Ready, Set, Innovate!

ENTREPRENEURSHIP FLOURISHES AT THE LABORATORY

Lawrence Livermore's Industrial Partnerships Office uses its technology-transfer expertise to help the Laboratory's successful innovators contribute to the nation's economy. These top inventors are enshrined in the Entrepreneurs' Hall of Fame.

GREAT ideas percolate, evolving into even better ones. The best ideas can ultimately rise to the top and make a tangible difference in the nation—when given the right outlet. For close to 65 years, Lawrence Livermore has embraced all of these stages of innovation as a venue for scientific research and development, a proving ground for new technologies, and an advocate for transferring technology to the private sector. Livermore's culture of entrepreneurship ensures that innovations with broad applications find a purpose beyond Laboratory gates, providing economic benefit at the local, state, and national level.

Technology transfer, or the commercialization of an invention, is a complicated process. Wading through licensing agreements, nondisclosure contracts, and patent applications is only the beginning. Protecting intellectual property is critical, as are drafting a business plan, applying for funding, and formulating a go-to-market strategy. These tasks can seem daunting to a scientist or engineer whose day job is steeped in laboratory equipment or computer codes. Those who embark on the entrepreneurial journey often need help, which is where the Laboratory's Industrial Partnerships Office (IPO) comes in.

Livermore's concerted technology-transfer efforts began in the mid-1980s as part of its national security mission. IPO promotes Laboratory-developed technologies for commercial partners who identify opportunities and seek licenses or cooperative research and development agreements (CRADAs) to further shape the technology for market applications. (See *S&TR*, July/August 2008, pp. 4–11.) IPO Director Rich Rankin says, "The most challenging aspect of technology transfer is picking winners." Rankin's staff includes scientists and specialists in commercialization, intellectual property, product development, market analysis, business, and law. Rankin continues, "Our expertise helps us figure out how best to invest limited time and resources in promising technology that positively impacts the nation's economy."

IPO has organized networking events with potential investors and cohosted educational seminars with universities and other laboratories. Staff also participate in conferences, student mentoring, and business development webinars. Other outreach activities include membership in national laboratory consortia, onsite collaboration at the Livermore Valley Open Campus, and engagement with the Department of Energy's Energy I-Corps and other parts of the National Laboratory Accelerator Program. (See *S&TR*, March 2015, pp. 4–10; and the article beginning on p. 12 in this issue.)

Secrets of Success

IPO takes an end-to-end approach to entrepreneurship with initiatives that advise employees on everything from identifying a market need to finding a corporate partner who can transform the technology into a marketable product. For instance, the Entrepreneurs-in-Readiness Program connects Livermore entrepreneurs with seasoned experts from California's Silicon Valley. In addition to this program, the Laboratory uses the National Laboratory Entrepreneurship Academy at the University of California (UC) at Davis to educate scientists about the commercialization process. Serial entrepreneurs bring wisdom and fresh perspectives to early-stage technologies, often finding hidden potential or new ways of thinking about a technology's applications. These mentors can also help scientists tap into a network of investors and partners. IPO Deputy Director Roger Werne emphasizes the importance of a network for the aspiring entrepreneur. He says, "You must have advisors who can

provide insight into the market you're targeting." When the time is right, an employee may decide to create a startup or join an existing company to launch his or her product. IPO works with employees who wish to steer their careers in this direction. "Scientists and engineers can be naïve about what it takes to become commercially successful," says Werne. "Entering the marketplace is a gamble. Fortunately, Livermore's credibility in many industries means venture capitalists or angel investors will usually listen to what we have to say."

Although entrepreneurs may define success differently, success for IPO is measured by a license or CRADA to refine the technology for a commercial purpose. Eventually, a technology's impact in the market is measured by royalties on product sales. Annually, Livermore-developed technologies generate more than $300 million in sales, earning the Laboratory more than $8 million in licensing fees and royalties. With more than 1,000 active agreements and just as many patents and patent applications, IPO oversees upwards of 140 active commercial licenses and CRADAs. These quantities also boast quality—to date, Livermore scientists have received 155 R&D 100 awards. Winning one of these prestigious awards is considered a respected achievement that also enhances marketability.

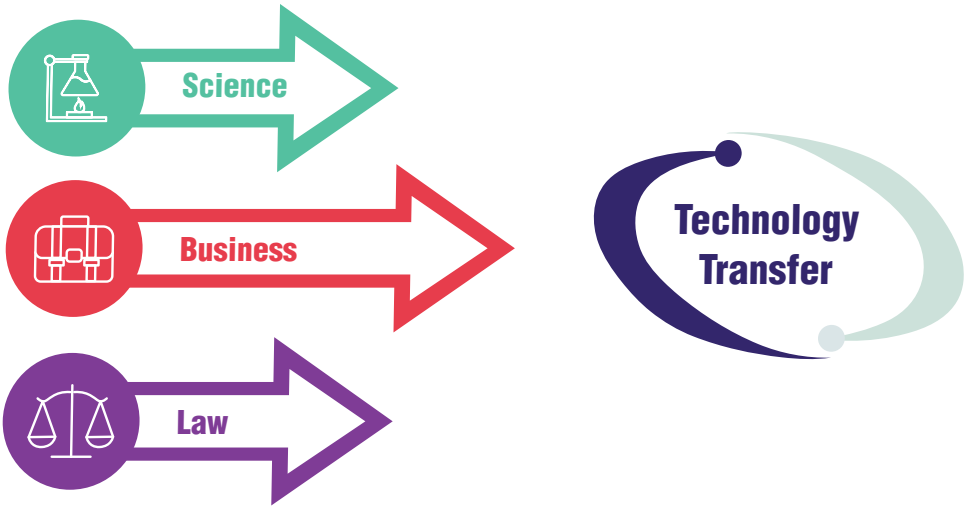
A Cooperstown for Innovation

To recognize scientists whose inventiveness and entrepreneurial spirit have made significant impacts on both the Laboratory and the private sector, Werne worked with Laboratory Director Emeritus Bruce Tarter to establish the

The Entrepreneurs' Hall of Fame, in Lawrence Livermore's Industrial Partnerships Office (IPO), recognizes successful entrepreneurs and their achievements.

Entrepreneurs' Hall of Fame (EHF) in 2012, coinciding with Livermore's 60th anniversary. Fifteen scientists were inducted in the inaugural class, with four more honored in 2015. (See *S&TR*, December 2012, p. 2; and *S&TR*, March 2015, p. 24.) Alone among national laboratories, Livermore's EHF benefits

IPO Director Rich Rankin defines technology transfer as the intersection of science, business, and law. He notes, "Our staff have experience in all of these areas."



Making Waves in Varied Ways

Lawrence Livermore's Entrepreneurs' Hall of Fame (EHF) honors scientists whose efforts at the Laboratory led to successful technology transfers. Many EHF inductees have continued their work regionally in California's Silicon Valley, a hotbed of startups full of like-minded innovators looking for leading-edge solutions to a range of problems. For example, Michael Farmwald addressed crucial performance problems in supercomputing and electronic microprocessors at the Laboratory before transitioning to serial startups. After beginning his career at the Laboratory, Bruce McWilliams brought his physics expertise to the semiconductor industry, founding or joining multiple companies while evolving his unique multichip packaging technology and other semiconductor components. Similarly, David Tuckerman joined McWilliams at two startups before founding a consulting firm that connects venture capitalists and industrial clients. Tuckerman's background in engineering, computer science, and angel investments have enabled him to nurture a new generation of entrepreneurs.

Other EHF members have invented new products or improved existing tools. James Bryan, known as the "Father of Precision Engineering," developed a telescoping magnetic ball bar that provides high-precision machine tool calibration. Thomas McEwan's work with Livermore's Nova laser—a predecessor to the National Ignition Facility—led to the invention of an ultrasensitive radar system called micropower impulse radar. This radar can be found in a variety of applications for military personnel—including landmine detection systems and wall-penetrating radar—and for homeowners, such as stud finders and motion detectors. The technology has garnered multiple awards and continues to be one of Livermore's biggest royalty generators. In a surprising benefit for consumer products, Robert Parker's stockpile stewardship work in temperature sensors led to a breakthrough in liquid crystal technology, whose applications included the popular "Mood Rings" of the 1970s. Parker's later inventions include a self-contained solder joint system and a visual temperature-distribution indicator for cookware.

EHF brainpower has also boosted computer technology. Curtis Widdoes and Thomas McWilliams designed the first supercomputer in the historic S-1 series, the Mark-1, and created the structured computer-aided logic design (SCALD) language to improve design processes. Computer engineer Jeffrey Rubin joined their effort to enhance and debug the system, and the three founded Valid Logic Systems to commercialize SCALD technology. All went on to pursue further innovations in hardware and software, and the industry took notice—McWilliams and Rubin's startup PathScale sold to Intel, while Widdoes's company, Logic Modeling Systems, was acquired by Synopsys.

Medical breakthroughs are also represented in the EHF. Fluorescence in situ hybridization (FISH), a method of binding molecules to nucleic acid fragments for easier detection of genetic sequences, was originally designed to evaluate radiation doses received by Hiroshima and Nagasaki survivors. With the Laboratory's help, Daniel Pinkel and Joe Gray licensed the technology to a commercial company. FISH is now a leading diagnostic technique for assessing radiation doses and other environmental exposures and has applications in genetic counseling and species identification.

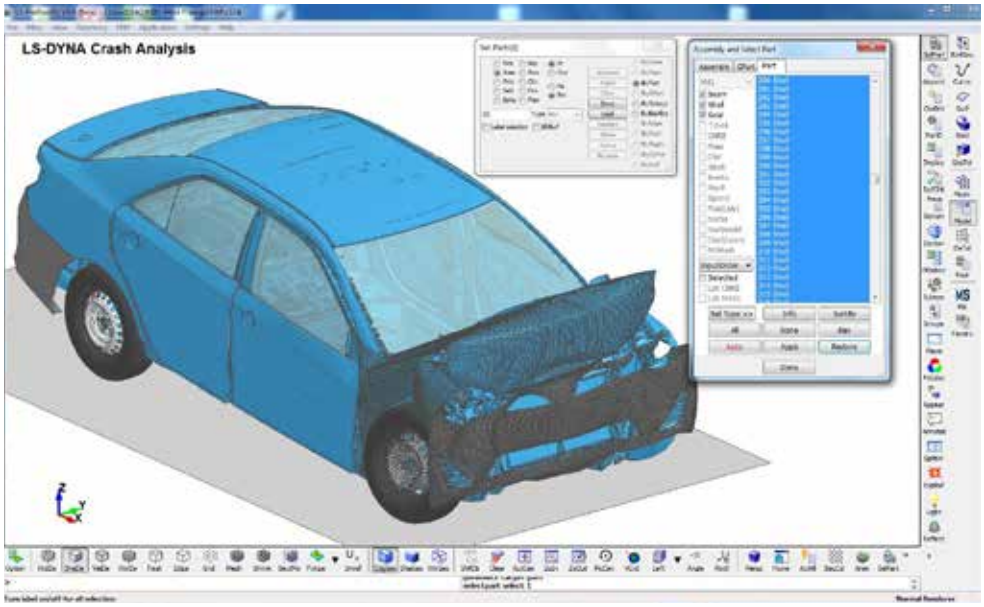
Advancements in another type of DNA analysis known as polymerase chain reaction (PCR) have come from multiple EHF inductees. Bill Colston and Fred Milanovich secured several patents, R&D 100 awards, and Laboratory Directed Research and Development Program funding for work that eventually led to a product called Droplet Digital PCR. The product divides a genetic specimen into thousands of equivalent samples for expanded testing and increased accuracy. Since commercialization, Droplet Digital PCR has penetrated the forensic science, DNA cloning, prenatal testing, and genetic analysis markets. (See *S&TR*, April/May 2017, pp. 4–12.)

Biomedical progress continues thanks to Allen Northrup, who used his expertise in microinstrumentation to create a silicon chip capable of rapidly copying billions of DNA samples via PCR. After successful deployment of biodetection field units in the wake of the 2001 anthrax attacks, the technology is now a mainstay of biotechnology, forensic analysis, and countering bioterrorism. Northrup's company, Cepheid, recently sold for $4 billion.

the Laboratory as much as the scientists it honors. Werne notes, "The Hall of Fame is demonstrable evidence of the value of our work."

EHF inclusion has three criteria—innovative technology, business acumen, and company value. Evaluating a prospective inductee takes time. Werne notes that companies typically need 10 to 20 years to achieve substantial success. By the time the Hall of Famers were officially honored, he says, "their mark in the commercial world had been made, and they had provided something of commercial value to the country." The motto of the National Baseball Hall of Fame—"Preserving History, Honoring Excellence, Connecting Generations"—could also apply to these notable entrepreneurs. All spent several years at the Laboratory developing their technologies before exploring commercial opportunities. Many give back to the Laboratory by volunteering their time as mentors and advisors in IPO's programs. According to Rankin, achievements honored by the EHF share a fundamental result: "These technologies impact more than the economy. They've changed how we live." (See box on p. 7.)

John O. Hallquist invented finite-element code DYNA3D, released commercially as LS-DYNA. In 1987, he founded Livermore Software Technology Corporation, which holds 65 U.S. utility patents. (Photograph by Julie Russell.)



LS-DYNA models mechanical failure. The code has been used in the automotive industry to save billions of dollars and has greatly improved safety. A car's behavior is simulated with a mesh of computational calculations, as seen in the compacted front end of the car shown. The car is covered with over 1.5 million points, each a separate calculation. (Image courtesy of Livermore Software Technology Corporation.)

Although individuals carve their own paths, five EHF inductees in particular underscore several essential phases common to all entrepreneurial journeys.

Phase 1: Develop the Product

In the early days of supercomputing, no existing code could predict the structural response of weapons impacting the ground prior to detonation. In the mid-1970s, John O. Hallquist was asked to develop simulation software with three-dimensional capabilities. Hallquist named his resultant 5,000-line code DYNA3D and later developed a two-dimensional version (DYNA2D) and other finite-element and visualization codes to simulate the mechanical behavior—bending, folding, collapse—of collision events. Hallquist acknowledges, "I was very lucky to work at the Laboratory when I did. Software development in house was superior to what was available outside, which motivated me to continue on that path."

Beyond national security applications, Hallquist realized DYNA3D could be used for any scenario in which materials collide at high speeds. Responding to external requests, the Laboratory released DYNA3D to the open-source community, where the code gained popularity among software developers working on similar impact problems in the automotive, aerospace, and nuclear industries. As interest in DYNA3D increased, Hallquist founded Livermore Software Technology Corporation to develop crash-test software, with emphasis on automotive and aerospace applications. The resulting commercial product, LS-DYNA, has also found a home in manufacturing, consumer products, civil engineering, electronics packaging, and defense. Other applications include

metal stamping, shipping container design, earthquake engineering, and even the simulation of sports equipment and aircraft bird strikes.

For the automotive industry, LS-DYNA has been nothing short of revolutionary. Hallquist's company developed crash simulations to predict vehicle behavior in collisions, reducing the need for expensive tests with real cars. Seatbelts, airbags, accelerometers, and other specialized vehicle components are also designed with the help of LS-DYNA. The industry has seen multibillion-dollar savings over the last three decades, and the Computer History Museum in Mountain View, California, honors Hallquist in its exhibit on crash-test software. Altogether, more than 2,500 companies worldwide have reaped benefits in cost savings and safety advancements with LS-DYNA's stress and deformation prediction capabilities.

Hallquist's code lives on at Livermore as the impact-simulation software PARADYN, which is scaled for massively parallel supercomputers. Among PARADYN's accomplishments is simulating impact response in military helmets to improve helmet padding and reduce traumatic brain injury. Laboratory defense systems engineers use PARADYN for modeling impact events that involve large deformations or debris fields, such as satellite collisions in space, or that occur over subsecond timescales, such as ballistic missile scenarios. (See *S&TR* July/August 2009, pp. 4–11; and *S&TR* September 2012, pp. 26–29.)

Hall of Fame inductee Martin Casado also received the 2012–2013 Grace Murray Hopper Award for Outstanding Young Computer Professional of the Year and has been featured in *Silicon Valley Business Journal*'s "40 Under 40" list, *Business Insider*'s "50 Most Powerful People in Enterprise Tech," and *Forbes Magazine*'s "Next-Gen Innovators." (Photograph by Julie Russell.)

Phase 2: Secure a Network

Martin Casado's journey to entrepreneurship began in high-performance and distributed computing. His simulation work at Livermore shifted focus to cybersecurity in the wake of the September 11, 2001, terrorist attacks. He states, "The Laboratory was my introduction to networking and security." Motivated to solve network vulnerability problems, Casado entered a Stanford University Ph.D. program, where he developed a method to protect networks by decoupling software from traditional hardware-centric systems. The network could now be managed by a software application instead of a traditional network and was therefore no longer constrained by or exposed to network security problems.

Software-defined networking (SDN), as Casado's concept came to be called, quickly transformed how the computer industry exchanged data. The paradigm enables microsegmentation, whereby system engineers can configure each application to access only the data needed, not an entire data center. In this way, the modern data center can provide both context—users, data, and files—and isolation, that is, sufficient security control. Casado notes, "SDN architectures can be made more secure than traditional architectures and offer more in-network security services." SDN technology is flexible and responsive and reduces the time and cost of provisioning and scaling a virtual network.

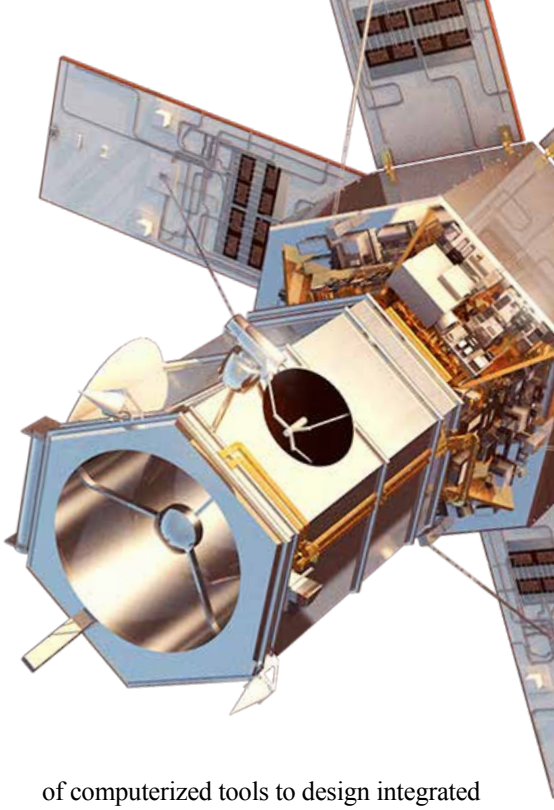
While at Stanford, Casado founded Illuminics Systems, an Internet protocol analytics company, and helped develop code for the network platforms OpenFlow and Open vSwitch, expanding SDN technology into the open-source community. A new market was thus born, along with Casado's second startup company, Nicira Networks, to develop SDN applications. Casado says, "My job at the Laboratory was the most formative job I've ever held and laid the foundation for my subsequent work."

In 2012, Casado sold Nicira Networks for $1.26 billion. Now a general partner at Andreessen Horowitz, he focuses on software infrastructure investments and works closely with the founders of companies in the portfolio. Healthcare, banking, and retail are just a few industries reaping the benefits of SDN. Casado explains, "Because this technology allows automation of network infrastructure and provides security services within a data center, it solves a lot of 'sticky' problems that come with computer virtualization, such as providing strong isolation and the mobility of security policies."

Phase 3: Achieve Liftoff

Laser physicist Brent Dane and physicist Lloyd Hackel combined their complementary backgrounds to achieve a manufacturing breakthrough. Hackel remembers, "Our group at the Laboratory had been developing laser technology for x-ray lithography to print computer chips and for space object imaging. We then realized that our laser was ideal for laser peening." Dane and Hackel eventually partnered with Metal Improvement Company, Inc., to evolve an advanced method of laser peening. Livermore's IPO brokered a CRADA for a commercial system, and both scientists eventually transitioned to Metal Improvement Company, which today is part of Curtiss-Wright Surface Technologies.

Laser peening, in which laser beams replace traditional metal shot, involves



Walter Scott helped found the company known today as DigitalGlobe, which most notably provides satellite imaging content for Google Maps. The company's satellites collect more than 4 million square kilometers of Earth imagery every day at industry-leading resolution, geopositional accuracy, and spectral diversity. The imaging technology's many applications include enabling relief agencies to reach people in need after a natural disaster, allowing companies to monitor global infrastructure, and helping humanitarian organizations expose human rights abuses. (Image courtesy of DigitalGlobe.)

firing a series of intense laser blasts at a surface. By producing a shockwave that creates a compressive stress field in the surface, the lasers strengthen the underlying material. Dane and Hackel pioneered a high-energy laser with increased pulse frequency, beam imaging, and robotic controls that enable components and systems to run longer and with greater safety margins. Their package of technologies became marketed under the name Lasershot Peening System. Dane notes, "Our work increases the fatigue strength of metal components by preventing the initiation and growth of cracks." The result is life extension for critical parts subject to intense conditions, such as aircraft fuselages and turbine blades used in jet engines and electric power generation. (See *S&TR*, March 2001, pp. 26–28.)

The team also developed a peening process to plastically strain materials to form precision curvatures in thick or complex components. Hackel explains, "We patented the concept of shaping metals with laser peening and preferentially controlled shaping with prestressing techniques." The process is most notably applied to workpieces over 100 feet long. Since 2008, the Boeing Company has used the Lasershot Peening System to manufacture wing panels for 747-8 aircraft. Dane adds, "We have a rapidly growing presence in defense applications where the use of laser peening has moved from engine components to airframes." Today, jet engines and aircraft wings run more efficiently and cost-effectively because of the team's innovations.

Additional metalworking products that benefit from the technology include arrestment hook shanks used for carrier-based aircraft and ship-propulsion shafts currently under development. A new mobile laser peening system rapidly delivers the process to remote locations, and in 2016, Metal Improvement Company successfully treated 110-ton steel pieces at a customer worksite. Hackel states, "We're also preventing stress corrosion cracking in containers for spent nuclear fuel."

Phase 4: Change Perspectives

Computer scientist Walter Scott joined the Laboratory in 1986. His development of computerized tools to design integrated circuits led to involvement in the Department of Defense's Strategic Defense Initiative. He then became leader of the Brilliant Pebbles Program, which aimed to stop ballistic missiles with small spacecraft. Scott notes, "Livermore is an incredibly exciting environment for a technologist, with opportunities to work on very hard problems of high national importance. Both aspects were strongly motivating." The work gave him insight into emerging trends in satellite technology, which was becoming more affordable thanks to microelectronic innovations, as well as advances in the graphics capabilities of personal computers.

Lloyd Hackel (left) and Brent Dane stand with a robot used in laser peening to strengthen critical parts for aviation and other industries. The duo successfully commercialized a laser peening technology—marketed as the Lasershot Peening System—used around the world in airplane fuselages and turbines, as well as in turbines for electric power generation. (Photograph by Julie Russell.)

The Lasershot Peening System has improved the fatigue life of jet engine and turbine components for a roster of high-profile commercial planes, such as Airbus's A340 and A350, Boeing's 777 and 787 Dreamliner, and Gulfstream's G650. The technology is also used in military aircraft, including the F-22 Raptor and F-15 Eagle. Ongoing development will expand this use to the A-10 Thunderbolt, C-17 Globemaster, and F-35 Lightning models B and C (B shown here). (Image courtesy of U.S. Navy.)

The geopolitical landscape was changing, too. Scott describes his "ringside seat to the end of the Cold War" as a formative experience. He says, "This fluid environment created an opportunity to use satellite imagery to provide global transparency to a much broader set of users." In 1992, Scott founded Colorado-based WorldView Imaging Corporation, which became the first company to strike a satellite-imaging deal with the U.S. government. Now named DigitalGlobe, Scott's company has launched a host of high-resolution imaging satellites, has amassed a 100-petabyte time-lapse image library, and most notably provides satellite imaging content for Google Maps and many other online mapping sites.

Early collaboration with John Henke, cofounder of the data visualization software company Keyhole, led to the industry's highest-resolution satellite imagery. Scott notes, "Google needed the data from our QuickBird satellite to build a world-class mapping application. After a meeting with [Google founders] Sergey Brin and Larry Page, we had a deal." DigitalGlobe's continued deployment of advanced technologies aboard commercial imaging satellites includes high-fidelity sensors that detect parts of the electromagnetic spectrum beyond human visibility. The company has created the most comprehensive geospatial ecosystem featuring a big-data platform, global distribution channels, and a growing repository of analytic tools. Now heading into a $2.4-billion acquisition, DigitalGlobe's geospatial analysis and satellite imaging technologies are poised for new applications with help from machine learning, elastic cloud computing, and crowdsourcing. Scott notes, "Combined, these tools unlock the rich information in our image library to create applications previously impossible, such as monitoring economic activity from space, developing continent-wide property databases for the insurance industry, enabling safe drone navigation, and supercharging the effectiveness of overworked intelligence analysts by narrowing the search space."

Investment in the Future

Surrounded by modern technology and with access to resources and equipment for experimentation, Livermore scientists solve complex problems every day. Rankin sees commercial potential in many growing research areas across the Laboratory. He notes, "We can make significant contributions in additive manufacturing and next-generation energy technology. Biomedical engineers are designing devices and processes that directly impact our quality of life." He cites as examples the three-dimensional printing of blood vessels (see *S&TR*, March 2016, pp. 13–16) and work under the National Institutes of Health's Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative.

Hall of Fame members also recognize the invaluable asset that IPO represents to Livermore scientists trying to convert their technology into a commercially viable product. Hackel says, "The Laboratory was a tremendous place to advance my knowledge and further my experimental and project management capabilities. IPO was especially helpful with patenting, agreements, and other legal support." Scott also acknowledges IPO's support, stating, "The Laboratory was willing to review intellectual property and give me clear guidelines, allowing me to continue my work while raising the financing to get DigitalGlobe off the ground." These achievements in technology transfer indicate how this mission of IPO's is a natural extension of Livermore's mission in national security. Rankin says, "The Laboratory is an exciting place behind the fences. We want the public to understand that the Department of Energy's technology base makes a positive impact on their lives in so many ways."

—Holly Auten

Key Words: commercialization, cybersecurity, DYNA3D, Entrepreneurs' Hall of Fame (EHF), entrepreneurship, geospatial analysis, Industrial Partnerships Office (IPO), laser peening, Lasershot Peening System, LS-DYNA, PARADYN, satellite imaging, software-defined networking (SDN), technology transfer.

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