Lawrence Livermore National Laboratory

2017

Technology Transfer Report

Innovation in Action

INNOVATION IN ACTION

Scientific Discoveries
Change Lives and Fuel Economic Growth.

The LLNL Innovation and Partnerships Office (IPO) 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 technology into a marketable product.
Our aim is to help them accelerate technology transfer to commercial partners, where it can be used to solve urgent problems.

These tasks can seem daunting to researchers, so the IPO team offers expertise to Lab innovators in a broad range of areas. Our team includes specialists in product development, market analysis, commercialization strategies, intellectual property, and law. We organize networking events with potential investors, and we host educational seminars.

Although our ultimate goal is to advance the development and commercialization of scientific discoveries, several metrics are evidence of our results. For example, our Lab currently has commercial licenses with more than 300 companies. Licensing and royalty income in recent years has topped $8 million annually. LLNL-licensed technologies enabled the launch of numerous new businesses that are helping drive economic growth.

As you browse this report, I hope you better understand our initiatives to educate budding entrepreneurs and foster successful technology transfer. We are proud to be part of Department of Energy efforts to increase the commercial impact of innovative technology developed at DOE National Labs.

—Richard A. Rankin

Director,
Innovation & Partnerships Office

INNOVATION & PARTNERSHIPS OFFICE
COMMERCIALIZING LLNL TECHNOLOGY

Cover:

Lawrence Livermore National Laboratory (LLNL) scientists recently used synchrotron X-ray scattering to fully capture the hierarchical structure in self-organized carbon nanotube materials from the atomic to micrometer scale. The cover depicts an artist's rendering of an X-ray scattering pattern containing information about the multiscale structure of a carbon nanotube "forest." In addition, the cover illustrates LLNL's use of a "power wall"—an interactive display that transforms data from high performance computer simulations into images that scientists can use to better understand simulation results

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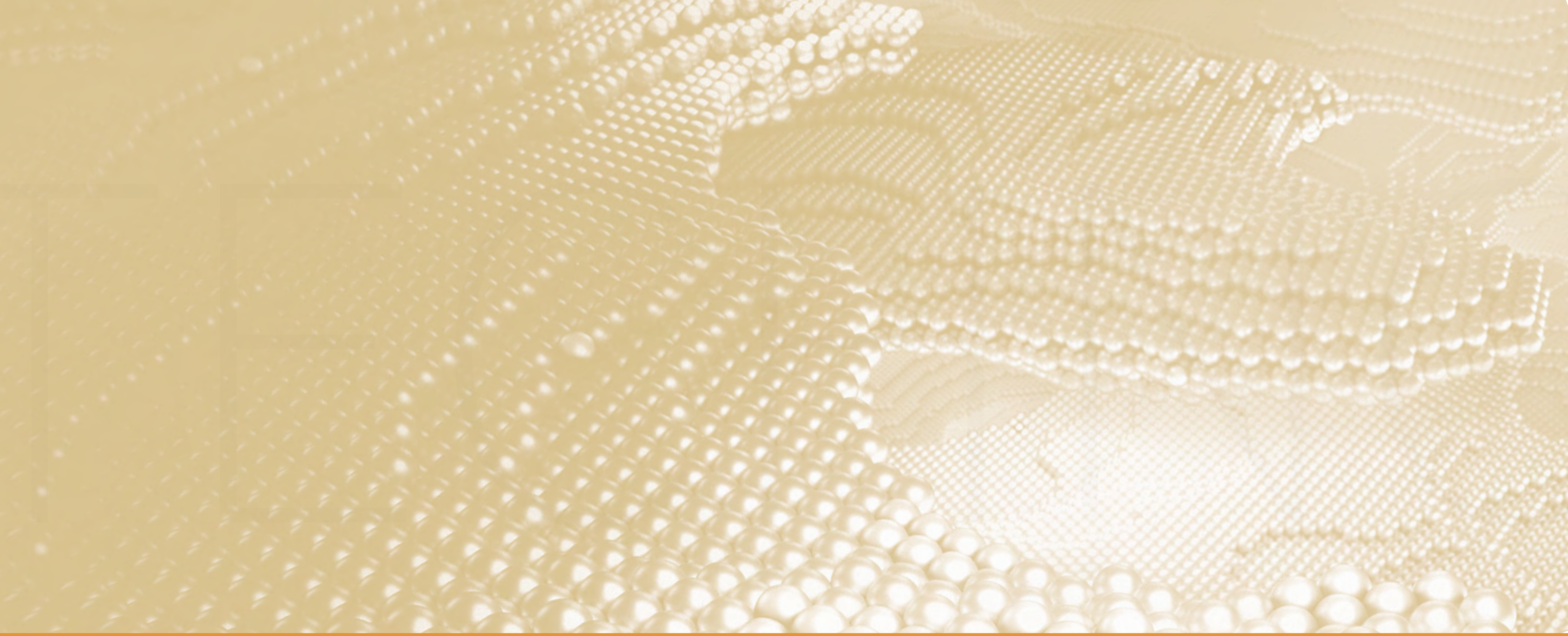

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From the Laboratory

to the **WORLD**

EXECUTIVE SUMMARY

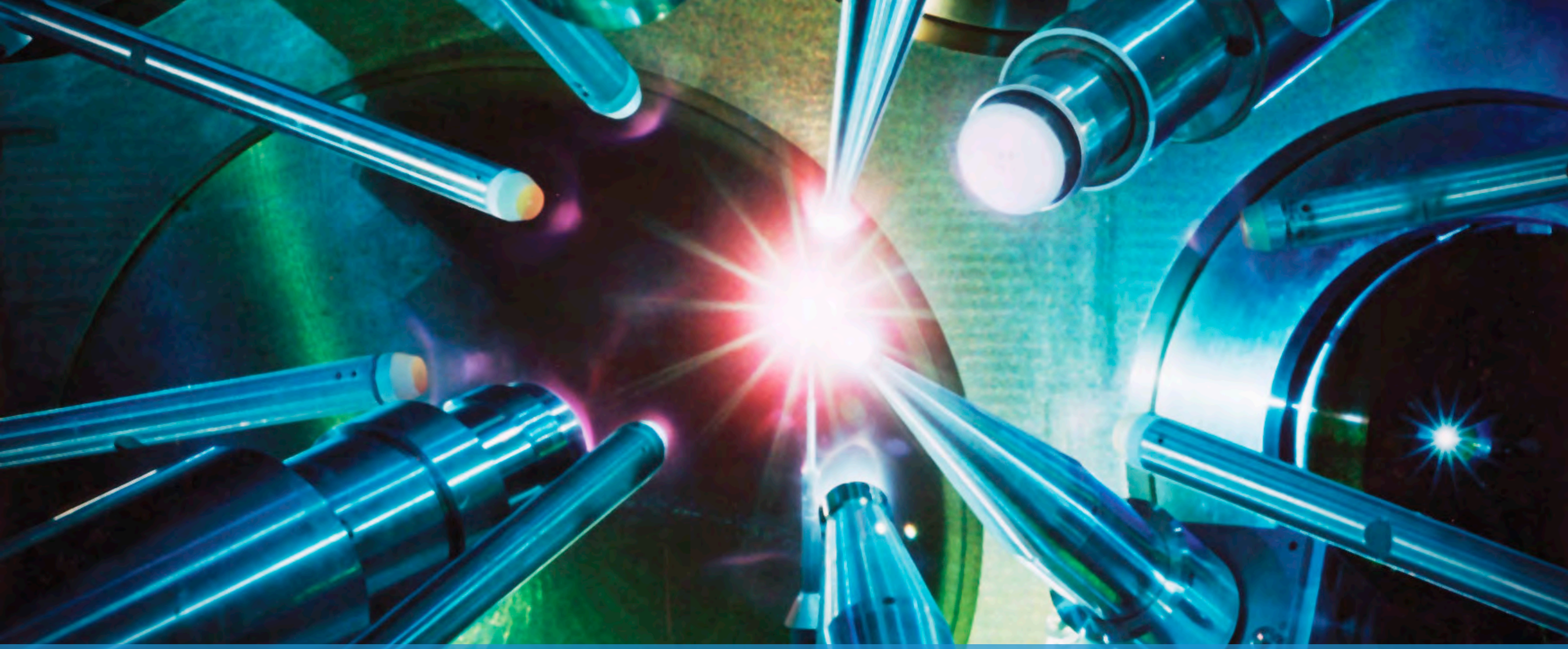
This year's technology transfer report highlights reasons why LLNL's tradition of innovation is stronger than ever—a place where innovation in action is thriving.

Lawrence Livermore National Laboratory (LLNL) is perched on the edge of California's Silicon Valley, making innovation a natural part of our efforts to advance science and technology. Entrepreneurs are close at hand, and innovation hubs are plentiful. The Lab's history of pursuing innovative solutions with commercial applications spans several decades. It is bolstered by an equally strong commitment to move inventions outside the Lab gates, where they can forge a brighter future for our nation.

In this report, we provide a glimpse of the entrepreneurial atmosphere at LLNL by sharing our most recent success stories involving technology transfer to commercial partners. For example, LLNL researchers developed next-generation high-power lasers capable of revolutionizing medicine and clean energy strategies. They are using the power of advanced manufacturing to create stronger, more adaptable materials. They are designing technology that offers the potential to double the current capacity of fiberoptic cables, and they are developing tools that can transform nanoelectronics.

Scientific discoveries made at LLNL are fueling economic growth as they are transferred to industry via license agreements or cooperative research and development agreements. Many of the discoveries that have been licensed to U.S. companies are aimed at solving healthcare challenges, from improved breast cancer screening, to development of personalized cancer vaccines, to new ways to detect pathogens in our food or screen for microbes that cause illness. LLNL-based innovations are also driving our nation's efforts to find clean energy solutions, such as smart sensor technology to aid in cleaner vehicle emissions.

While much progress has been made to facilitate transfer of LLNL inventions to the private sector, much work remains to be done. With this in mind, Lab experts actively engage with industry leaders and investors to identify new opportunities for collaboration. The Lab also invests in educating its entrepreneurs, offering a range of programs that help scientists refine their ideas, promote their discoveries to investors, and ensure that the invention achieves its full commercial potential.



Hot Technologies Transforming our World

As LLNL's multidisciplinary teams of scientists and engineers leverage our Lab's world-class research assets, they create a unique research and development environment. Thus, it's no surprise that our experts continue to develop innovative technology solutions that we expect to transform our world.

In this section of our report, we highlight some of the newest technologies developed at LLNL, including:

- A next-generation solution for high-power lasers that offers the potential to revolutionize fields ranging from medicine to clean energy.
- A faster path to develop cancer therapeutics that leverages LLNL's high performance computing resources to move through the pre-clinical phase of drug development in under 12 months.
- Carbon fibers produced via advanced manufacturing that offer the same level of performance as traditionally manufactured material, but with just one-third of the carbon fiber volume—offering new opportunities to manufacture materials with greater precision and design flexibility.
- A fiberoptic amplifier that can double the capacity of current fiberoptic cables, helping meet the growing demand to provide better and faster bandwidth to Internet users.
- A method of mapping the structural characteristics of carbon nanotubes, which will make it possible to transform the design of nanoelectronics, energy storage devices, and other items that rely on the ability to design hierarchical nanomaterials.

BUILDING NEXT-GENERATION HIGH-POWER LASERS

High-Repetition-Rate Advanced Petawatt Laser System (HAPLS)

Challenge:

Recognizing Livermore's preeminence in high-power laser technology, in 2013, the European scientific community engaged with the Laboratory to design and construct the world's first laser capable of generating 30 femtosecond (quadrillionth of a second) pulses with peak power of more than one petawatt (1 quadrillion watts, or 10^{15} watts) 10 times a second. Called the High-Repetition-Rate Advanced Petawatt Laser System (HAPLS), this machine will be a major resource for the European Union's Extreme Light Infrastructure (ELI) Beamlines facility, located in the Czech Republic. The system had to be capable of firing at 10 hertz with each pulse delivering 30 joules of energy in less than 30 femtoseconds for a peak power of 1 petawatt per shot. The system must also have low power consumption. While current laser systems require up to 2.2 megawatts of power, HAPLS operates at less than 150 kilowatts.

Collaboration:

For the Laboratory, the HAPLS project provided several opportunities, including the ability to participate in an international effort to deliver a cutting-edge laser for a flagship research facility. "This project allowed us to advance Livermore knowledge and expertise and push the frontiers of science and technology," says Constantin Haefner. Such knowledge can only serve to benefit the Laboratory and its missions. Haefner is optimistic the project will also help energize U.S. short-pulse and high-average-power laser research efforts. He notes that several nations in Europe and Asia are planning advanced high-repetition-rate lasers such as HAPLS because of their potential to revolutionize fields ranging from medicine to clean energy. He adds that a valuable aspect of HAPLS' design is its scalability.

As Livermore scientists help to integrate the laser system into the ELI Beamlines facility, Haefner and other Laboratory researchers are looking to develop the next generation of HAPLS-type lasers and advance several technologies originally developed for the laser system. Haefner says, "We want to continue to engineer technologies important to U.S. economic competitiveness, national security, and entirely new applications."

Solution:

HAPLS embraces a host of groundbreaking methods and technologies developed largely at Livermore, including arrays of laser diodes that replace less efficient and bulky flashlamps; advanced gratings for compressing high-peak-power and high-average-power laser light without damaging optics; automated control systems to continuously monitor components, minimized need for human intervention; and advanced optics and optical coatings. The system also uses a Livermore-developed helium-gas cooling method for laser amplifier components. Together, these advances contributed to making HAPLS the most compact petawatt laser ever built.

HAPLS also features an automated, integrated control system, similar to the one operating at NIF. The control system features multiple ultrafast diagnostics that continuously monitor the health of the laser. The sophisticated control system has a high level of automation including an auto-alignment capability and immediately stops the laser if any component is out of specification. The system's high level of automation is largely responsible for allowing the laser to be operated by as few as two people, which meets an operational requirement.

In addition, adaptive optics help produce a high-quality beam a few micrometers in diameter, which when focused on a target will eventually enable HAPLS to generate intensities of 10^{23} watts per square centimeter. These optics correct for any distortions in the laser beam and allow users to shape experiment-specific intensity distributions.

Impact:

The Livermore-designed High-Repetition-Rate Advanced Petawatt Laser System (HAPLS) will be a key component of the European Union's Extreme Light Infrastructure (ELI) Beamlines facility, which was built for the international scientific user community to study laser-matter interactions. Coordinated by the Czech Republic's Institute of Physics, Academy of Sciences, ELI Beamlines is the largest scientific project in that country. Construction of the facility began in October 2012 and was completed in early 2017, although key systems are still being installed. The first experiments are scheduled for spring 2018.

Although ELI Beamlines will house at least two other lasers, HAPLS is expected to be the "workhorse" laser and will be known as the L3 laser system. The facility will include seven experimental chambers located in the basement, including a large experimental chamber dedicated to academic research of laser plasma. Scientists will be able to direct the output from any laser to whichever experimental chamber is needed.

A FASTER PATH TO CANCER TREATMENT

Accelerating Therapeutics for Opportunities in Medicine (ATOM)

Challenge:

Cancer is the second leading cause of death in the United States and has been for decades. To decrease the burden associated with cancer, research has focused on understanding this disease. This focus has resulted in a 25% decrease in cancer mortality in the U.S. from 1991 to 2014.

Although a great achievement, there is still a lot of work to be done. Rare cancers are on the rise and require new and innovative approaches to solving the cancer puzzle. Furthermore, the current process for creating new cancer therapeutics takes approximately 10 to 15 years and costs billions of dollars. The extreme costs and lengthy timelines cannot address the new and rare cancers that are emerging. To progress cancer therapeutics, a recent initiative was put in place: The National Cancer Moonshot Initiative. The initiative calls for innovative approaches to developing cancer therapeutics.

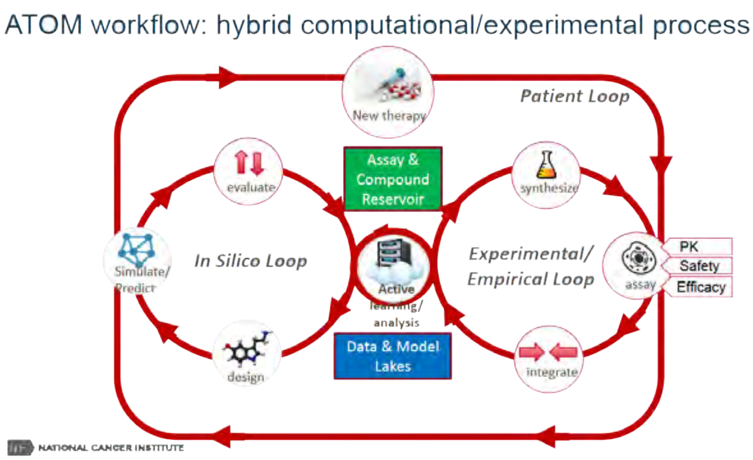
Collaboration:

In order to harness high performance computing and data science to accelerate the discovery and development process of disease therapeutics, LLNL was invited to take part in the National Cancer Moonshot Initiative, leveraging the Lab's supercomputing expertise.

The initial partners are LLNL, GlaxoSmithKline LLC (GSK), Leidos Biomedical Research, Inc. under its National Cancer Institute (NCI) operations contract for the Frederick National Laboratory for Cancer Research (FNLCR), and the University of California- San Francisco (UCSF). Each party is actively engaged in this collaborative consortium and brings its unique expertise. GSK is a large pharmaceutical company with a strong cancer product pipeline, FNLCR is a national resource for cancer information and research, and UCSF is a world-class academic medical center with expertise in cancer biology and drug discovery. The collaboration intends to engage new members, further diversifying the expertise and allowing for faster progression of cancer therapeutics.

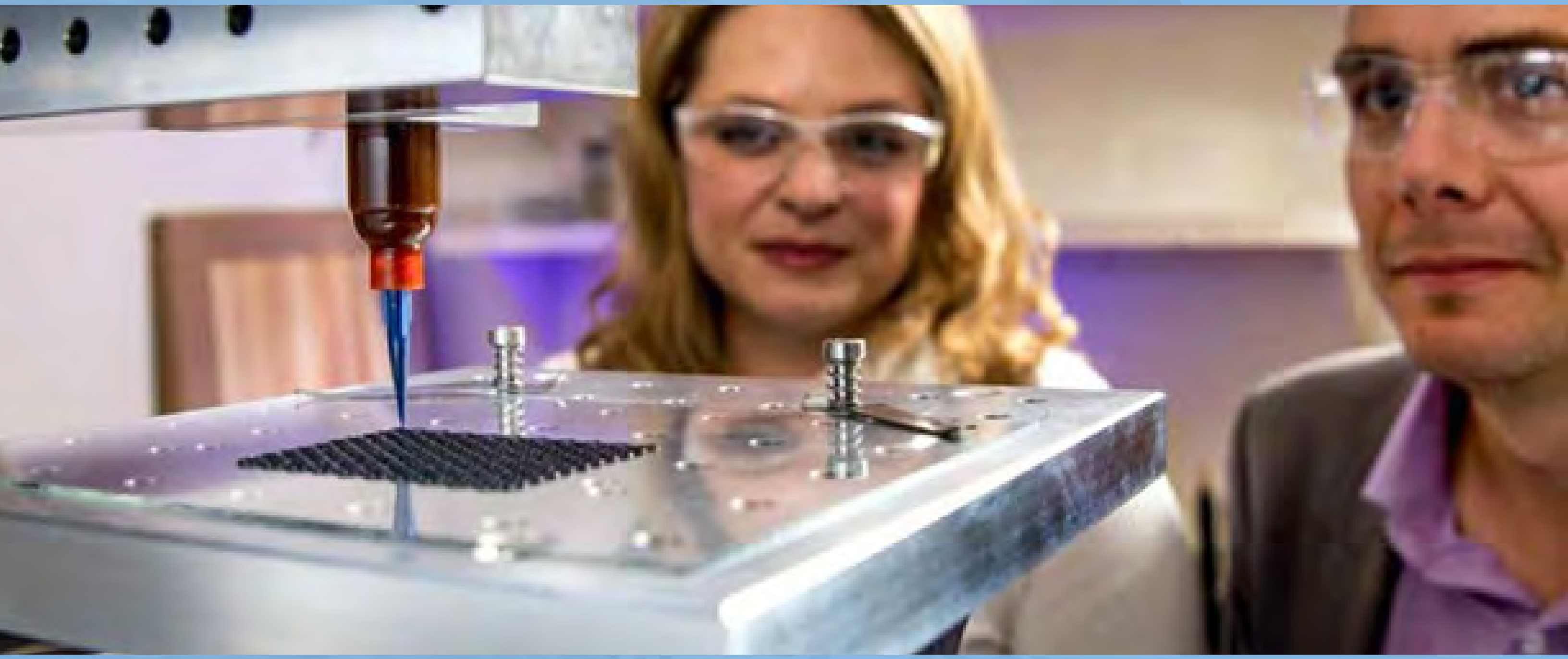
Solution:

LLNL's High-Performance Computing (HPC) resources store and process large amounts of data at a tremendously efficient rate. While the HPC is processing data (the in silico loop), collaborative research will take place (the empirical loop), providing more data to the HPC. These processes will be simultaneous and iterative with the hope of providing more accurate results for potential drug candidates for Phase I trials. By combining the expertise of current and, potentially, new collaborators, new and innovative cancer therapeutics may be possible.



Impact:

By harnessing the potential of HPC and biological data, the goal of the consortium is to reduce the time it takes to move from a selected biological disease target to a regulatory filing to initiate first human trials in under 12 months. This initial pre-clinical phase of drug development currently takes approximately 3 to 6 years, or nearly a third of the time it takes to produce an FDA-approved therapeutic. This decrease in time to market would fundamentally transform the treatment landscape for cancer and has the potential to reduce the burden of cancer in the United States and around the world. The collaboration will enable DOE to enhance its capabilities in high-performance computing, machine learning, and analytics in a new and challenging area that contributes to long-term mission needs.



ENGINEERING STRONGER MATERIALS AT THE MICROSCALE

Carbon Fiber Advanced Manufacturing

Challenge:

Carbon fiber composites have become the material of choice for many applications in aerospace, transportation, defense, and energy storage because they are stronger than steel, yet lightweight as plastic, and because they are electrically conductive and highly temperature resistant. The heterogeneous nature of these mixtures of carbon fibers and resin allows for greater customization of structure and properties than with more homogenous materials, such as steel. However, the materials also pose significant manufacturing challenges.

Use of additive manufacturing's 3D printing could eliminate many manufacturing concerns. By depositing a material layer-by-layer in a precise sequence specified in a computer file, AM enables greater precision, design flexibility, and repeatability than conventional manufacturing techniques. Plastic and metal AM technologies are well established, but printing carbon fiber composites is a tangle that scientists and engineers have only begun to unravel over the past few years.

Carbon fiber composites are made of fibers just 5 to 10 micrometers in diameter, set in a polymer matrix known as a resin. The carbon fibers provide most of the material's strength and other performance characteristics. The resin binds the fibers together to prevent buckling, but also represents one of the biggest obstacles to three-dimensional (3D) printing of high-performance parts using direct ink writing (DIW). DIW is a high-speed, low-cost additive manufacturing (AM) technique in which "ink"—a material in liquid form—is extruded through a tiny nozzle and onto a platform that is moved to deposit the ink where needed to build up the desired object, layer by layer, in three dimensions. With DIW, manufacturers can print a wider variety of structures, geometries, and patterns than with conventional approaches, but existing DIW resins are not strong enough for high-performance applications such as aerospace. In addition, most high-performance resins are not suitable in another important regard—curing time. Conventional resins can take hours or days to harden, while the DIW process requires a resin that can hold its shape as the component is built up. Furthermore, most conventional composites would clog the nozzle of a DIW printer rather than extrude smoothly and continuously.

Use of additive manufacturing's 3D printing could eliminate many of these manufacturing concerns. By depositing a material layer-by-layer in a precise sequence specified in a computer file, AM enables greater precision, design flexibility, and repeatability than conventional manufacturing techniques. Plastic and metal AM technologies are well established, but printing carbon fiber composites is a tangle that scientists and engineers have only begun to unravel over the past few years.

Solution:

With no commercially available resin to meet their needs, the LLNL research team created a resin specifically for high-performance component printing—one that gels in 5 seconds or less, fully cures with heat in 10 minutes, and offers flow characteristics suitable for AM. A low-volume of high-surface-area silica nanoparticles yields an optimal resin consistency and allows the carbon fibers to orient themselves in the direction of the flow as they are squeezed through the nozzle, preventing clogging.

The resin formula is as much a product of computer simulation as of innovative chemistry. In developing the resin, the team's computational experts used LLNL supercomputers to model the flow of carbon fibers through the ink nozzle at several scales. Simulation results both validated and explained what was observed experimentally—that with the right ingredients in the right ratio and the right nozzle size and shape, the resin can efficiently deliver carbon fibers without clogging the printer.

Because no existing composite-design algorithms could satisfactorily optimize performance, the team has been writing their own, building on team and institutional expertise in multiscale material modeling and systems optimization.

Computational optimization is an essential step toward making carbon fiber 3D printing predictable, repeatable, and highly customizable. Although still in its infancy, this effort aims to integrate process modeling and computational optimization with in-house tool-path planning algorithms, for a workflow of robust, computationally aided design, development, and manufacturing. The tool-path planning currently under way will assess a part's optimized design, confirm that the design is printable, and then translate the design parameters into instructions that the 3D printer understands. To this end, the team continues to investigate the structure and properties of the composite ink when used in DIW manufacturing. Characterization and modeling aim to better understand and control the properties and performance of the resulting AM structures.

Impact:

Standard mold-based manufacturing methods, and even some other DIW formulations, produce parts with a more random fiber distribution and alignment than available through LLNL's approach. With fibers that are more consistently aligned in the flow direction, LLNL parts have superior mechanical properties compared to those with the same density of fibers produced by other methods.

By gradually increasing the volume of carbon fiber in their formula, the team can now create parts with the same level of performance as traditionally manufactured parts, but with just one-third the carbon fiber volume that would be required by other carbon fiber composites. With enhanced design flexibility, manufacturing repeatability, and part performance, AM technology is expected to spur wider adoption of the team's versatile carbon composite.

BOOSTING THE CAPACITY OF THE INTERNET

Amplifiers for Fiber Optic Cables

Challenge:

More than 3.4 billion people are connected to the Internet, placing an ever-increasing demand on the telecom industry to provide bigger, better, and faster bandwidth to users. Most Internet data travel on fiberoptic cables, which are made up of bundles of glass threads that transmit laser light. However, as the fiber gets longer, power is lost due to attenuation.

In the late 1980s and early '90s, researchers discovered that they could mitigate this loss by developing inline fiber-optic amplifiers. At the time, lasers operated at a wavelength of 1.3 microns, or 1,300 nanometers (nm). However, no optical amplifiers were developed that worked well in that region. Researchers were able to develop an amplifier at 1.55 microns, or 1,550 nm, so laser transmission systems were switched to match.

At the same time, researchers discovered that inline optical amplifiers allowed them to amplify many different lasers at one time, a discovery that increased the information-carrying capacity of a single optical fiber from 155 megabits per second to more than one terabit per second. While this was a huge increase, it is still not enough information, requiring many cables to transmit the amount of data needed.

Collaboration:

LLNL researchers have taken an important step in addressing this need by developing a new type of optical fiber amplifier that could potentially double the information-carrying capacity of fiberoptic cables. The new optical fiber amplifier technology was initially demonstrated through a project funded by LLNL's Innovation Development Fund (IDF). The IDF is a mechanism to fund the advancement of technology and intellectual property developed by LLNL employees, enhancing the likelihood of transferring Lab-developed technologies to industry.

After this successful demonstration, the technology through the IDF-funded project, the new optical fiber amplifier technology is now being offered to interested telecommunications network providers and component manufacturers looking to partner with the Lab through Cooperative Research and Development Agreements (CRADAs) and licenses.

Solution:

LLNL researchers are the first to successfully develop a practical fiberoptic amplifier that generates significant optical gain from 1,390 nm to 1,460 nm with relatively good efficiency. This discovery enables the potential for installed optical fibers to operate in an untapped spectral region known as the E-band, in addition to the C- and L-bands where they currently operate—effectively doubling a single optical fiber's information-carrying potential.

LLNL's new amplifier design is based on a novel Neodymium-doped micro-structured optical fiber that is tailored to preferentially enhance optical signal gain in the E-band, while effectively suppressing competing gain in other spectral bands. The new amplifier design is built around the same architecture as current conventional erbium-doped fiber amplifiers, which are already widely deployed. Instead of having to lay more cable, these new amplifiers could be installed in the same buildings as the current amplifiers, resulting in twice as much bandwidth on current cables.

Impact:

More and more Internet-connected devices are going mobile, driven by exploding demand for smart phones and tablets with universal connectivity. As current global smart phone usage crosses the billion-user mark, access to mobile communications including video, cloud-based services, and internet connectivity has never been more important. All these devices are networked and drive significant traffic to the broadband network, stimulating the need for more optical bandwidth. According to WinterGreen Research, the global market for optical amplifiers is anticipated to reach $2.8 billion by 2019.

BUILDING BLOCKS FOR NEW MATERIALS

Mapping the Structure of Carbon Nanotubes

Challenge:

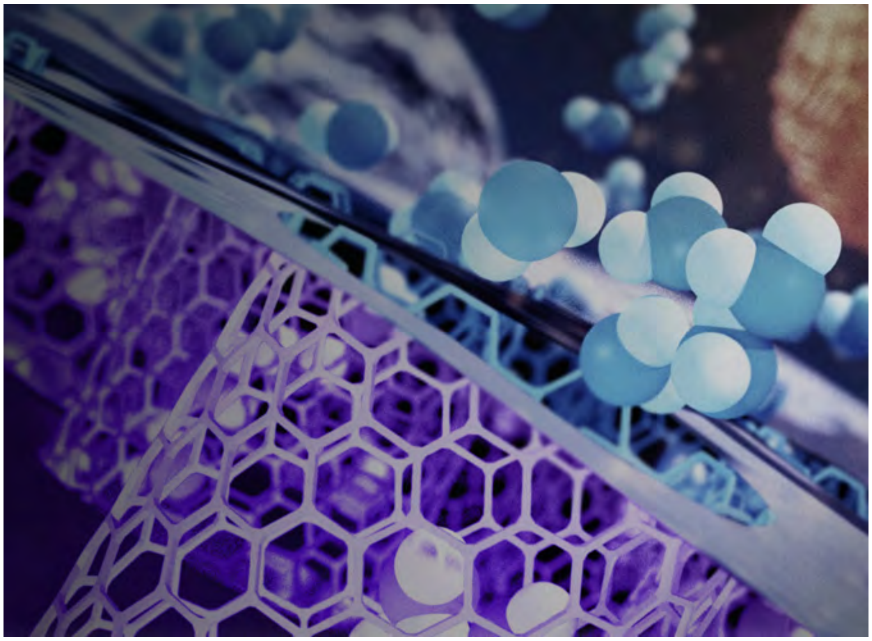
Complex hierarchical structures made from synthetic nanocarbon allotropes, such as nanotubes and graphene, promise to transform countless applications in structural composites, nanoelectronics, energy storage, filtration, and separation. Just as the arrangement of atoms and defects at the scale of angstroms are known to govern a material's properties, the order and alignment of larger nanoscale building blocks also influence the material's performance. A lack of comprehensive, multiscale structural characterization has been a crucial bottleneck to progress in application-targeted synthesis of hierarchical nanomaterials.

Collaboration:

For this work, the LLNL research team leveraged a collaboration with the Advanced Light Source (ALS) and the Molecular Foundry. "We would like to see more of this type of cross-pollination between DOE facilities so that our users can fully exploit cutting-edge structural characterization at the ALS to inform nanostructure synthesis," said Teyve Kuykendall, a principal scientific engineer at the Molecular Foundry.

Solution:

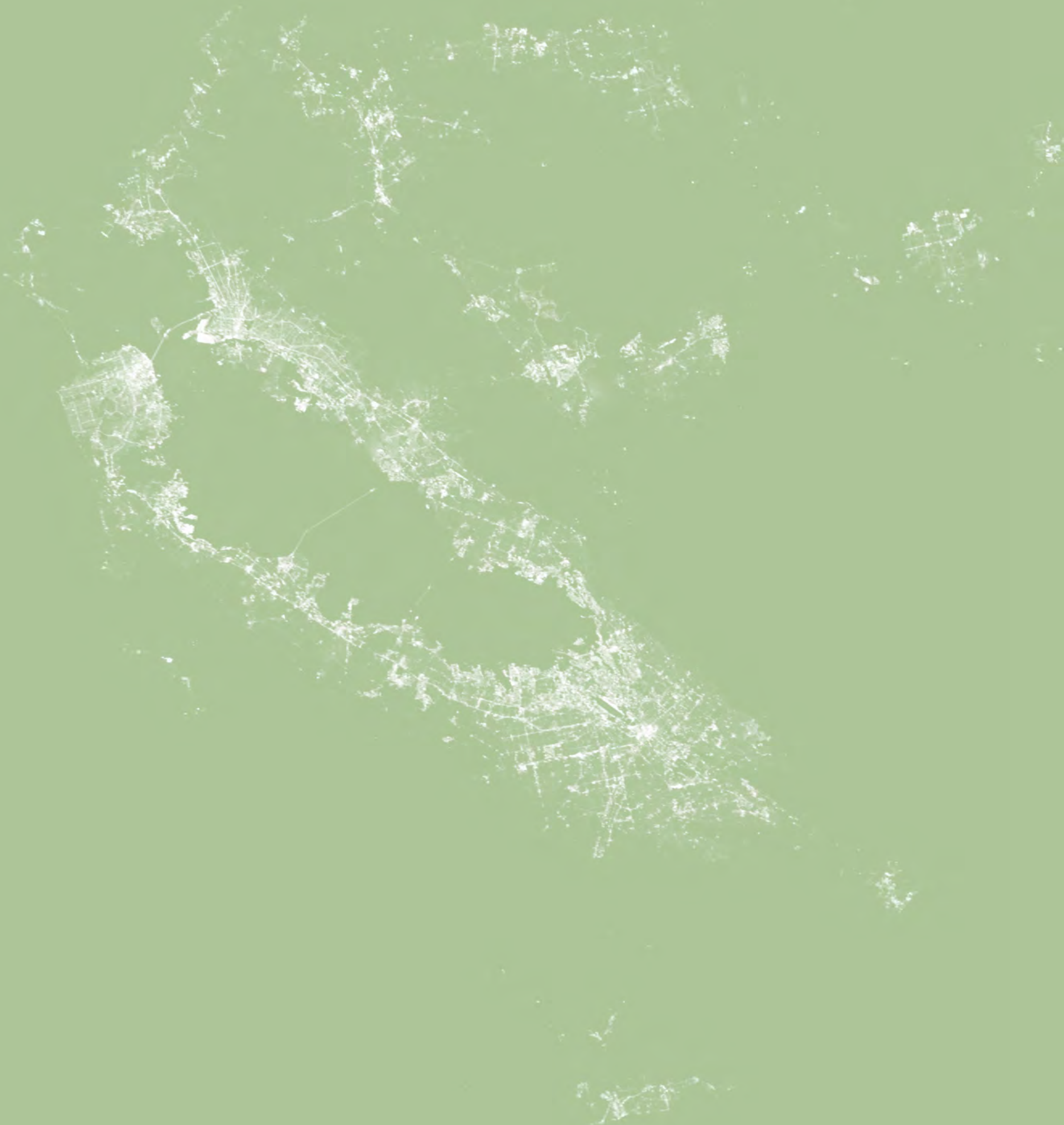
LLNL scientists have published the hierarchical structure of self-organized carbon nanotube materials from the atomic to micrometer scale. It is the first continuous map of the nanotube ensemble structural order across four orders of magnitude in length scale using a single technique—synchrotron X-ray scattering. The correlations revealed that the packing density of nanotubes influences alignment at every length scale, and that the carbon nanotube materials may form corrugations with high microscale order, despite having low nanoscale order.

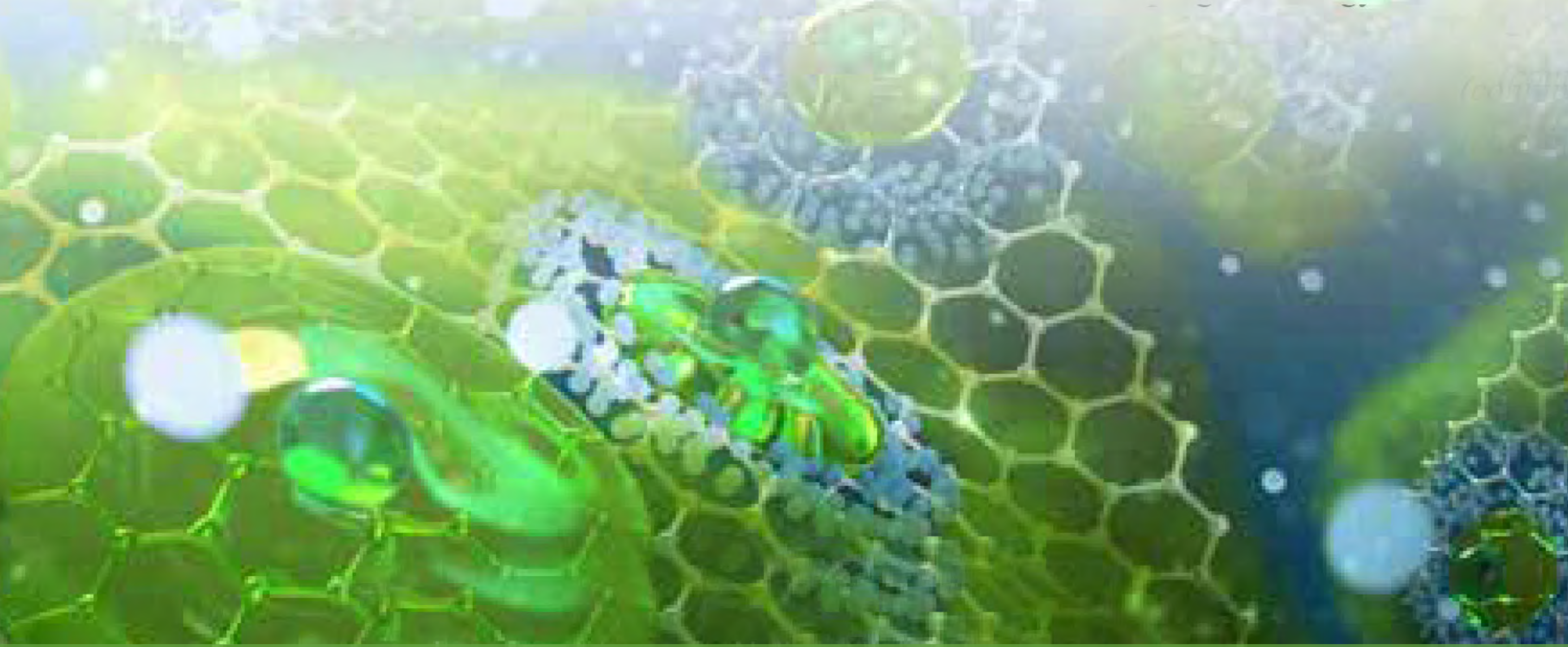


Francesco Fornasiero and his research team at LLNL are leveraging the carbon nanotube data to evaluate membranes that can be used to develop a flexible membrane (purple) with carbon nanotube openings that are 5,000 times smaller than the width of a human hair. With the ability to allow water molecules (white and blue) to pass through while keeping out larger molecules, viruses, and bacteria, materials made with this membrane can provide soldiers and first responders with breathable clothing that also allows them to work safely, for longer periods, in environments where chemical and biological agents are present.

Impact:

This multiscale array of information is significant for establishing structure-performance relationships toward application-oriented design and manufacturing. For example, the LLNL team uses this carbon nanotube data to evaluate membranes with the goal of building breathable garments that protect against biological threats. According to LLNL scientist Francesco Fornasiero, structural characteristics like pore size distribution, pore density, and tortuosity dictate membrane transport performance and can be quantified easily with X-ray methods.





Partnering to Boost Economic Development

Through business and community partnerships, the innovative solutions developed at LLNL are driving economic growth locally, regionally, and beyond. We are eager to invest in scientific discoveries that can be transferred to industry, launching new businesses and stimulating commercial activity, while addressing some of our nation's most pressing problems.

In this section, we feature new partnerships and agreements to commercialize technology developed at LLNL. These collaborative efforts include:

- Opcondys, Inc., a local start-up company with exclusive patent rights to the opticondistor, a revolutionary power-switching device that will provide more efficient control of electrical energy.
- POC Medical Systems, Inc., with patent rights to MammoAlert™, a portable breast cancer screening test that can detect cancer biomarkers from a drop of blood using advanced microfluidics—bringing breast cancer screening to places where established screening methods are not widely accessible.
- Bionomics Diagnostics Inc., a wholly-owned subsidiary of LexaGene Holdings Inc., a biotechnology company that develops instrumentation for pathogen detection, and is using technology developed at LLNL to screen food samples for pathogenic organisms.
- EmiSense Technologies, a company with patent rights to sensor technology developed for the automotive market, which will enable EmiSense to develop smart sensors for clean emissions.
- Applied Biosystems, who licensed technology known as Lawrence Livermore Microbial Detection Array (LLMDA), which uses DNA probes to screen for microbes that can potentially cause illness.
- EVOQ Therapeutics will leverage an exclusive license to nanolipoprotein particles technology as the company develops peptide-based, personalized cancer vaccines.

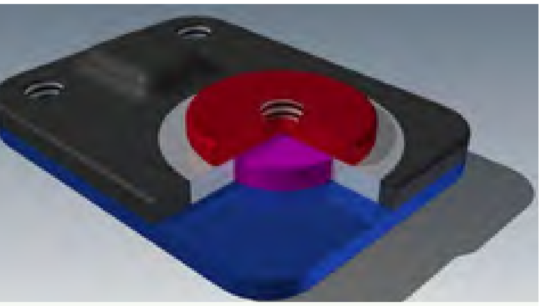
REGIONAL PARTNERSHIPS

Opcondys and Opticondistor Technology

Opcondys, Inc. is an early-stage start-up based in Manteca, California, whose mission is to develop and manufacture the opticondistor, a revolutionary high voltage power-switching device. Stephen Sampayan, Chief Technical Officer, invented the opticondistor at LLNL. Opcondys has secured exclusive patent rights to the opticondistor from LLNL in the field of power electronics.

The opticondistor enables smaller, more cost-effective and energy-efficient high voltage equipment than is possible with existing power electronic devices. Opcondys will provide products to manufacturers of food sanitization and cancer treatment systems, radar and other military equipment, renewable energy inverters, grid-tied energy storage systems, and electric power transmission and distribution gear.

Opcondys has successfully completed a proof-of-concept demonstration under the first phase of a National Science Foundation (NSF) Small Business Innovation Research Grant (SBIR). Opcondys is now developing a prototype and has applied for the second phase of the NSF SBIR grant to support the two-year prototype development effort.



The Opcondys prototype illustrated here promises to provide high-speed optical switching for energy storage systems connected directly to the power grid.

Recently, Opcondys received $3M from ARPA-E's CIRCUITS (Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors) program to develop a high voltage (800 VDC to 14.5 kVAC), 60 kW power converter design for energy storage systems connected directly to the power grid. The team seeks to achieve significant efficiency gains over existing systems while also dramatically reducing the system size and cost. The converter will rely on a high-speed, optically switched, SiC-based power electronics device to produce extremely high-efficiencies of 99% while eliminating complexity. If successful, project developments could open the door to increased integration of grid-level energy storage at much lower cost.

Opcondys' first product will be delivered to customers in 2019. They are raising seed funding from private investors to prepare for production. Opcondys' vision is to see the opticondistor adopted worldwide as the next generation in power-switching devices.

POC Medical Systems

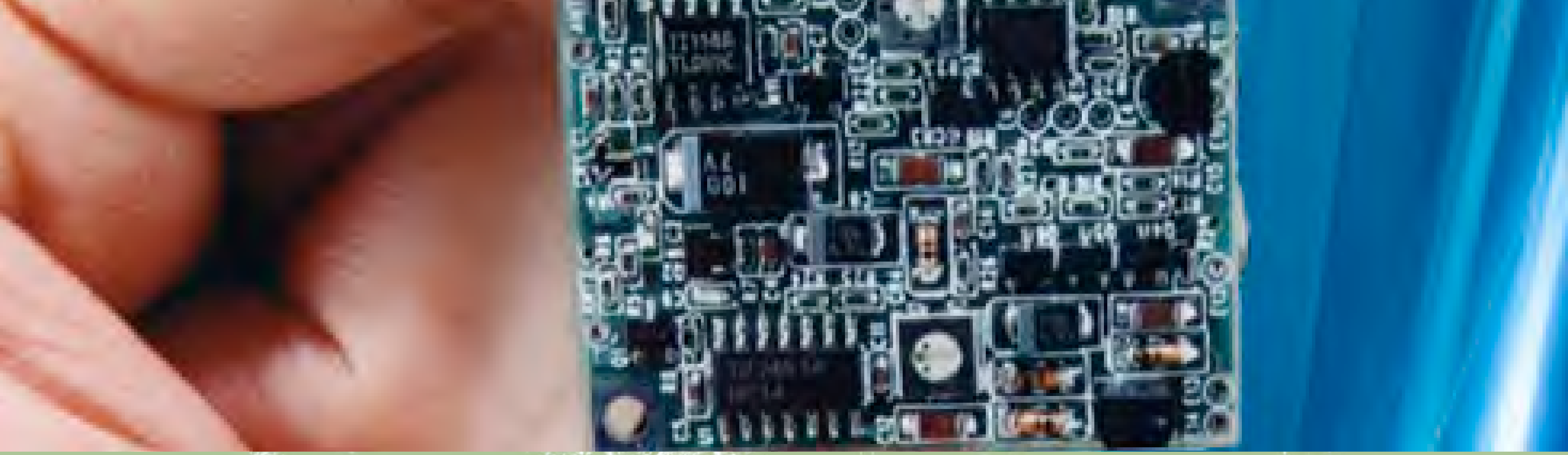
POC Medical Systems Inc. recently raised $21 million in Series A funding for clinical beta testing and initial commercialization of a rapid, portable breast cancer screening test, known as MammoAlert™, which is based on technology developed at LLNL. The blood-based test is designed to enable breast cancer screening in regions of the world where established screening methods are not widely accessible to large populations of women. The initial test of the technology will take place in India, and will be the first application of the company's Pandora CDx™ Microfluidics-based platform.

The MammoAlert™ test generates a result in 15 minutes. The test employs a mobile device like a tablet that stores the data securely in the cloud, where it can be shared remotely with doctors and healthcare systems. The test detects multiple cancer biomarkers from a drop of blood using advanced CD microfluidics based on a low-cost microfluidic disk, and then applies sophisticated algorithms to produce a result.

POC Medical Systems, which was incubated at i-Gate in Livermore, California, was founded by entrepreneur Sanjeev Saxena, and has as its mission to make cancer and infectious disease screening accessible and affordable on a worldwide basis. The company's technology platform resolves two key issues in modern medical diagnostics: geographic inaccessibility and cost prohibition. POC's goal with the technology platform is to help save millions of lives through early stage screening and detection, and in turn, significantly reduce medical treatment costs.

The company has secured exclusive patent rights to device, array, and methods for disease detection and analysis from LLNL in the field of diagnostics and screening of various human diseases, including cardiac, cancer, neurological and infectious diseases..

The Pandora CDx™ promises to provide early stage screening and detection for breast cancer.



LICENSING HIGHLIGHTS

LexaGene and Pathogen Detection

LexaGene Holdings Inc., a biotechnology company that develops instrumentation for pathogen detection, announced that the technology for its automated pathogen detection instrument has been successfully de-risked through a series of tests that looked at each of the instrument's critical functions.

The company recently unveiled the pre-alpha prototype at the International Association for Food Protection annual meeting. LexaGene believes that the technology is particularly well-suited to benefit this industry, as the technology offers several features that have been long-sought-after by many in the food safety industry. LexaGene's technology is anticipated to be the first that is capable of processing large volumes of samples and can screen for indicator species and pathogenic organisms at the same time. Furthermore, the technology does not require a licensed technician to operate; anyone from a farmhand to a PhD will be able to test a sample and get quick, accurate results.

The LexaGene prototype promises to provide fast, accurate screening for pathogenic organisms when operated by anyone from a farmhand to a PhD scientist.

The industry is in dire need of a pathogen detection instrument that is not only highly effective and sensitive, but also easy-to-use and adaptable. LexaGene's technology will require as little as one hour of wait time to get results, compared to standard food safety tests that take up to five days, allowing food producers to make quick decisions regarding the safety of their products.

The food industry in the U.S. loses $55.5 billion each year due to safety issues. Additionally, the average cost of a recall to a food company is $10 million in direct costs, not including brand damage and lost sales. Overall, each year, there are 2.6 billion tests conducted and 626 food recalls.

LexaGene's next milestone is to complete the alpha prototype and then finish testing the prototype by November 2017 in order to verify that it meets specifications.

LexaGene has secured exclusive patent rights to diagnostic kiosk for food safety, water quality monitoring, and human/veterinary clinical diagnostics from LLNL in the field of environmental surveillance, food testing, and human clinical diagnostics.

EmiSense Technologies and a New Generation of Emissions Sensors

In 2009, EmiSense Technologies was formed from the combined assets of Coorstek and Innovate! Technology, and began exploring sensors for the automotive market. The company aimed to develop smart sensors for clean emissions, recognizing that clean combustion could be the most impactful form of clean technology in the next decade. In 2014, Coorstek acquired Emisense in full.

The company has developed several automotive sensors, including a simplified NOx (oxides of nitrogen) sensor. Clean combustion demand, including both on-road and off-road diesel and turbo-gasoline applications, are the company's major near-term drivers for smart sensors.

"The trends towards downsizing and turbo-charging will continue, regardless of geography or fuel stock," concluded Patrick Thompson, CEO of EmiSense. "These trends require smarter sensors to maximize efficiency while minimizing emissions." gasoline direct ignition (GDI) and homogeneous charge compression ignition (HCCI) applications are also expected to benefit from sensing technology breakthroughs.

EmiSense products are critical enablers for next-generation ultra-efficient engines—helping address the problems of fossil-fuel dependence and climate change. Clean combustion is the most impactful form of clean technology in the next decade.

EmiSense became interested in the innovations developed and protected by LLNL and began a collaboration with the Lab to bring the early stage innovations to market via a CRADA agreement. The company also obtained exclusive patent rights to sensor technology for combustion engines, boilers and burners from LLNL.

Cross section of prototype NOx sensor, which will enable engine makers to maximize fuel efficiency and minimize emissions.

Applied Biosystems and Microbial Detection Array (LLMDA) Technology

We live in a microbial universe. Every substance we breathe, swallow, and touch exposes us to microbes (bacteria, viruses, fungi, archaea, and protozoa). Everything we encounter, including other people, is a carrier and/or host to microbes. Over 12,000 microbes have now been sequenced, and nearly 1,000 of them are known to cause illness in humans, while many others infect animals and plants.

In an effort to more effectively identify the presence of microbes, a team of LLNL researchers developed the Lawrence Livermore Microbial Detection Array (LLMDA), which contains 1.4 million DNA probes—short pieces of microbial genomes selected by advanced bioinformatics software to be discriminating at genus, species, and strain taxonomic levels. The array can efficiently screen for all sequenced microbes from any sample of clinical, environmental, and manufactured products.

Since 2008, LLNL has been testing early versions of the array, which used traditional glass slides, as part of more than 40 collaborative efforts. These earlier arrays were limited to 1-12 samples per array, and were far less cost-effective than the new 96-sample version. However, the early versions demonstrated that the pan-microbial array technology works to discover known (i.e., already sequenced) and suspected causative pathogens in a wide range of clinical samples (including blood, urine, feces, sputum, cerebral-spinal fluid, and a variety of tissues) from human, primate, swine, sea mammal, and other hosts. The precursor array was also used to detect microbial contaminants in vaccines and biological products. In addition, it was used to conduct environmental analyses of air, soil, and water samples, as well as samples collected from the International Space Station.

The LLMDA detects consequential microbes for health, agriculture, food, product, and environmental safety.

Any microbial-screening application can benefit from the low cost, high-throughput, enhanced resolution offered by the latest version of the detection array, which is now commercially available. LLMDA technology was licensed to Applied Biosystems (now part of Thermo Fisher Scientific), which developed a commercial product known as the Axiom™ Microbiome Array.

Microarrays can be more efficient than DNA sequencing at detecting the presence of known microbes because they are designed to look only for the definitive genomic regions of these microbes. Any samples that yield no definitive microbe results after the array screening may be selected as a candidate for a more expensive and time-consuming deep DNA-sequencing process to potentially discover a novel or engineered organism. The high-throughput Axiom™ format opens up new opportunities to examine consequential microbes for health, agriculture, food, product, and environmental safety.

EVOQ Therapeutics and Nanolipoprotein Particles

Over the past decade, an LLNL research team has been developing nanolipoprotein particles (NLPs), which hold great potential as platforms for drug and vaccine delivery, and other biotechnology applications.

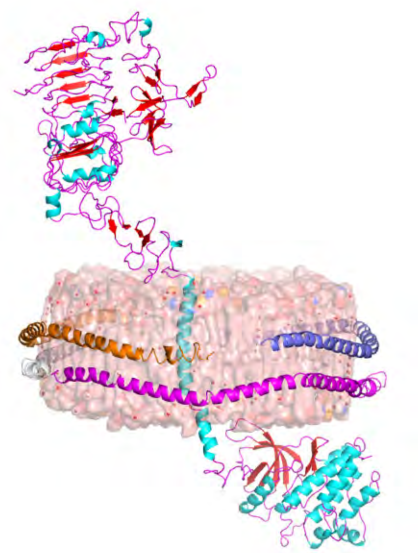
NLPs can offer distinct advantages over other membrane model systems in terms of particle size and solubility. The protein scaffold, along with the lipid bilayer composition, contributes to improved NLP thermal stability as compared with micelles or liposomes. The size and stability of NLPs is useful for a broad range of biotechnology applications, primarily involving the solubilization of functional membrane proteins. The NLP lipid bilayer features a hydrophobic core capable of accepting hydrophobic or amphiphilic molecules (i.e. drugs), as well as membrane proteins.

NLP formulations are useful as biological and small molecule drug delivery vehicles. NLPs also provide several advantages with in vivo drug delivery, including rapid cellular uptake, high biocompatibility and minimal toxicity, versatility in choice of lipids and scaffold proteins, and size flexibility by altering the molar ratios of lipids to scaffold proteins. In addition, the versatility of NLP synthesis to incorporate functionalized lipids greatly expands the range of biomolecules that can be chemically conjugated to the NLP bilayer surface, including peptides, proteins, oligonucleotides, and carbohydrates. Importantly, the flexibility in NLP design and fabrication provides a facile means of co-localizing antigens and immunogenic adjuvants for vaccine applications.

LLNL granted a license to NLP technology to EVOQ Therapeutics. EVOQ intends to leverage the potential of NLPs to serve as a vehicle for delivery of peptide-based, personalized cancer vaccines.

Peptide-based cancer vaccines have been extensively investigated due to their enhanced safety profiles and ease of manufacturing and quality control. However, their anti-tumor efficacy in clinical trials has been disappointing, a phenomenon attributed to inefficient co-delivery of antigenic peptides and adjuvants to draining lymph nodes.

Cancer cells express certain peptides, known as neoantigens, that are entirely absent from the normal human genome. Since neoantigens in cancer cells are unique to each patient, cancer vaccines based on neoantigen peptides (neoepitopes) require a personalized approach. With the development of deep-sequencing technologies, it is now possible to identify the mutations present within the protein-encoding part of the genome of an individual tumor, and thereby predict potential neoantigens. The frequency of mutations, which drives the formation of neoantigens, varies widely. Cancers with a high frequency of neoantigens are ideally suited for neoepitope-based cancer vaccines, and NLP technology offers the potential to serve as a delivery vehicle for these vaccines.



NLPs are analogous to high-density lipoproteins (HDLs), particles that are naturally involved in mammalian lipid metabolism. Multiple apolipoproteins encircle the periphery of the lipid bilayer to form a 'belt' or scaffolding, constraining the dimensions of the bilayer and helping to maintain particle diameters.

Investing in Innovation

Investing in innovators helps them discover ways to change our world through science and technology. With this in mind, we offer LLNL scientists and engineers a wide range of support, from coaching, mentoring and access to state-of-the-art research tools, to financial investments in their work.

In this section of our report, we share stories about those investments, and how they generated exciting results. Highlights include:

- Educational programs that help LLNL personnel learn entrepreneurial skills, analyze the commercial potential of their work, and understand how to share their ideas with potential investors and business partners.
- Investments aimed at helping scientists and engineers develop their innovative technologies to a stage that attracts private sector interest.
- Customer discovery initiatives that help LLNL innovators identify and connect with potential investors and business leaders able to provide market-based feedback and connections with industry partners who may be interested in commercializing the technology.
- Research and development awards that recognize top inventions by LLNL scientists and engineers.

EDUCATING ENTREPRENEURS

Entrepreneurship Academy

Each year, LLNL hosts a three-day entrepreneurship business training course specifically designed for Lab scientists and engineers (S&Es). The Entrepreneurship Academy is offered in partnership with Sandia National Laboratories and the University of California, Davis, Graduate School of Management.

The course covers content that is needed by national lab innovators, such as business models, value propositions, and customer discovery. They also learn how to communicate with the business world, becoming familiar with industry terminology and learning to rely less on technical language. The Academy also highlights the experiences of employees who left the labs and started companies that were successful or not so successful.

National Lab scientists and engineers attend the Entrepreneurship Academy hosted by LLNL.

Another objective of the Academy is to prepare S&Es for DOE-sponsored programs in entrepreneurship, such as the Energy I-Corps program, which focuses on how to be more effective in orienting their research toward eventual commercialization.

A dozen LLNL scientists and engineers attended the 2016 Entrepreneurship Academy, along with individuals from Sandia National Laboratories, Pacific Northwest National Laboratory, and the U.S. Department of Energy.

National Lab Accelerator Program

In FY2017, DOE asked national laboratories for ideas regarding how to expand on the success of the Energy I-Corps program. LLNL proposed a broader, more ambitious business education program, based the Entrepreneurship Academy model. DOE decided to expand LLNL's approach and offer all DOE laboratories a new, larger program, dubbed the National Laboratory Accelerator Program.

Participants in the Accelerator Program first attend the Entrepreneurship Academy. After this initial training, each budding entrepreneur pairs with an experienced non-Lab business mentor, who helps them further develop their initial concept. The next step in the Accelerator Program is for S&Es and their mentors to participate in Energy I-Corps or a similar program, where they can intensively study customer discovery, product-market fit, and business model development.

The most promising team from each of the 10 participating national laboratories will be invited to a "National Lab Shark Tank" in November 2017, which will be held near Silicon Valley in California. At this event, participants will pitch their technology to investors who are ready to offer seed funding to the right team

While attending DOE's Energy I-Corps Program, Ye's team conducted 100 interviews with prospective customers to discover how to adapt technology to business. After considering several applications that might benefit from reusable microcapsules that can rapidly absorb CO_2, including waste gasification, fertilizer production, and deep-water diving, they did not have to go far to find the next promising lead. The Energy I-Corps boot camp was held in Golden, Colorado, the home of Coors Brewing Company and part of the Denver metro area, which boasts more than 200 microbreweries.

Energy I-Corps Spotlight: Carbon Capture Technology

Sometimes a scientific breakthrough can occur in the most unexpected places. Congwang Ye, an LLNL engineer working with carbon capture microcapsule technology intended to use the technology for filtering CO_2 from power plants. However, he learned that his innovative technology could end up solving a big problem for craft beer makers.

When meeting with Coors and a local CO_2 supplier, Ye's team learned that during the fermentation process, breweries produce about three times the amount of CO_2 needed for carbonization and packaging. Furthermore, typically 80 percent of the cost of purchasing CO_2 comes in transporting the CO_2. If breweries could capture and reuse CO_2 using the microcapsules, they could be self-sustaining and sell the excess CO_2 to other nearby consumers.

With this information, the team initially decided to focus their attention on microbreweries, which generally cannot afford large commercial CO_2 reclamation systems, but produce enough carbon dioxide to make an impact. The breweries were interested, but they did not like the idea of a large, monolithic system.

The team then presented a propane tank model, a less complex CO_2 capturing system that uses barrels filled with millions of microcapsules that absorb CO_2 from the fermentation gas. In theory, the team's company—with a working name of MECS (Micro-Encapsulated CO_2 Sorbent)—would provide the equipment at no cost up front. The brewers would collect CO_2 gas from the fermenters, fill the tanks, and MECS would send trucks to pick up the full tanks. The captured CO_2 would be reclaimed at a centralized hub and sold back to brewers at a significant discount. MECS would keep the surplus and sell it on the open commodities market. The idea could potentially save microbreweries tens of thousands of dollars a year.

LLNL has has been an important partner in the DOE Energy I-Corps since its inception in 2014. The majority of the six LLNL teams that have participated received follow-on research funding as a direct result of the customer discovery performed during Energy I-Corps.

TECHNOLOGY TRANSFER PROGRAMS

Technology Commercialization Fund

During FY2017, two LLNL innovators were able to expand their work to develop promising energy technologies, thanks to funding they received from the DOE Technology Commercialization Fund (TCF).

LLNL engineer Brian Guidry, one of the first recipients of an award from DOE's Technology Commercialization Fund, examines innovative cryo-compressed hydrogen tank technology.

LLNL engineer Brian Guidry received funding for his cryo-compressed hydrogen tank technology, an advanced fuel system that uses hydrogen instead of fossil fuels in a combustion engine. The project's industrial partner, GoTek Energy, provides matching funds to help Guidry and his team create a prototype system.

LLNL material scientist Jeff Haslam and his team also received a TCF award for FY17, enabling them to continue work on their fire- and water-resistant ceramic pre-filter system, designed to protect HEPA filters in radiological facilities. Funds will help the team refine the system's design and develop a prototype to attract industry investors.

During the Office's second funding cycle, six LLNL teams received TCF funding. They are eager to expand their work on their innovative technologies, which include upgrading bio-gas to commercial-grade methane, using non-destructive means to test for water entry into solar panels, extracting rare earth elements using innovative biotechnology, producing thermoelectric generator materials through additive manufacturing, and exploring a novel approach to energy storage. One additional award will support work on a smart grid simulator tool with a commercial partner.

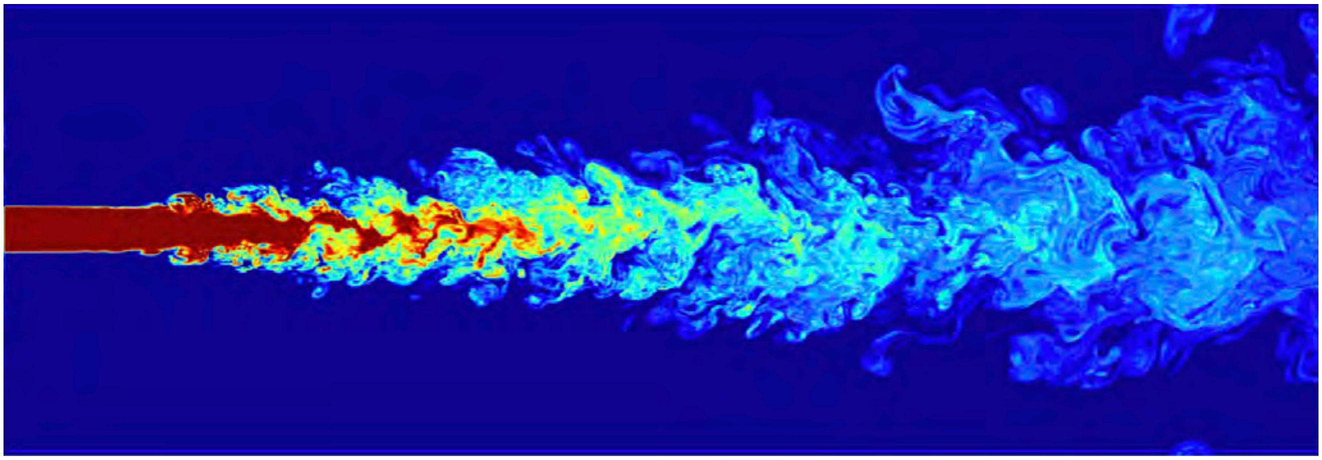
The Lab's TCF awards highlight the growing commercial interest in technologies created at LLNL. TCF provides funding to mature a technology to the point where a commercialization partner would be interested in the technology, or to engage a commercialization partner in steps toward bringing a new commercial product to market.

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 or advancement of high performance computing to address manufacturing challenges. The program aims to optimize production processes, enhance product quality and speed up design and testing cycles, while decreasing energy consumption. LLNL leads the HPC4Mfg program, in partnership with Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory.

In 2017, DOE awarded $3.9M for 13 new HPC4Mfg projects. LLNL partnered on 6 of these projects to:

- Reduce defects in additively manufactured parts
- Improve powder bed formation in additively manufactured processes
- Develop new lightweight alloys
- Enable gasification technologies to reduce landfill waste and create renewable energy
- Develop a robust computational fluid dynamics (CFD) model to evaluate the performance of Allam Cycle combustors
- Develop a multiphase CFD model for turbulent bubbly flow in airlift bioreactors

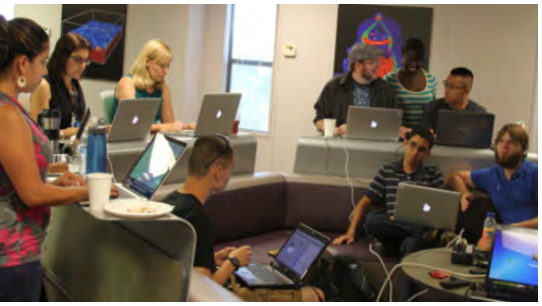


The Large Eddy Simulation Computational Fluid Dynamics simulation demonstrates how HPC elucidates turbulent flow in engine and mixer designs.

FOSTERING COLLABORATION

Open Resources Foster Collaboration

High Performance Computing Innovation Center



The HPC Innovation Center is a hub of collaborative activity, such as "hackathons" sponsored by the Lab's Computation Directorate to encourage collaborative programming and creative problem solving by employees and students at LLNL.

The High Performance Computing Innovation Center (HPCIC) provides LLNL's workforce with a more accessible venue to engage with partners on leading-edge, high-impact projects that align with the Lab's mission. Strategic partnerships boost the development of modeling and simulation, data analytics, and cyber programming models and methods that can then be applied to national security missions. In addition, public-private partnerships help drive the computer industry to develop new hardware and software with capabilities that benefit NNSA, DOE, and other government agencies.

Through enabling collaborative engagements, HPCIC can help companies increase their understanding of complex technologies and systems, accelerate their innovation processes, and expand the value they derive from their use of computing.

Advanced Manufacturing Lab

The reconfigurable layout at the Advanced Manufacturing Lab (AML) allows rapid response to dynamic mission requirements and sponsor needs. Its location at the Livermore Valley Open Campus (LVOC) enhances LLNL's ability to actively promote collaborative relations between NNSA laboratories, production plants, academia, and industry, providing mutual benefit to the Lab and its partners. NNSA is currently investing in advanced manufacturing initiatives that support the modernization of its manufacturing infrastructure, ultimately reducing time to product, decreasing manufacturing footprint, and minimizing waste.

LLNL anticipates that researchers will produce breakthroughs and lead development of innovative technologies that strengthen advanced manufacturing companies 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, including economic competitiveness.

Partnering agreements and new facilities offer expanded opportunities for LLNL to engage with external entities; maintain second-to-none science, technology, and engineering capabilities; and attract and retain the work-force needed for national security missions.

Partner Discovery

IN-PART: Connecting with Industry Leaders

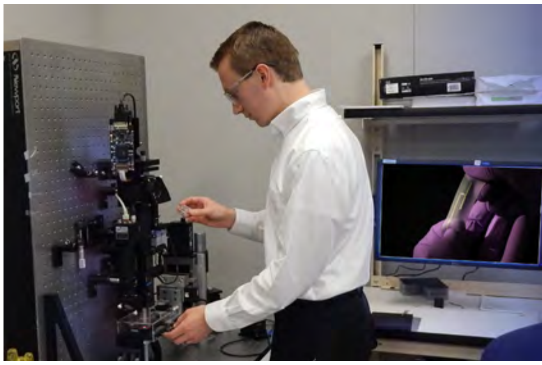
In FY2017, the LLNL Innovation and Partnerships Office (IPO) launched a pilot project with IN-PART, a matchmaking platform that provides access to a global network of research and development decision-makers who are ideally placed to commercialize the Lab's research and provide feedback regarding market viability. IN-PART connects researchers with innovative companies, providing viable leads for potential partnerships and technology licensees.

Since initiating the pilot project, LLNL has posted 86 technologies. IN-PART has already referred 16 company leaders who indicated an interest in LLNL's technologies.

Market Discovery Webinars: Connecting with Investors

LLNL's Technology and Market Discovery program presents webinars that introduce LLNL technologies to entrepreneurs and angel investors. The technologies and their capabilities are described, and attendees provide market-based feedback. Each webinar features a presentation followed by an interactive Q&A session with the audience. To date, LLNL has hosted more than 50 webinars, including the following webinars held in 2017:

- Saline Solutions: Better Water for Better Living
- Hydroscanner
- Cost-Effective Technology Pathways to a Low-Carbon Electric System: How to Efficiently Eliminate Fossil Fuels
- From Power Plants to Breweries: Lab-Corps Story of Team MECS
- Bio ID: A Rapid and Portable System for Microbial Identification
- Preparing for a Rad/Nuke Terrorist Event: Realistic Radiation Detection Training without Radiation Sources
- Additively Manufactured High-Performance Carbon Composites
- CryoH2: Enabling Practical Zero-Emission Transportation



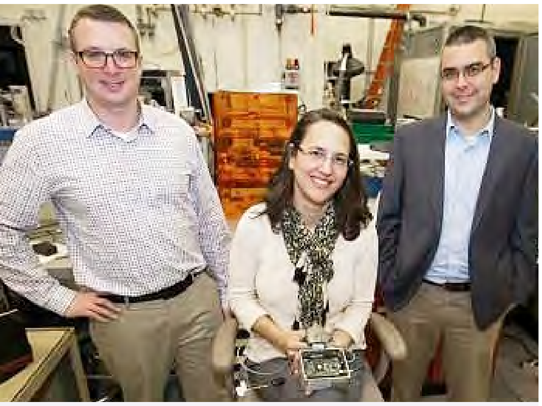
By leading a Market Discovery webinar, LLNL engineer Robert Panas connected his "Light-field Directing Array" work with entrepreneurs, angel investors, venture capitalists, and other industry players."

FUNDING INNOVATION AT LLNL

LLNL's Innovation Development Fund (IDF) is a program managed by the Innovation and Partnerships Office (IPO) that provides researchers with funds to further develop promising, early state technologies, so that they are less risky for businesses and potential investors. This is intended to help bridge the gap between when a technology is promising and when it moves forward into commercialization.

The IDF is funded by a share of the licensing fees and royalties retained by the Lab from the performance of technology transfer activities. The funds support the advancement of laboratory technology, and are typically used for activities that include market research, technology maturation, and technology demonstration. To date, the IDF program has provided approximately $1.8M to fund more than 15 projects at LLNL.

IDF Investment Highlights



IDF funding helped LLNL engineer Rebecca Nikolic and her team develop a hand-held thermal neutron detector. Team members include engineer Adam Conway (left) and postdoc John Murphy.

One research team, led by Rebecca Nikolic, is developing a hand-held thermal neutron detector that could be used to locate nuclear materials. The team received two years of funding to work with Honeywell to incorporate the firm's boron coatings into the detector. This new detector is very compact, could be used for search missions, and could serve as a replacement for helium-3 detectors, which rely on a material that is expensive and face deployment challenges.

"Funding from the IDF Program has been very helpful to our team, allowing us to continue to advance our technology and make progress toward our goal of commercialization," Nikolic said.

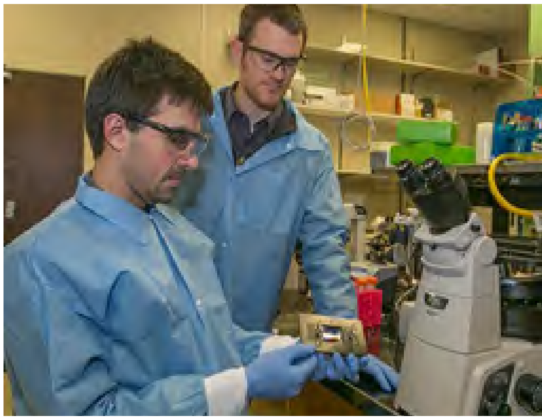
LLNL engineer Ray Mariella sees two potential uses for the laser decontamination technology he is developing with support from IDF funds. The first use is in post-detonation nuclear forensics, an application that has already attracted federal funding. The laser process could also decontaminate radioactive, mixed waste or solid hazards, such as mercury, lead, arsenic, beryllium or uranium, on concrete or painted surfaces.

Using his technique, Mariella shines a neodymium-based laser through stagnant or gently flowing water. Once the laser strikes the surface, a fine powder is released. “In effect, the laser unzips the surface. It looks as though the cement is transiently dissolved. The material is turned into particles and can be washed away,” Mariella said.

Mariella is collaborating with New Jersey-based Metal Improvement Co. Inc., which has a manufacturing facility in Livermore. The company has already licensed an LLNL laser technology for peening jet engine fan blades and turbines, and other aircraft structures, in one of the Lab’s most successful technology commercialization partnerships.

“The IDF program has been vital for our commercialization efforts because we can now conduct a demonstration of the process that is relevant for our customers,” Mariella explained.

In a third project, Maxim Shusteff and his team are working on a vaccine purification system for malaria. They are developing a microfluidic device to separate malarial parasites by their viability. Shusteff noted that the technology had been sitting in mothballs for nearly four years, and has been given new life through the IDF investment.



LLNL engineer Maxim Shusteff (left) and Nick Watkins, a postdoctoral scientist, used IDF funding to help them develop a vaccine purification system.

“The assistance I’ve received from the IDF has been critical for advancing the technology and for starting to test it on real-world problems.”

Shusteff is confident that the device has the capability to determine which parasites are viable, and then help separate them from the other parasites. According to Shusteff, his team wants the parasites that are fully viable to be used in vaccine formulation. When they’re not viable, the effectiveness of the vaccine drops.

Shusteff has been collaborating for about a year with Maryland-based Sanaria Inc., which is the only company in the world working to commercialize a whole parasite malaria vaccine.

RECOGNIZING LLNL INNOVATORS

R&D 100 Awards

In FY17, LLNL researchers garnered three awards for inventions that were among the top 100 industrial inventions worldwide. These newest awards bring the total count of R&D 100 awards received by LLNL innovators to an impressive 158 awards since LLNL started participating in 1978.

"This recognition in the R&D 100 competition is a great tribute to the innovative spirit of our scientists and engineers," said Lab Director Bill Goldstein. "Teaming with industrial collaborators is an important element in ensuring that technologies developed here will be of benefit to the nation."

GLO Transparent Ceramic Scintillator technology dramatically increases throughput for high-energy, or mega-electron-volt, radiography by providing imaging that is seven times faster than glass scintillators and decreases the X-ray dose required to obtain detailed imagery. Mega-electron-volt radiography is the most effective method for looking inside large, high-density cast metal parts, like power plant turbines, and complex metal assemblies such as jet engines. It is also the most effective method for identifying defects in welds, for example, during shipbuilding.

Polyelectrolyte Enabled Liftoff (PEEL) technology is a robust, scalable method of fabricating freestanding polymer films that are larger, stronger, and thinner than the films produced by conventional methods. With the new PEEL process, very thin films can be directly delaminated from their deposition substrates over very large areas. PEEL eliminates the need for often-used sacrificial layers, and it allows the remarkable properties of polymers to be exploited in vanishingly thin films.

The Carbon Capture Simulation Initiative is a suite of computational tools to accelerate the development of carbon capture technology for manufacturers and businesses. The toolset is the only suite of computational tools and models specifically tailored to help maximize learning and reduce risk during the scale-up process for carbon-capture technologies.

In addition to these three awards, six of LLNL's 2017 submissions were named as R&D 100 finalists:

- The Lawrence Livermore Microbial Detection Array efficiently screens and identifies more than 12,000 microbial species that may be present in complex clinical, environmental, and product samples.
- The Earth System Grid Federation peer-to-peer enterprise system is the largest-ever collaborative data effort in Earth system science.
- The Laser Damage Resistant Anti-Reflection, Transmissive Grating Debris Shield is a stable, transmissive diagnostic grating optic that is resistant to optical damage on the world's most powerful fusion-class laser.
- Providing Reproducibility for Uncovering Non-Deterministic Errors in Runs on Supercomputers is a software toolset to detect and remedy errors in large parallel applications that occur only occasionally or seemingly without a pattern.
- The Radiation Field Training Simulator provides realistic training for first responders by injecting high-fidelity synthetic radiation signals into the same detectors that first responders use during real operations.
- State of the Art, High-Efficiency, Thin-Film Polymer, F#2 Fresnel Lens enables production of high-resolution imaging satellites at a fraction of the weight and cost of traditional satellites.

Four LLNL co-submissions were named as R&D 100 finalists:

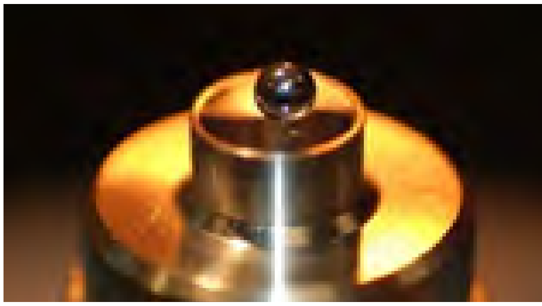
- ACE: The Ageless Aluminum Revolution is a Ce-Al alloy that is easy to work with, lightweight, corrosion-resistant, and exceptionally stable at high temperatures—making it ideal for automotive, aerospace, power generation, and other applications.
- Geometrically Enhanced Photocathode technology increases the measured total electron yield by up to 3 times in the 1–2 keV energy range.
- The National Risk Assessment Partnership Toolset is a suite of computational tools to assess environmental risk performance of geologic carbon dioxide storage sites.
- Zirconia Electrochemical Hydrogen Safety Sensors make the hydrogen supply chain, as well as filling up hydrogen-fueled vehicles, a lot safer.

Zachary Seeley from LLNL holds a gadolinium-lutetium-oxide (GLO) transparent ceramic scintillator plate. The GLO scintillator—a technology recognized by a R&D 100 award—provides imaging that is seven times faster than glass scintillators.

FLC Technology Transfer Awards

LLNL received two regional Federal Laboratory Consortium (FLC) Outstanding Technology Development awards. Since 2007, LLNL has garnered 30 regional FLC awards (resulting from 46 entries) for technology transfer. Since 1985, LLNL has received 35 National Recognition FLC Awards (resulting from 68 entries).

This year's FLC awards include PEEL technology, which was also recognized with an R&D 100 award. The technology was also highlighted in FLC's 14-month calendar. Another FLC award this year was Neodymium-Doped Fiber Amplifier and Laser technology. This new type of optical fiber amplifier can potentially double the information-carrying capacity of fiber-optic cables.



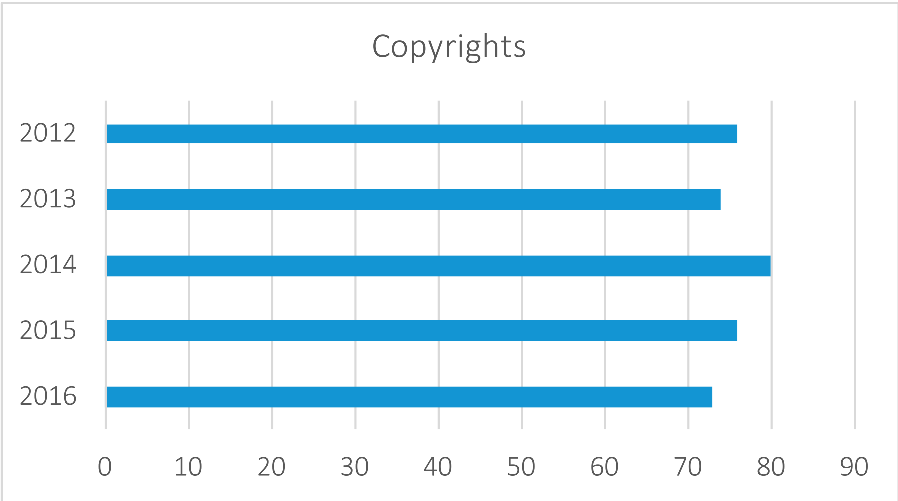
A stainless steel ball is supported by a thin sheet of plastic that is approximately 200 atoms thick, produced using the polyelectrolyte enabled liftoff (PEEL) technique. Developed by LLNL scientists Salmaan Baxamusa and Michael Stadermann, along with colleagues from General Atomics, PEEL received an R&D 100 Award in 2016, as well as a regional FLC Outstanding Technology Development award

METRICS

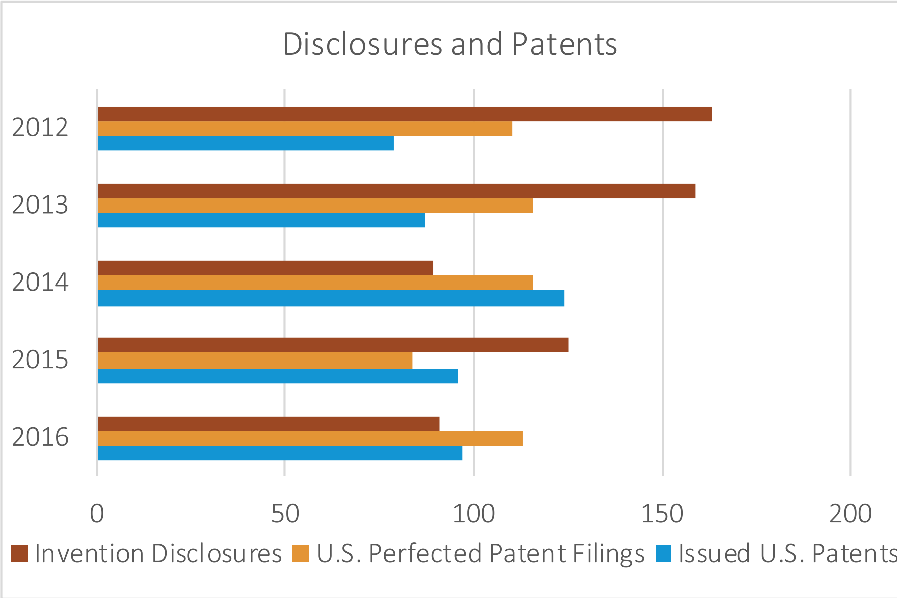
Intellectual Property

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

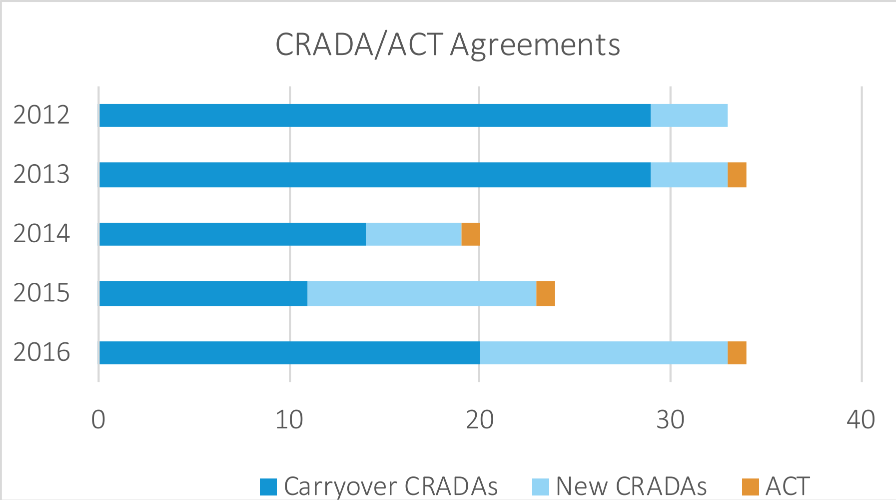
Each year, LLNL files between 70 and 80 copyright assertions, helping protect our scientists' innovative ideas.



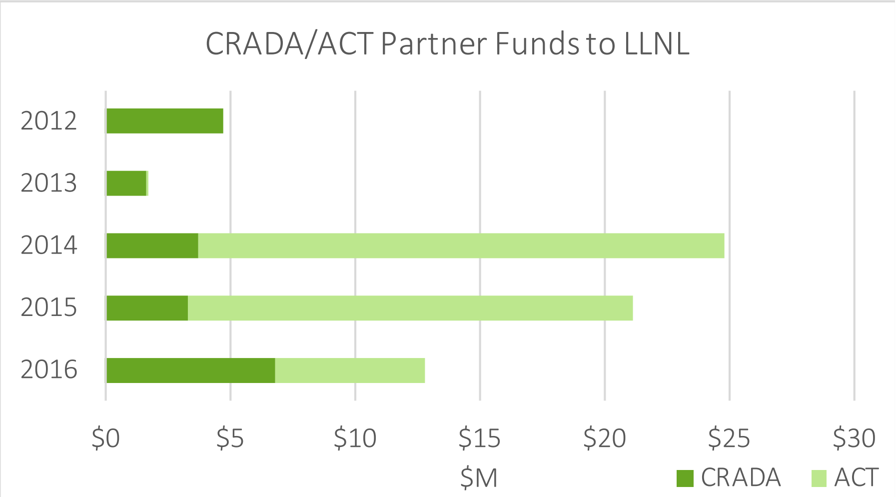
LLNL-based inventions are protected by more than 1,000 active patents and patent applications.



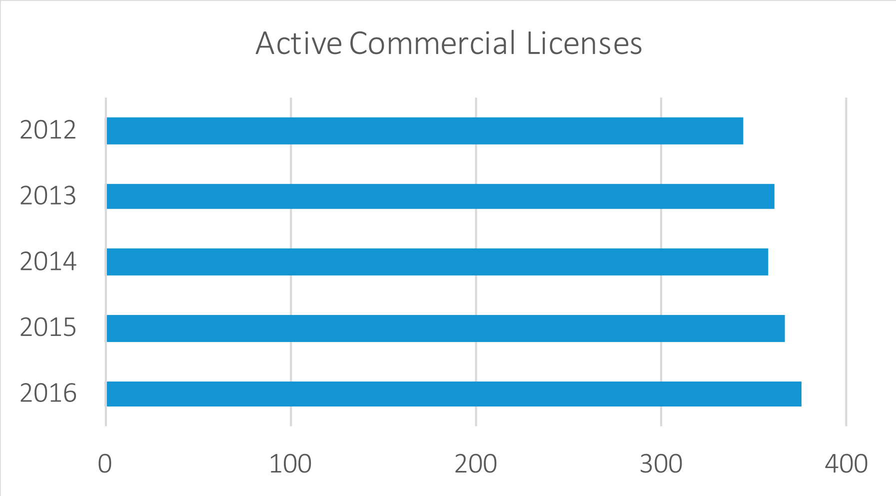
Industry Agreements



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 are as high as $25 million annually, and last year they topped $12 million.



LLNL currently has 376 active commercial licenses.

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