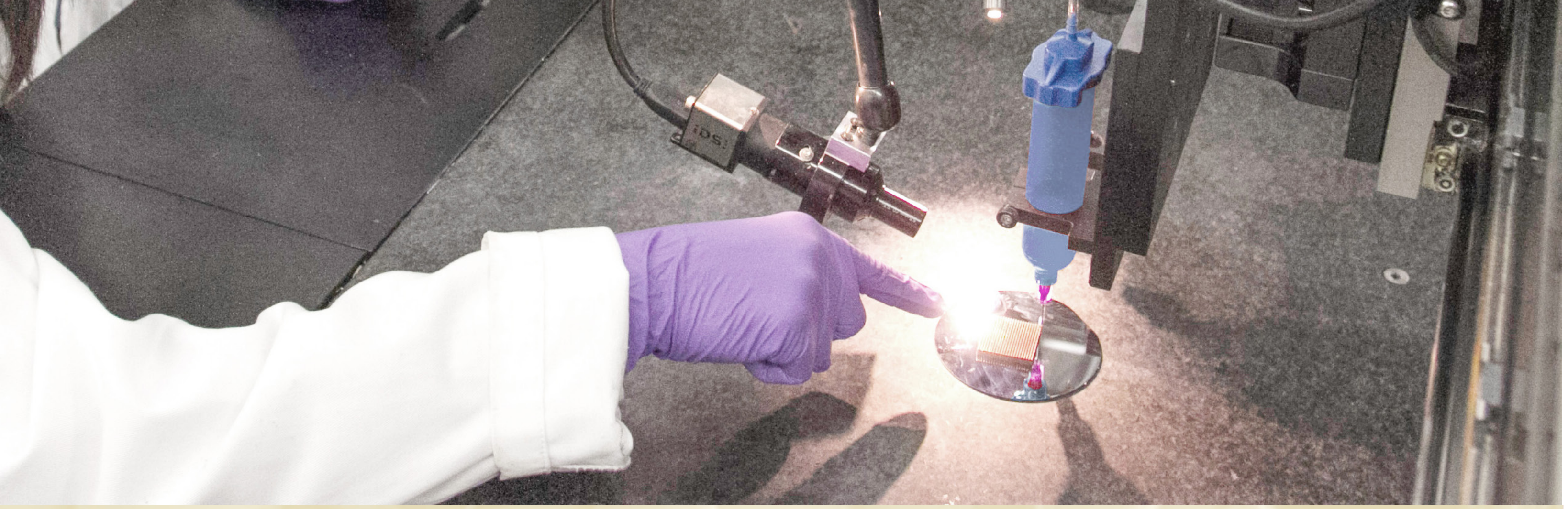
Depiction of how ground-to-satellite optical communications can travel through sensors on airplanes or balloons. (Image from Google's March 2018 patent.)

Investing in Innovation

Transforming the spark of a promising new idea into an industry game changer requires time, money, and resources.

While LLNL scientists and engineers actively seek out funding to meet identified needs, LLNL's Innovation and Partnerships Office fills in the gaps to make sure that our technology ignites progress in the commercial sector. We accomplish this by training and mentoring LLNL entrepreneurs, while strengthening our networks within industry. Over the past year, we:

- Received $1.5 million in funding from DOE's Technology Commercialization Fund (TCF) along with substantial matching investments from industry partners to advance promising LLNL research towards market adoption
- Opened the Advanced Manufacturing Laboratory, a 14,000-square foot state-of-the-art research facility aimed at fostering collaborations between LLNL and industry, academia, and other federal labs
- Won 7 prestigious R&D100 awards known as top honors for inventors
- Invested $750,000 of LLNL licensing and royalty funds for TCF recipient technology
- Hosted the national pitch finals for the DOE National Laboratory Accelerator, with first place awarded to an LLNL scientist
- Sponsored the National Labs Entrepreneurship Academy, a three-day business training course for scientists and engineers from national laboratories and NASA Ames Research Center



TECHNOLOGY TRANSFER PROGRAMS

Technology Commercialization Fund

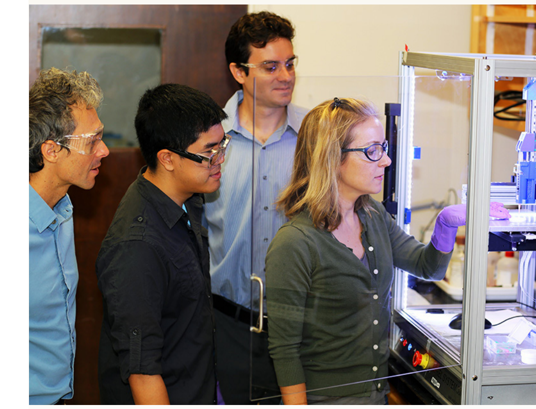
DOE's Office of Technology Transitions continues to invest in efforts to commercialize technology developed at LLNL. The Lab's innovators secured six awards from the Technology Commercialization Fund (TCF) for FY18, garnering $1.5 million in federal funding, along with $750,000 from industry partners and a $750,000 investment of LLNL licensing and royalty funds.

LLNL energy experts **Liang Min** and **Vaibhav Donde** are leading a two-year project aimed at helping utilities plan how to use their resources as the power grid becomes increasingly more complex. Current grid simulators cannot integrate transmission and distribution data, making it challenging to analyze large-scale power grids, with thousands of transmission substations and distributed energy resources, such as solar photovoltaics. In collaboration with Eaton, a power management company, the team will integrate the co-simulation platform developed by LLNL with Eaton's distribution simulator, demonstrate the benefits of this power co-simulation tool, and scale the technology for commercialization. Several public utilities are already interested in using the technology, recognizing its potential to support their large-scale planning initiatives.

Physicists Harry Radousky, Scott McCall, and Elis Stavrou (from right) are exploring a cold-spray additive manufacturing technique to fabricate customized thermoelectric generators and help recover wasted thermal energy

Harry Radousky, a physicist in LLNL's Materials Science Division, is using his TCF funding to develop technology aimed at reducing the cost to recover wasted thermal energy and convert it to usable electricity. He is validating the use of a cold-spray additive manufacturing technique to fabricate thermoelectric generators at a much lower cost than what is possible using current manufacturing methods. The research offers the potential for large-scale, low-cost, automated fabrication of thermoelectric generators in a range of shapes, which can be tailored to specific waste-heat recovery applications.

LLNL physicist **Mihail Bora** is developing an instrument that can assess water intrusion into photovoltaic modules of solar panels, which can degrade performance. The goal of this TCF-funded project is to demonstrate the feasibility of using Fourier transform infrared spectroscopy (FTIR) to measure water ingress in solar modules, enabling engineers to design solar panels with improved performance and reliability.

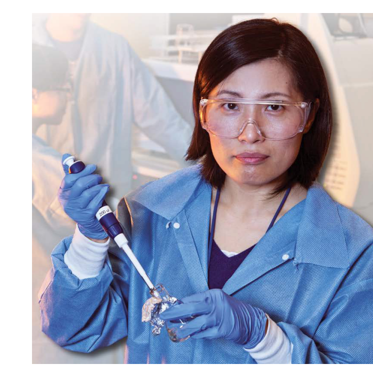


A team of LLNL investigators is exploring a novel use of microencapsulated CO_2 sorbents to upgrade biogas to biomethane, providing a new domestic energy resource. Team members include environmental scientist Joshuah Stolaroff, engineer Du Nguyen, and materials scientists Maxwell Murialdo and Sarah Baker.

In their TCF-funded project, materials chemist **Sarah Baker** and her team are collaborating with Delta Diablo, a wastewater treatment facility in California, to explore how a transformative new class of materials developed at LLNL can be used to upgrade biogas to biomethane with the purity needed for natural gas vehicles or injection into the natural gas pipeline. Delta Diablo provided LLNL investigators with biogas samples, which the LLNL team is using to test microencapsulated carbon dioxide sorbent (MECS) technology. Investigators are exploring whether the biosorbents can achieve the required biomethane purity. If most U.S. organic wastes were converted to biogas and upgraded to biomethane, they would provide a new, high quality domestic energy resource, reducing energy imports, while turning existing waste into revenue.

Earth scientist **Tom Buscheck** received TCF funding in FY18 and FY19 to develop his innovative technology, known as the Earth Battery, which could revolutionize long-term energy storage. (More information regarding the Earth Battery project can be found earlier in this report.)

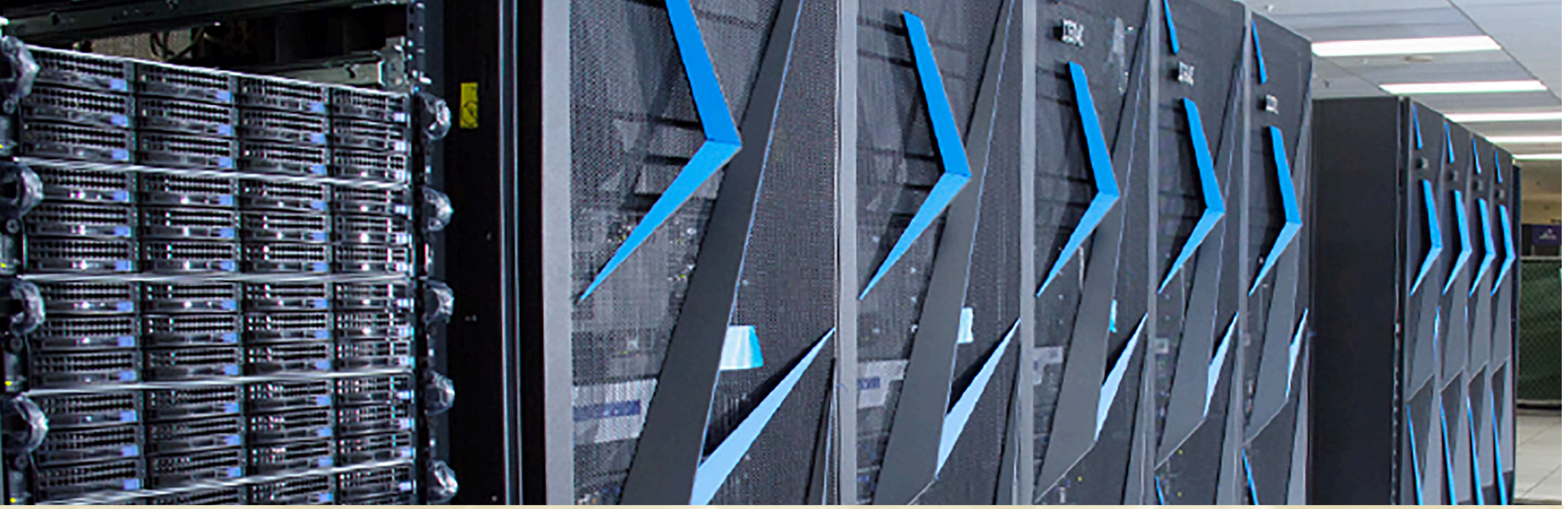
A team led by microbiologist **Yongqin Jiao** is using TCF funding to further develop an innovative biotechnology aimed at cost effectively extracting rare earth elements (REE) from non-traditional sources, such as geothermal brines and byproducts of coal production. There is an increasing demand for REE in a range of consumer products, such as mobile phones and laptops, as well as many national security applications. The technology holds promise to drastically reduce the overall cost of REE extraction, using an innovative, ecofriendly biotechnology to sequester REE from low-grade feedstocks, where conventional approaches, such as hydrometallurgy or solvent extraction, are not feasible. LLNL investigators are collaborating with Duke University researchers to scale up and demonstrate the technology's performance.



Microbiologist Yongqin Jiao is developing an innovative biotechnology aimed at cost effectively extracting rare earth elements (REE) from non-traditional sources, such as geothermal brines, to meet the increasing demand for REE in a wide range of consumer products.

In August 2018, LLNL learned about TCF awards for five new projects that will start in FY19, representing a $2.4 million investment by DOE, along with more than $3 million in matching funds from commercial partners. The FY19 projects include a new phase of the Earth Battery project, along with the following technology maturation projects:

- Accelerating the process to ensure the quality of complex metal parts produced using additive manufacturing, in collaboration with the GE Global Research Center.
- Incorporating microencapsulated sorbents into bioreactor chips for CO_2 capture, conversion, and air purification, in collaboration with Artveoli, a Silicon Valley company that produces air purification systems.
- Conducting pilot testing of NanoDeposit, a novel nanocrystal manufacturing method, in collaboration with Voxtel Nano, a company that makes infrared imagers.
- Developing a new amplifier with the potential to double the capacity of existing fiber optics using a spectrum not currently employed by existing networks.



SUPERCOMPUTERS DRIVE INNOVATION

Industry Partners

- Vitro Flat Glass LLC
- General Motors LLC
- Arconic, Inc.
- VAST Power Systems, Inc.
- KeraCel
- Seurat Technologies

HPC4Mfg Program

The High Performance Computing for Manufacturing (HPC4Mfg) program unites the world-class computing resources and expertise of National Labs with U.S. manufacturers to speed adoption of high-performance computing (HPC) to address manufacturing challenges, advance clean energy technologies, and increase energy efficiencies. The program aims to optimize production processes, enhance product quality, and speed up design and testing cycles, while decreasing energy consumption. By participating in the program, companies lower the risk often associated with HPC adoption.

LLNL leads the HPC4Mfg program, in partnership with Lawrence Berkeley National Laboratory (LBNL) and Oak Ridge National Laboratory (ORNL). The program offered two funding cycles in 2018.

In January 2018, DOE awarded $1.87 million to seven new public-private partnership projects. These projects included partnerships between LLNL and the following companies:

- Vitro Flat Glass LLC – Develop real-time glass furnace control
- General Motors LLC – Reduce cycle time in composite manufacturing
- Arconic, Inc. and ORNL – Understand the non-equilibrium metallic phases of metal additive manufacturing processes

In August 2018, DOE awarded $3.8 million to 13 new HPC4Mfg projects. LLNL expanded its involvement with the HPC4Mfg program in FY18 through three partnerships.

LLNL will collaborate with VAST Power Systems, Inc., and Argonne National Laboratory (ANL) to increase the efficiency of gas turbine combustors and reduce their start-up times. In a second project, KeraCel and LLNL will partner to optimize manufacturing of robust solid-state batteries.

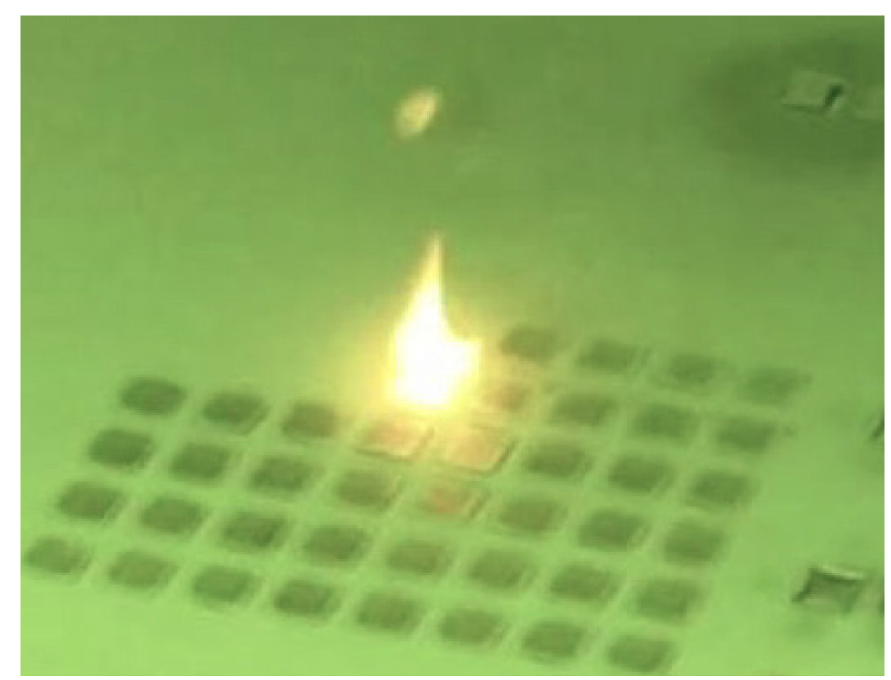
LLNL will also partner with Seurat Technologies to optimize an additive manufacturing technology originally developed at LLNL. The DOE funding through the HPC4Mfg program will allow Seurat to optimize the capabilities of its laser powder-bed fusion additive manufacturing printers. In addition, Seurat closed a $13.5 million Series A round of funding led by True Ventures. The funds will accelerate commercialization of the company's breakthrough metal additive manufacturing technology, enabling Seurat to bring to market an industrial metal printer with unparalleled speed and resolution.

An example of the simulation capabilities that will be explored during a collaboration between LLNL, ORNL, and Arconic, aimed at providing more reliable microstructure modeling of additively manufactured metal parts. This molecular dynamic model shows how atoms within a microstructure behave at the liquid-solid interface. Data obtained from this type of simulation is expected to provide essential information for tailoring the mechanical performance of 3D-printed alloys by controlling the rapid solidification of microstructures.

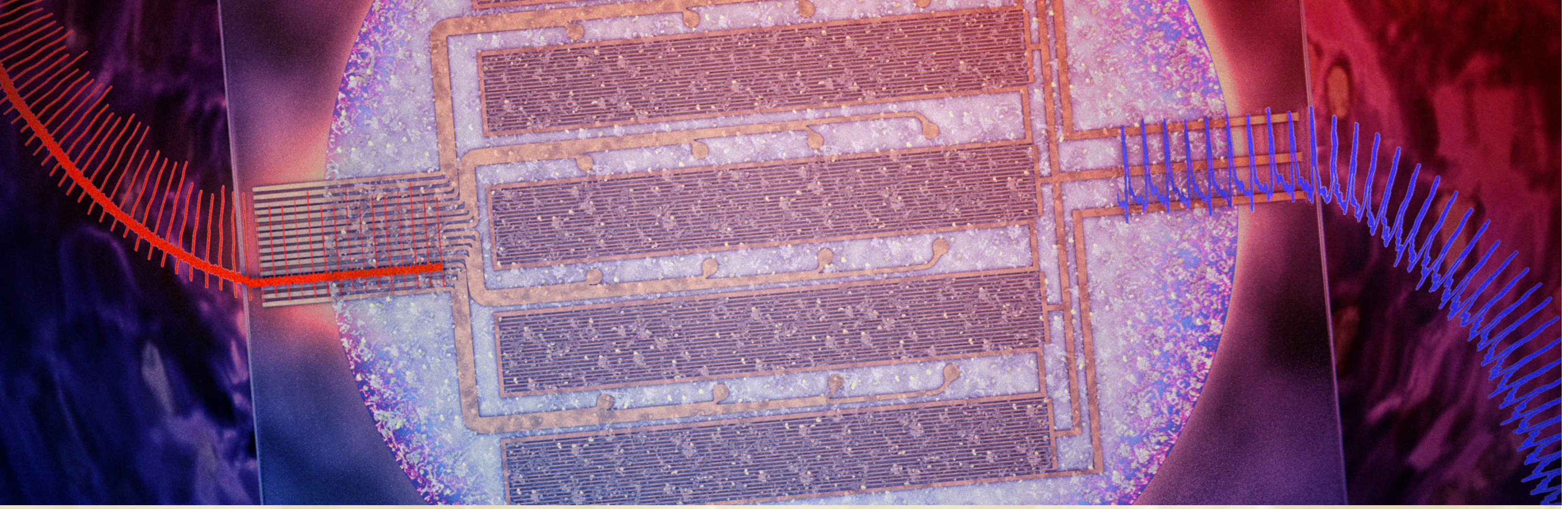
HPC4Mtls Program

In FY18, DOE announced an opportunity to fund up to $3 million in projects related to improving materials in severe or complex environments through the new High Performance Computing for Materials in Applied Energy Technologies (HPC4Mtls) Program. Similar to the HPC4Mfg program, HPC4Mtls brings together industry partners and DOE scientists to work on short-term, collaborative projects. Instead of focusing on manufacturing challenges, the HPC4Mtls program focuses on applying high-performance computing to challenges associated with materials used in energy technologies.

Led by LLNL, in partnership with the National Energy Technology Laboratory (NETL), Los Alamos National Laboratory (LANL), Pacific Northwest National Laboratory (PNNL), and ORNL, the HPC4Mtls program offers a low-risk path for U.S. manufacturers interested in adopting use of HPC modeling, simulation, and data analysis to address key challenges in developing, modifying, or qualifying new or modified materials. The first of these projects is expected to start in December 2018.



LLNL licensed a novel metal additive manufacturing technology to Seurat Technologies, which will enable Seurat to bring to market an industrial metal printer with unparalleled speed and resolution.

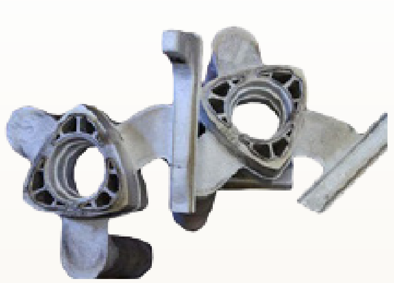


RECOGNIZING LLNL INNOVATORS

7 R&D 100 awards received by LLNL innovators in FY18

165 R&D 100 awards received by LLNL since 1978

Lawrence Livermore Microbial Detection Array (LLMDA)



ACE: Aluminum/Cerium Alloy

R&D 100 Awards

In FY18, LLNL researchers garnered seven R&D 100 awards for inventions recognized as some of the top 100 science and technology innovations worldwide.

The Lawrence Livermore Microbial Detection Array (LLMDA), the first high-throughput, pan-microbial detection device, can rapidly detect thousands of viruses and bacteria. It can analyze 96 samples in parallel, with each sample exposed to 1.4 million DNA probes, which can detect more than 12,000 microbial species. The array offers throughput levels not attainable by DNA sequencing, enabling new opportunities for health and safety screening. LLMDA was licensed by Thermo Fisher Scientific.

ACE: Aluminum/Cerium Alloy, an innovative alloy that performs up to three times better than standard aluminum alloys at higher temperatures, offering excellent castability and high corrosion resistance. It eliminates the need for heat treatment after casting, saving energy and reducing manufacturing costs by up to 60%. LLNL collaborated with ORNL, NASA Ames Lab, and Eck Industries to develop this innovative material.

Geometrically Enhanced Photocathodes, which offer quantum efficiencies three times greater than traditional photocathodes, making it possible to improve the efficiency x-ray detectors. The enhanced photocathode technology was developed in collaboration with National Security Technologies, LBNL, and NanoShift.

Hydrogen Safety Sensor. This zirconium oxide, electrochemical, hydrogen safety sensor can detect an accidental hydrogen release, trigger mitigation strategies to prevent hazardous situations, and autonomously shut down a system. The sensor was developed in collaboration with LANL and Hydrogen Frontier, Inc.

The National Risk Assessment Partnership (NRAP) Toolset, a software package used to assess the environmental risk of geologic carbon dioxide storage sites. The toolset supports industry and regulatory agencies as they design and implement carbon storage projects to sequester large volumes of human-made carbon dioxide. In addition to LLNL, National Energy Technology Laboratory (NETL), LANL, LBNL, and PNNL are also members of NRAP.

The Earth System Grid Federation (ESGF), a collaborative effort to link climate centers and users around the world to geophysical data. The peer-to-peer enterprise system, powered by supercomputers, supports research in earth system science, providing a robust tool where scientists can access and manage datasets in a virtual, collaborative environment. In addition to LLNL, other ESGF consortium members include the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Australian National University's National Computational Infrastructure, German Climate Computing Centre, Institute Pierre-Simon Laplace, and Centre de Recherche Informatique de Montréal.

The Radiation Field Training Simulator (RaFTS), described earlier in this report, also received an award.

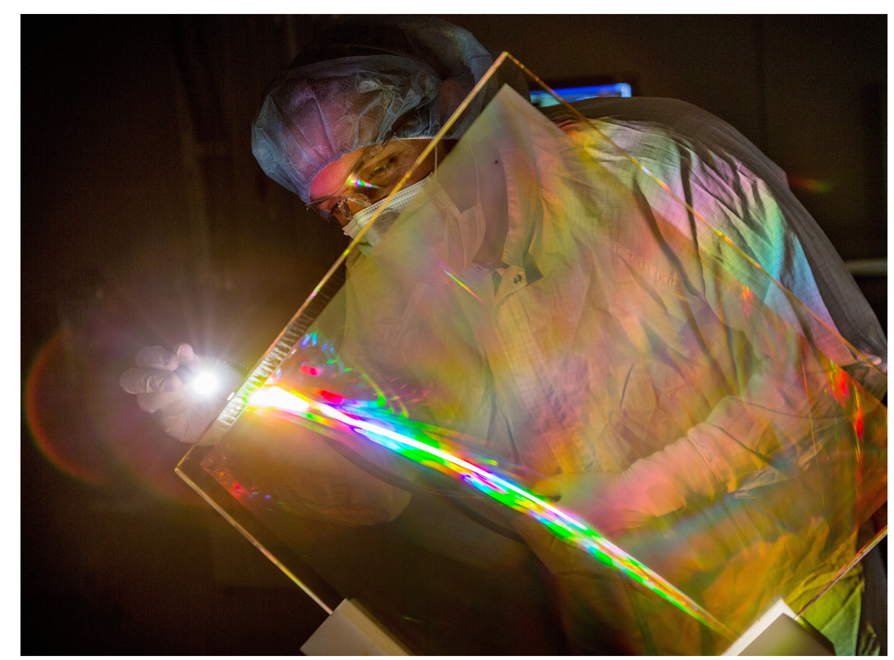
"The R&D 100 Awards that our Laboratory received over the years represent international recognition of LLNL's spirit of scientific and technological innovation, and attest to the impact of our contributions across a wide range of technologies and applications."

—Bill Goldstein, LLNL Director

R&D 100 finalists from LLNL

- **STAPLE: State-of-the-Art, High-Efficiency, Thin-Film Polymer, F#2 Fresnel Lens,** which enables scientists to produce small, high-resolution imaging satellites or drones at a fraction of the weight and cost of traditional satellites.
- **PRUNERS: Providing Reproducibility for Uncovering Non-deterministic Errors in Runs on Supercomputers,** an open-source software toolset to detect and remedy errors in large parallel applications.

Hydrogen Safety Sensor



LLNL's Anti-Reflection Grating Debris Shield (AR-GDS) technology was named as an R&D award finalist in FY18. This fused silica optic is resistant to damage caused by fusion-class laser systems, providing a cost-effective way to measure the power and energy of these powerful laser systems.

LLNL's FLC awards

33 regional FLC awards received since 2007

35 national recognition FLC awards received since 1985

LLNL leveraged its expertise in high-power lasers through a partnership with the European scientific community to develop HAPLS, the world's first laser capable of generating 30 femtosecond pulses with peak power of more than one petawatt. HAPLS is fully integrated, operational, and is available to scientists worldwide for studying laser-matter interactions.

FLC Technology Transfer Awards

LLNL received three technology transfer awards in 2018 from the Federal Laboratory Consortium's Far West Region. They include an Outstanding Commercialization Success award for one of the Lab's largest-ever technology transfer projects—the design, development and construction of the **High-repetition-rate Advanced Petawatt Laser System (HAPLS),** which is operational at the European Union's Extreme Light Infrastructure (ELI) Beamlines facility. Under a $52 million agreement with ELI, scientists at LLNL developed and constructed the laser system in only three years, from concept to product, delivering the laser to the facility (located in the Czech Republic) in 2017.

The Lab received an Outstanding Partnership award for an **electrochemical solid-state nitrogen oxide detector** for diesel engines, developed by LLNL scientists, which is being commercialized by CoorsTek Sensors, a Colorado-based company. The detector could be an important step in development of accurate and affordable emission sensors for diesel engines in cars, commercial and marine vehicles, locomotives, and stationary equipment. Existing nitrogen oxide (NOx) detectors are expensive and fragile, limiting their industry adoption. The Livermore/CoorsTek NOx detector is simple and inexpensive, potentially opening the door to a $2.5 billion industry by 2023, as the regulation of diesel engines continues to expand.

The LLNL-developed detector technology was licensed to EmiSense, a developer of advanced sensor technologies, who advanced the technology through a 30-month cooperative research and development agreement (CRADA) with LLNL. In 2014, EmiSense was acquired by CoorsTek Sensors. The technology is expected to hit the market within the next several years.

A novel additive manufacturing (AM) technology, known as **FemtoProWrite,** received an Outstanding Technology Development award. This projection lithography technique can print 3D plastic structures with submicron features. The fine resolution of such structures allows the technology to be used in a variety of fields to fabricate micro- and nanoscale 3D structures. For example, the structures can be used to achieve superior functionality in fast-charging solid-state batteries, efficient photovoltaics, and high-sensitivity chemical and biological sensors. FemtoProWrite—named for its ability to print in femtoseconds (a quadrillionth of a second)—leverages a light-directed writing technique (known as two-photon polymerization) to increase throughput of submicron AM by a factor of at least 35 times, without degrading resolution.

Investing in Innovation

The Innovation Development Fund (IDF) is a program managed by LLNL's Innovation and Partnerships Office (IPO). IDF provides LLNL researchers with funds to develop promising early stage technologies so that they are a lower-risk investment for industry and other potential investors. IDF investments help bridge what is commonly referred to as the "valley of death"—the gap between when a technology is promising and when it moves forward into commercialization.

Targeting a broad range of technologies and applications, IDF is funded by a portion of the licensing fees and royalties retained by the Laboratory from the performance of authorized technology transfer initiatives. These funds support the enhancement of technology transfer activities at LLNL and are typically used for projects that include market research and technology maturation.

Since its inception in 2014, IDF has funded 21 projects, with a total investment of just over $2 million. Interest in the program is growing as an increasing number of LLNL investigators are developing innovative technologies with commercial applications. The number of proposal submissions increases each year.

In some cases, the development and subsequent commercialization of early-stage technologies can take as long as 10 years or more before there are significant product sales associated with an LLNL technology. While most of the projects funded by IDF are ongoing and still considered in the development phase, several projects have entered the commercialization phase. This step occurs when the technology is sufficiently mature, or when the associated risk of adoption has been reduced. Technologies in the commercialization phase are actively marketed by IPO for licensing or co-development, in the form of a CRADA between the Lab and a private company or university.

"The assistance I received from the Innovation Development Fund was critical for advancing my technology and testing it on real-world problems."

—Maxim Shusteff
LLNL engineer and IDF recipient

21 projects funded since 2014

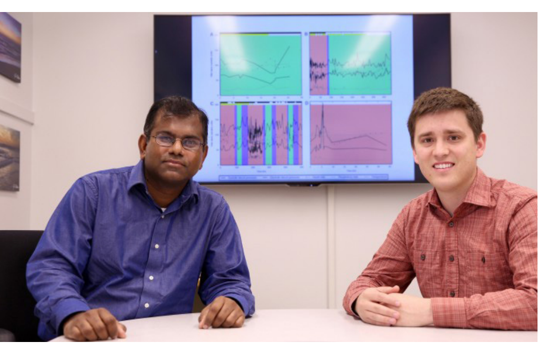
$2 million in total investments

$95,000—the average investment per project

FOSTERING COLLABORATION

Open Resources Foster Collaboration

High Performance Computing Innovation Center



The High Performance Computing Innovation Center is a hub of collaborative activity and workshops. Here, LLNL researchers discuss how they may be able to track the progression of sepsis, a potentially life-threatening condition characterized by an extreme reaction to infection, with more precision and confidence using machine learning models developed at LLNL in conjunction with health care provider Kaiser Permanente.

The High Performance Computing Innovation Center (HPCIC) provides industry and academia with an accessible point of entry to engage with LLNL on leading-edge, high-impact projects aligned with the Lab's mission. In turn, these activities enhance the HPC skills of the Lab workforce. In FY18 alone, HPCIC enabled more than 20 collaborative engagements. These engagements will ultimately help companies increase their understanding of complex technologies and accelerate innovation.

HPCIC creates and manages strategic partnerships to boost the Lab's capabilities in the development of modeling and simulation, data analytics, and cyber programming methods that can then be applied to national security missions. IBM, RAND Corporation, and Georgetown University are among the many strategic partners who add value to the Lab's mission through HPC activities.

The Center hosts a series of annual events, fostering innovation through collaborative activities. For example, HPCIC hosts the annual Current Challenges in Computing (CCubed) conference and the institutional Computational Grand Challenge program, which both encourage advanced explorations of HPC applications. HPCIC hosts other events, like hackathons—24-hour events that promote collaborative programming and creative problem solving by LLNL employees and visiting students. Sponsored by the Lab's Computation Directorate, the hackathons are held three times a year.

From fostering collaboration internally to engaging industry externally, HPCIC serves as LLNL's front door for industry. The Center does so by reaching out to companies interested in Lab-developed technologies, such as ALE3D for Industry, a highly versatile simulation code that is one of LLNL's featured "hot technologies" (earlier in this report). HPCIC also encourages companies to continue collaborating with LLNL after completing HPC4Mfg technology transfer projects.

Advanced Manufacturing Lab

The 14,000 square-foot Advanced Manufacturing Laboratory (AML), located on the Livermore Valley Open Campus, houses a reconfigurable layout, which allows it to rapidly set up space to meet the changing needs of its collaborators. AML enhances LLNL's ability to actively promote mutually beneficial collaborations between federal laboratories, academia, and industry.

LLNL anticipates that the AML will enable researchers to produce breakthroughs that will lead the development of innovative technologies needed to strengthen advanced manufacturing and enhance the domestic supply of machines and materials. These efforts will support NNSA missions that include stockpile stewardship, energy security, and intelligence, as well as other DOE thrusts, such as economic competitiveness.

New facilities, like the AML, offer expanded opportunities for LLNL to engage with collaborators, maintain first-in-class science, technology, and engineering capabilities, and attract and retain the workforce needed for national security missions.

Designed to spur interest in industry and academic collaboration, a Partnering for Success event was held at the Livermore Valley Open Campus in May 2018. Over 90 participants from more than 30 companies in the additive manufacturing (3D printing), automotive, and aerospace industries gathered together with innovators from LLNL and academia. The day-long event included presentations on LLNL efforts in advanced manufacturing, along with afternoon breakout sessions in applications, materials, processes, design optimization, and qualification and certification. Attendees also engaged with each other in one-on-one sidebar discussions on potential projects.

Participant Steven Adler, CEO of A3DM Technologies (an additive manufacturing company based in Vermont), was impressed by the AML, and said he is already envisioning collaborations in metal powders and processes.

> *"The AML will be an excellent resource to advance the state-of-the-art in manufacturing."*
>
> —Tom Markel, strategic accounts manager for Aerotech, a company based in Pennsylvania that designs and manufactures motion control products

LLNL physicist Manyalibo (Ibo) Matthews, front, shows the Advanced Manufacturing Laboratory AML to representatives from the additive manufacturing, automotive, and aerospace industries. Located on the Livermore Valley Open Campus, AML is the Lab's newest facility.

Indicators highlighting the need to expand our workforce in advanced manufacturing:

20% of U.S. jobs require significant knowledge in at least one STEM field

STEM-related jobs will grow by more than 9 million between 2012 and 2022

3D printing may affect 35% of global output, due to steady growth in this form of advanced manufacturing

Partner Discovery

IN-PART: Connecting with Industry Leaders

In late 2016, IPO launched a pilot project with IN-PART, a matchmaking platform that connects university and national laboratory research with innovative companies that can provide viable leads for potential collaboration partnerships and technology licensees. Participation on the IN-PART platform has been a worthwhile investment for IPO, as access to a global network of research and development decisionmakers has also provided LLNL researchers with a source of feedback regarding their technology's market viability. Overall, IN-PART can help make the initial connection for technology transfer between LLNL and companies simple, efficient, and scalable.

To date, 34 companies have expressed interest in more than 100 LLNL technologies featured on the platform, thanks to introductions facilitated from IN-PART. Based on the platform's 6-month and 1-year impact reports, LLNL-submitted projects attracted interest from companies at similar or above average rates compared to other technologies on IN-PART.

LLNL is renewing its IN-PART subscription for a third year into 2019. The Lab looks forward to utilizing the platform's new dashboard feature and the new Discover Industry Calls for Opportunity campaigns.

LLNL engineer Reg Beer describes his team's autonomous collision avoidance technology during a presentation to potential investors during an IPO-sponsored market discovery webinar. The technology, which leverages artificial intelligence to create a "smart" network of machines, could be applied to autonomous vehicles, drones, or underwater robotic vehicles.

Market Discovery Webinars: Connecting with Investors

IPO strives to make the business community aware of LLNL technologies and collaboration opportunities through diverse communication strategies. To foster our network of entrepreneurs and investors, IPO produces and hosts the Technology and Market Discovery webinar series. In these sessions, Lab scientists present their technologies and its capabilities. In turn, audience members provide market-based feedback to the Lab. Each webinar features a presentation that is followed by an interactive Q&A session with the audience. To date, more than 50 webinars have been presented. Those held in FY 2018 include:

- Research at LLNL's Energetic Materials Center
- Eye-Watering Images from Tiny Telescopes: Rugged and Compact Monolithic Telescopes for Nano-satellites and UAVs
- ALE3D for Industry: Multiphysics Simulations for the Nation's Future
- High Speed Optical Recording with a Sub-Picosecond Rolling Camera Shutter
- Lightfield Directing Array: Key Enabling Technology for Autonomous Vehicles
- New Fiber Amplifier for Telecom: Doubling the Information Carrying Capacity of Optical Fiber Networks
- Autonomous Collision Avoidance

Investment Spotlights

SHAPE MEMORY MEDICAL

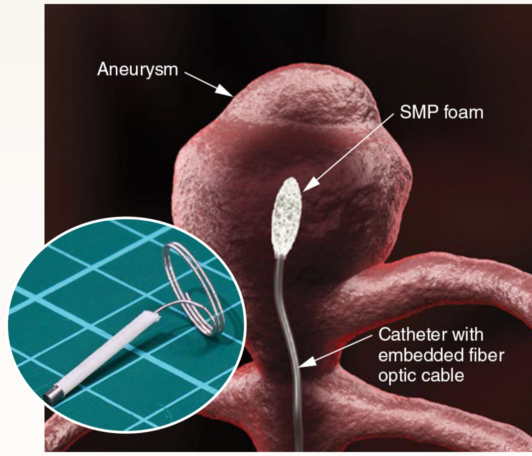
Commercializing LLNL-developed smart polymer technology

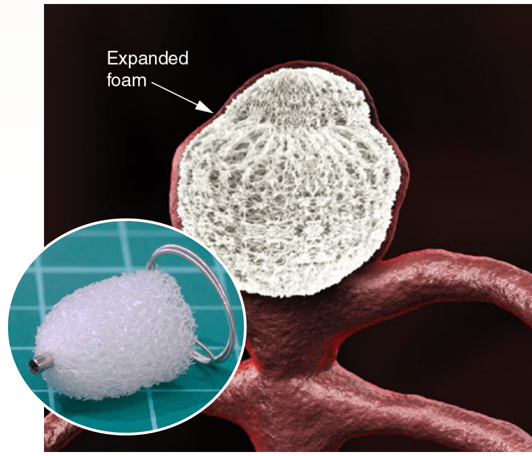
Aneurysms, or outward bulges formed at weakened areas of artery walls, lurk in the brains of an estimated 1 in 15 people. If an intracranial aneurysm bursts, blood rushes to other areas of the brain, causing massive tissue damage, stroke, and even death. For those lucky enough to be diagnosed with an aneurysm before it ruptures, medical treatment is possible. The goal of treatment is to isolate the aneurysm sac from the rest of the arterial blood flow to reduce pressure on the weakened vessel walls.

Researchers at LLNL, in collaboration with Texas A&M University, pioneered the use of advanced materials and computational fluid dynamics analysis to develop a shape-memory-polymer foam that is biologically compatible and can be used to plug an aneurysm before it bursts. Shape memory foams can be made thin enough to be inserted into blood vessels and arteries. Once in place, they expand either on a time-release basis or when heated by the blood to seal up vessels and arteries and allow for healing tissue to develop.

This novel material significantly increases the efficacy of treatment and reduces patient risk compared with traditional techniques. The technology is being commercialized by Shape Memory Medical, a California-based company co-founded by former LLNL scientist Duncan Maitland, as the IMPEDE® embolization plug.

In 2018, the FDA approved the use of Shape Memory Medical's IMPEDE® embolization plug in humans to deliberately block blood flow in order to treat bleeding abnormalities or other conditions.





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

LexaGene

With food safety recalls on the rise, there is a significant need for scalable, easy-to-use technology that can quickly detect pathogens. **LexaGene,** a Massachusetts-based biotech company, has developed the LX6, an automated instrument that can provide results in an hour, allowing food producers to make quick decisions regarding the safety of their products. The instrument employs diagnostic technology developed at LLNL, which is used as part of a license agreement with LexaGene.

ENGAGING ENTREPRENEURS

2018 National Lab Accelerator Program

169 scientists and engineers participated in formalized business training

80 members of the business community mentored laboratory scientists and engineers

59 business model presentations were judged

9 finalists pitched their ideas to Silicon Valley investors

3 winners received funding to continue their research toward commercialization

Entrepreneurship Academy

The skills of resiliency, focus, and vision that make a good entrepreneur are also crucial for fostering scientific innovation. While these skills are taught in business schools, they are not part of the core curriculum of scientific training. To provide scientists and engineers with skills to excel in their scientific work—as well as prepare them for commercializing their technology—LLNL's IPO sponsors the National Labs Entrepreneurship Academy.

The three-day business training course, presented by the Graduate School of Management at the University of California, Davis, imparts key knowledge about important areas such as business models, value propositions, and building a customer base. It also highlights the experiences of scientists-turned-entrepreneurs who left National Labs to start successful companies.

One objective of the course is to prepare attendees for other National Lab programs focusing on entrepreneurship, such as Energy I-Corps and the National Lab Accelerator Program. Both programs teach scientists to be more effective in orienting their research toward commercialization.

The overall goal of this type of business training is to improve the ways Lab scientists and engineers communicate with sponsors and increase the flow of LLNL-developed technology to the private sector. After completing the course, attendees understand that treating sponsors like "customers" improves relationships and supports outcomes.

The October 2017 Academy was attended by scientists and engineers from LLNL, Sandia, and NASA Ames Lab. Overall, five Entrepreneurship Academies have been conducted in recent years, with 169 National Lab personnel receiving training.

National Lab Accelerator Program

An accelerator is a training model used by the venture capital community for finding and training would-be entrepreneurs in business, market research, customer discovery, and product development. Typically lasting for several months, accelerators begin with classroom training and education in business concepts and models. Then, student entrepreneurs develop their own business model under the guidance of experienced mentors. Successful individuals form companies and receive seed funding through the accelerator to continue their work.

The National Lab Accelerator Program was established based on this proven model. Its goals are to connect laboratories with their surrounding business communities, prepare scientists and engineers with the business knowledge to connect effectively with those communities, and increase the probability that technology developed at National Labs will be effectively transferred to the private sector.

In addition to LLNL, eight national labs participated in the pilot program, funded by DOE's Office of Energy Efficiency and Renewable Energy (EERE): Argonne National Laboratory, Brookhaven National Laboratory, Idaho National Laboratory, Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratory. Each Lab provided training, one-on-one business mentorship, and the opportunity to pitch technologies to EERE's scientists and engineers.

"I thought developing the technology was difficult. It turns out formulating a business plan has challenges of its own. What I learned is we can only get the technology so far until we have to understand the business side to actually move it out and make an impact."

—Robert Panas, LLNL engineer who received 1st place in the 2018 National Lab Accelerator pitch event

"I hear many pitches, and these were among the top."

—Tony Lazar, Harvard Angels

Regional Innovation Ecosystem

The Innovation & Partnerships Office at LLNL fosters close connections to the San Francisco Bay Area's regional economic development ecosystem. From our location within a Bay Area innovation and investment hub, LLNL benefits from a business community that is well-poised to support and help shepherd the commercialization of Lab technology.

The i-GATE Innovation Hub, originally founded through a collaboration between the City of Livermore, Sandia, and LLNL, aims to support startups and economic development in the Tri-Valley region of California, particularly centered around the National Labs as anchors of innovation.

i-GATE manages an incubator and coworking space called The Switch, which provides entrepreneurial training and resources to support the local entrepreneurial ecosystem. i-GATE and The Switch have supported a number of high-tech startups that are commercializing technologies originally developed at LLNL.

Three current LLNL licensees are incubated in the facility. One of the most successful startups to utilize i-GATE resources is POC Medical Systems, a medical device company bringing low-cost cancer screening to the developing world, based on patented technology developed by, and licensed from, LLNL.

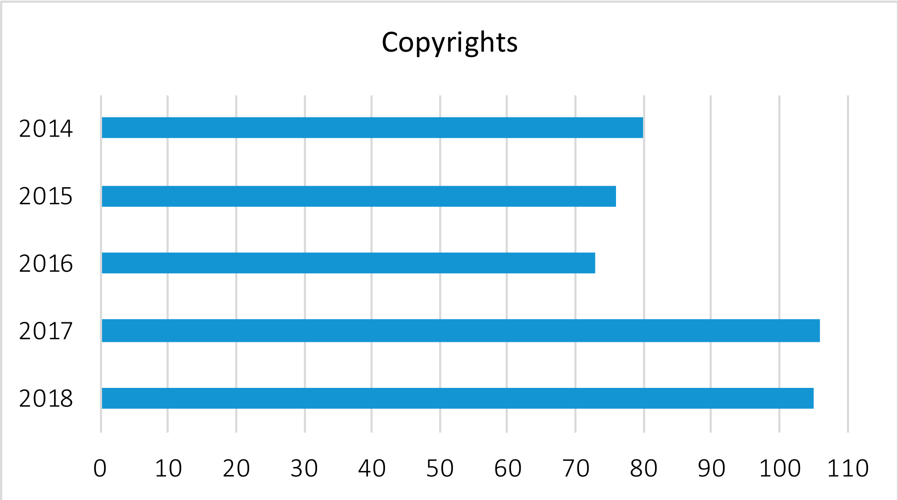
THE SWITCH
INNOVATION STARTS HERE
Powered by i-GATE

METRICS

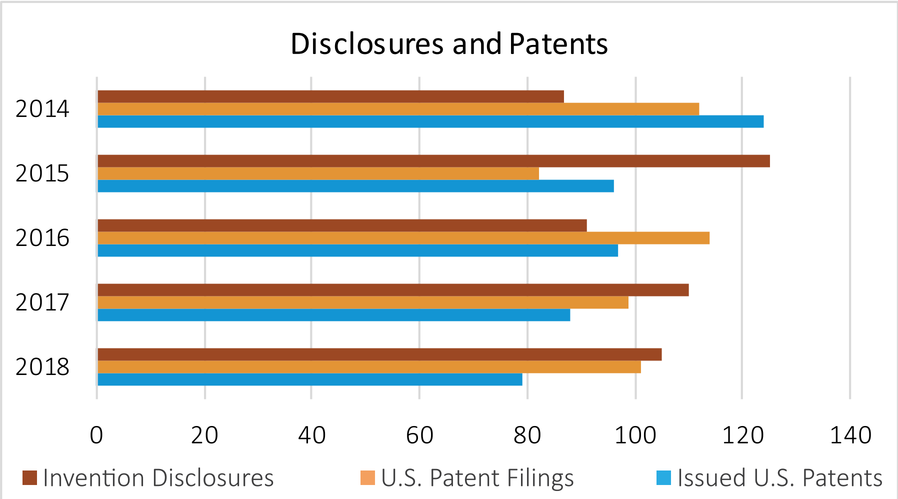
While narratives that describe scientific discoveries at LLNL provide evidence of innovation in action, they do not tell the whole story. Here, we share metrics that serve as quantitative indicators of our success in transferring technology from LLNL to commercial partners.

Intellectual Property

During the last two years, LLNL filed more than 100 copyright assertions per year, helping protect our scientists' innovative ideas.

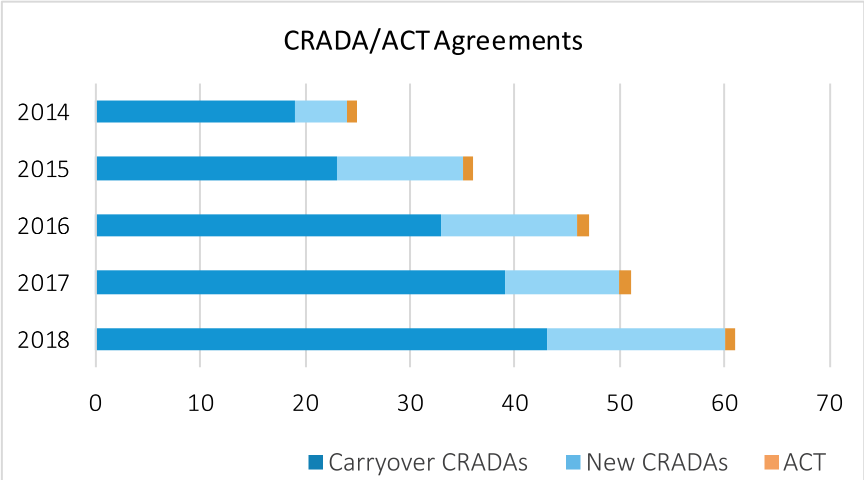


LLNL-based inventions are protected by more than 1,000 active patents and patent applications.

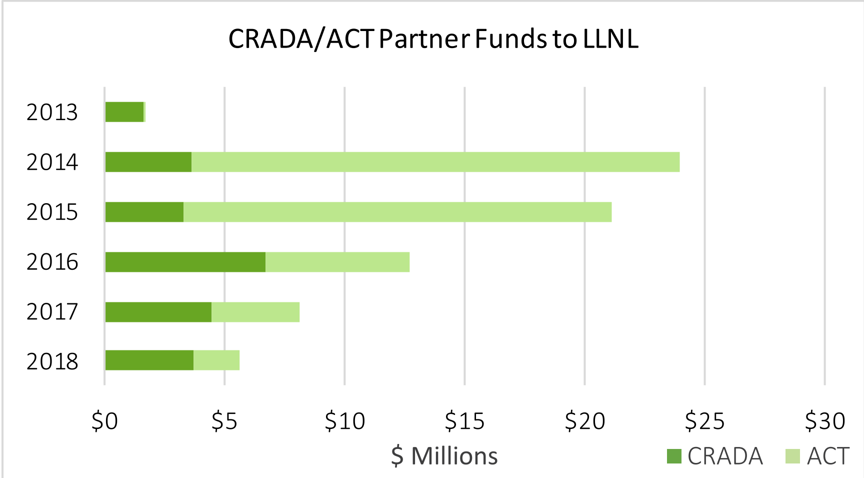


Industry Agreements

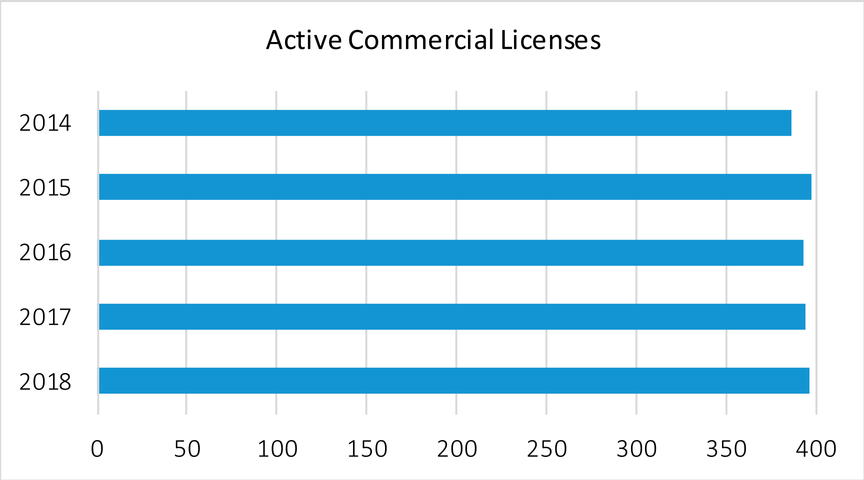
LLNL has dozens of active CRADAs, which help our scientists transform promising technology into marketable products.



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



LLNL has nearly 400 active commercial licenses.



Contacts

LLNL Innovation & Partnerships Office
ipo.llnl.gov

POC for external parties to contact the IPO:

> Richard A. Rankin, Director of the
> Innovation & Partnerships Office
>
> Lawrence Livermore National Laboratory
> P.O. Box 808, L-795 Livermore, CA 94551
> Phone: 925.423.9353
> Email: *rankin8@llnl.gov*

For questions and comments, contact
ipo@llnl.gov

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

> Roger Werne, Deputy Director,
> Entrepreneurial Development and Outreach
>
> *Werne1@llnl.gov,* 925.423.7302
>
> Nina Potter, Manager of IP & Agreements Management
>
> *Potter14@llnl.gov,* 925.423.7310
>
> Michael Sharer, Manager of Regional Engagements
>
> *Sharer1@llnl.gov,* 925.422.9839
>
> Annemarie Meike, Business Development Executive,
> Chemicals & Materials, Energy & Environment
>
> *Meike1@llnl.gov,* 925.422.3735
>
> Candice Gellner, Business Development Executive,
> Computational Biology Software
>
> *Gellner2@llnl.gov,* 925.423.9724
>
> Charity Follett, Business Development Executive,
> Information, Communications, Software
>
> *Follett2@llnl.gov,* 925.422.1817
>
> David Dawes, Business Development Executive,
> Lasers & Optics, Radiation Detection
>
> *Dawes4@llnl.gov,* 925.422.0801
>
> Genaro Mempin, Business Development Executive,
> Advanced Manufacturing, Instruments/Sensors/
> Electronics
>
> *Mempin1@llnl.gov,* 925.423.1121
>
> 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