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February 2018

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 **ON THE COVER**

Darryn Fleming, a principal investigator at Sandia Labs in Albuquerque, is surrounded by the workings of the labs' 1 megawatt thermal supercritical carbon dioxide recompression closed Brayton cycle test loop. Sandia is working with three industry partners to commercialize the distributed power system, which could produce cheaper, cleaner, more efficient electricity.

(Photo by Randy Montoya)



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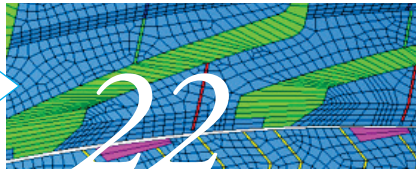
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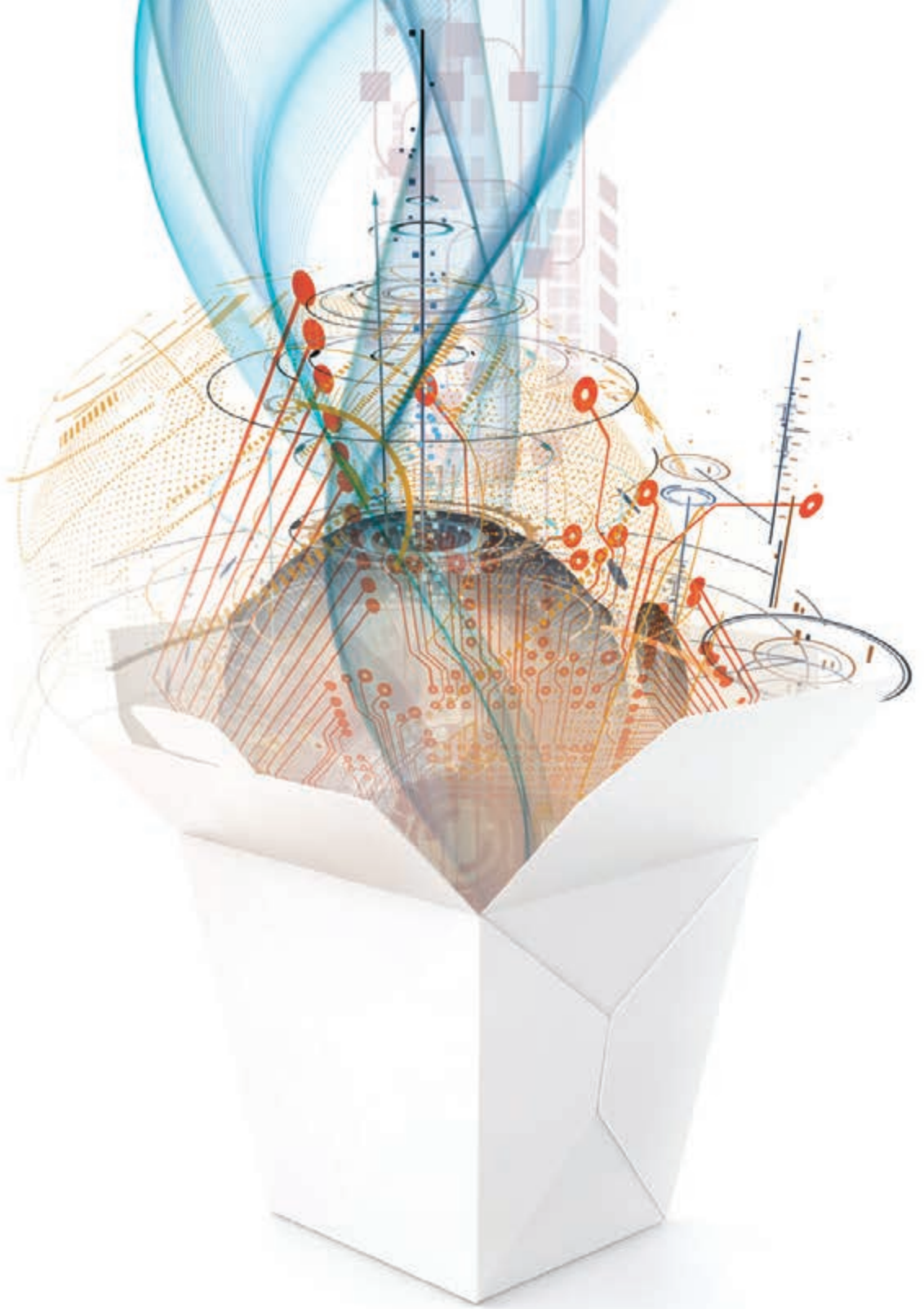
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TECHNOLOGY

By Nancy Salem

Sandia Labs has bright minds tackling big challenges in science and engineering. That work creates a treasure trove of technology vital to national security but also to everyday life. From solid state lighting to medical diagnostics, the lab consistently hands over skills, knowledge and technologies to the private sector, and ultimately the public.

T O G O

Dan Daily grew up watching his mom run a day care center for severely disabled children in Taos, New Mexico. “The kids impressed me,” he said. “They were regular people but with disabled bodies. It stuck with me.”

Daily became a musician and, inspired by those kids, dreamed of developing an electronic instrument anyone could play. He wanted to bring music to people who didn’t have the mental or physical ability to play a traditional instrument. He envisioned a microcontroller-based system that would send signals through a USB connection to another electronic device, such as a sound module or computer, which would produce the tones of trumpets, horns, strings, drums and other musical instruments, all controlled with a simple joystick or mouse.

The technology was more than Daily could handle, but as a tiny startup venture, he couldn’t afford R&D. He turned to the New Mexico Small Business Assistance (NMSBA) program, which lets entrepreneurs get technical help from premier scientists at Sandia and Los Alamos national laboratories. Daily was paired with Sandia microsystems engineer Kent Pfeifer, who had a background in music and helped him bring his dream to life.

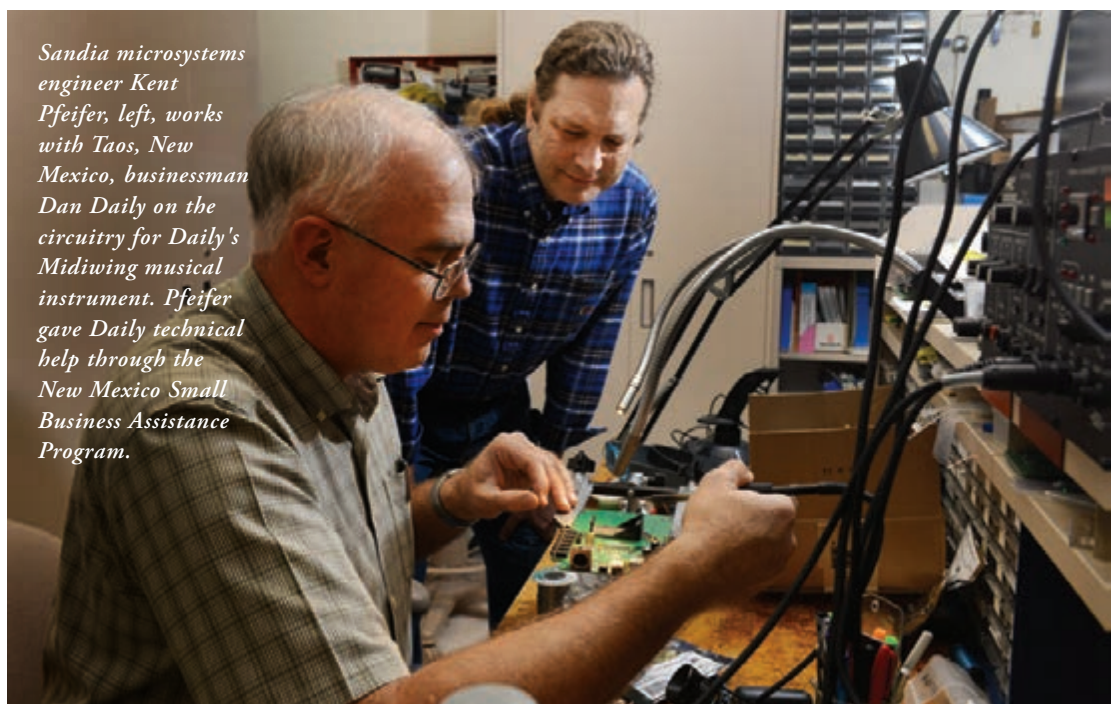
Daily’s MidiWing can be manufactured for schools, hospitals, therapy and rehab centers and other

places where people want to make music. “My motivation was to bring music-making to more people,” said Daily, who founded a company, Musicode Innovations. “Kent was pivotal. It was an incredible collaboration because he is a musician. The key to the whole project was that he understood what I was trying to do from a musician’s standpoint. He was perfect. He has a music background and designs microcontroller products. I can’t imagine how it could have gone better.”

A mandate to share

Hardly a day goes by at Sandia Labs that technology isn’t transferred to the private sector. “Tech transfer is a government-mandated mission for institutions receiving federal funding for research,” said Susan Seestrom, Sandia’s chief research officer and associate laboratories director for Advanced Science and Technology. “That mission is deeply rooted at Sandia.”

The labs have a wide variety of programs that hand over skills, knowledge and technologies to those who can further develop them into new products, processes and services for the public good. Programs such as NMSBA, Cooperative Research and Development Agreements and intellectual property licensing ensure that the public can access taxpayer-funded research and world-class scientists and facilities. The labs work in partnership with private businesses — large and small — and with federal, state and local agencies, academic institutions and the local community.



Sandia microsystems engineer Kent Pfeifer, left, works with Taos, New Mexico, businessman Dan Daily on the circuitry for Daily’s Midiwing musical instrument. Pfeifer gave Daily technical help through the New Mexico Small Business Assistance Program.

“Tech transfer is a powerful economic development tool,” said Grant Heffelfinger, Sandia’s director of Research and Development Science and Engineering. “Sandia’s programs have created thousands of jobs, launched dozens of companies and pumped billions of dollars into the local, regional and national economies.”

The numbers are staggering. Sandia has signed more than 5,000 partnership agreements in the past five years to develop its own technology and to help others. The labs worked with 830 unique industrial partners and hundreds more small and startup businesses.

Products that have become a part of peoples’ daily lives, such as solid state lighting and high efficiency engines, came from Sandia R&D that was commercialized. “Sandia’s technologies are vital to national security, and moving them swiftly to the marketplace advances U.S. economic competitiveness,” said Mary Monson, Sandia’s senior manager of Technology Partnerships. “Sandia’s strategic partnerships with industry and universities strengthen and accelerate technology transfer.”

Here’s a look at some of Sandia’s key technology transfer programs, and their impact on the public:

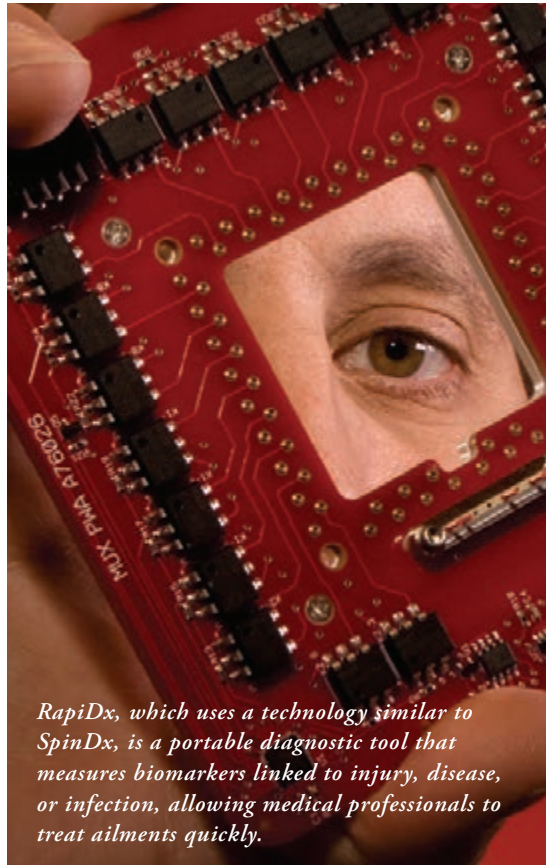
New Mexico Small Business Assistance

NMSBA lets small companies with technical challenges work with scientists and engineers at Sandia and Los Alamos free of charge. It was established in 2000 by the state legislature, which funds it through a tax credit. The program has provided 2,648 companies in all 33 of the state’s counties \$53.3 million worth of research hours and materials.

It has helped create and retain 5,734 New Mexico jobs at an average salary of \$39,000, increase small companies’ revenues by \$272 million and decrease their operating costs by \$142 million. Those companies invested \$109 million in other New Mexico goods and services, and received \$111 million in new funding and financing.

“NMSBA is a phenomenal way to help small companies that don’t have the resources to do advanced research and development,” said Jackie Kerby Moore, Sandia’s manager of Technology and Economic Development. “National laboratory

expertise helps these business people realize their dreams and stimulates the state’s economy.”



RapiDx, which uses a technology similar to SpinDx, is a portable diagnostic tool that measures biomarkers linked to injury, disease, or infection, allowing medical professionals to treat ailments quickly.

Entrepreneurial Separation to Transfer Technology

For more than 20 years, Sandia researchers have been able to leave to start or join small companies, knowing they can return. Their work has made a difference by creating hundreds of jobs, bringing national lab expertise into the private sector and boosting economic development.

“The Entrepreneurial Separation to Transfer Technology program is an innovative tech transfer tool that has endured,” said Kerby Moore. “We have many success stories and have measured the economic impact, which shows positive benefits to the local community. And entrepreneurs who return to Sandia bring new experiences that benefit the labs.”

One of Sandia’s hottest technologies, the medical diagnostic lab-on-a-disk SpinDx, is being commercialized through the program. Greg Sommer, a former Sandia researcher who helped develop SpinDx, co-founded and is chief executive officer

Sandia's X-Ray Toolkit, a software program that helps emergency responders disable IEDs, is being used by most of the 467 recognized non-military bomb squads across the United States.



ChangingLIVES

Sandia's tech transfer efforts have been recognized dozens of times by the Federal Laboratory Consortium, a nationwide network of more than 300 federal laboratories, agencies and research centers that fosters commercialization best practice strategies and opportunities for accelerating federal technologies out of the labs and into the marketplace. The Sandia awards have been in categories ranging from Excellence in Technology Transfer to State and Local Economic Development to

Regional Partnerships. Among the technologies singled out were:

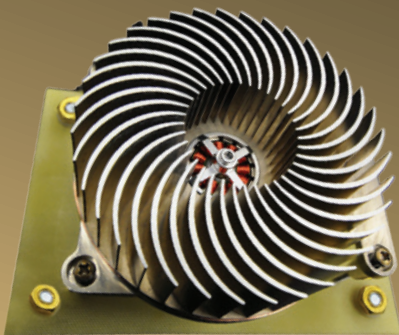
- BaDx, a credit-card-size device that can detect bacteria that cause anthrax;
- Sandia Cooler, which reduces energy to cool computer processor chips;
- GazeAppraise, an eye movement analysis software;
- X-Ray Toolkit, a software program that helps emergency responders perform effectively in the high-stress, time-critical act of disabling improvised explosive devices;
- Decontamination Technology for Chemical and Biological Agents, which neutralizes 99.99999 percent of bacteria, viruses and fungi;
- Twistact, designed to take wind energy to the next level;



Researcher Mark Tucker demonstrates Sandia's decontamination formula, which renders all types of chemical and biological toxins harmless.

- H2FIRST, an effort to increase the number of fueling stations for hydrogen cell electric vehicles.

Susan Seestrom, Sandia's chief research officer and associate laboratories director for Advanced Science and Technology, said U.S. taxpayers have invested billions in research and development at federal laboratories, and the return is scientific and technological breakthroughs that lead to new companies, jobs and growth in the economy. "Our technology transfer programs ensure that the nation receives the maximum return from the R&D investments made at Sandia," she said. "These are technologies that change lives and make the world a better place." ■



The Sandia Cooler reduces the energy needed to cool the processor chips in data centers and large-scale computing environments. It is getting commercialization funding from the Department of Energy Office of Technology Transitions.

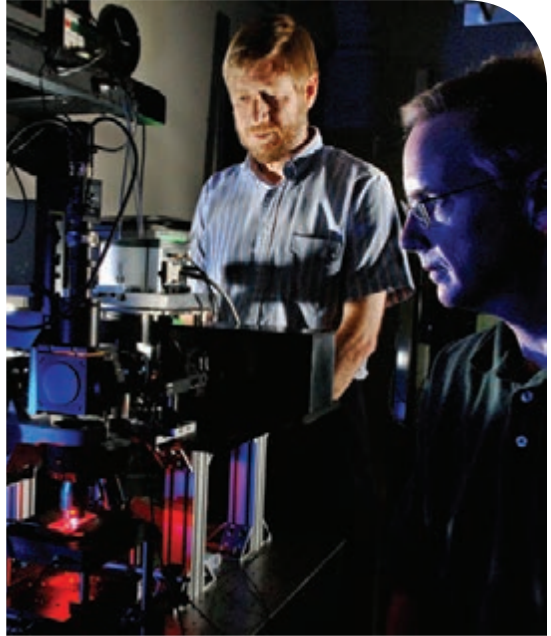


SEE VIDEO

of Sandstone Diagnostics in Livermore, California, which is bringing the technology to market. “The high-tech environment at Sandia is ripe for innovation and game-changing technologies,” he said. “The entrepreneurial separation program allowed us to launch Sandstone and develop cutting-edge medical products based on technology we originally developed for Sandia’s biodefense missions.” Some 156 Sandia researchers have left, 70 to start a business and 86 to expand one. About 30 of the companies they joined or started licensed a Sandia technology.

Entrepreneur Exploration

EEx is designed to invigorate an entrepreneurial culture at the labs and inspire researchers whether they leave or remain at Sandia. The program has been in place about two years and includes entrepreneur office hours, when researchers can meet and talk to members of the business community; workshops; roundtables; boot camps; and social gatherings.



Scientists Michael Sinclair, foreground, and Dave Haaland work on a hyperspectral confocal microscope developed at Sandia. Monsanto Corp. partnered with Sandia through a Cooperative Research and Development Agreement to build a similar microscope to use in its operations.

“More than 1,800 community leaders, entrepreneurs and Sandians have attended the EEx events,” Kerby Moore said. “It links the community to Sandia with opportunities for entrepreneurs.”

Sandia Science & Technology Park

The park is a 300-plus acre master-planned technology community affiliated with Sandia and adjacent to Kirtland Air Force Base, giving companies easy access to top-notch facilities. The park is home to 42 companies and organizations with 2,163 employees. The average annual salary is \$83,000.

Since the park opened in 1998, public investment has totaled \$89 million and private \$286.5 million. Some 6,593 direct and indirect jobs have been created. Wages and salaries from park activities total \$4.4 billion.

“The park plays a critical role in our economy,” said Kerby Moore, the park’s executive director. “It creates high-quality, high-wage, long-term jobs rooted in technology, innovation and entrepreneurship.”



The Sandia Science & Technology Park is a 300-plus-acre research park located next to Sandia Labs and Kirtland Air Force Base, giving companies the ability to collaborate with scientists and engineers.

Small Business Vouchers

Sandia is one of five leads in a Department of Energy pilot program that gives small, clean-energy companies access to national laboratory expertise and resources. Eleven DOE labs are working with the private sector with a combined budget of \$22 million. Sandia's 17 vouchers from the program's first three rounds total \$3.7 million and include projects in advanced manufacturing, bioenergy, fuel cells, geothermal energy, solar energy, wind and water power.

Sandia has active CRADAs with 84 partners ranging from small businesses to nonprofits to industry giants.

"This is a great mechanism for getting national laboratory technology into the private sector," said Sandia CRADA specialist Jason Martinez. "We develop cutting-edge technology and capabilities with underlying science that is phenomenal. The CRADA is a vehicle to take that work and benefit the U.S. economy."



General Atomics Aeronautical Systems engineers test the Claw interface for the company's Lynx radar. General Atomics worked with Sandia on the Lynx system.

Ben Wu, chief of operations for Sandia's energy programs, said companies can propose collaborative research with a particular scientist, request technical assistance from an engineer or gain access to such Sandia facilities as the Microsystems Science and Technology Center, the National Solar Thermal Test Facility or the Battery Abuse Testing Laboratory.

"The program gives companies an array of options to meet their technical challenges," Wu said.

"Sandia and the other labs have decades of R&D experience in clean energy technologies and an incredible amount of knowledge to share with these small businesses."

Cooperative Research & Development Agreements

A CRADA is an agreement between a government agency and a private company or university — or at least one non-federal entity — to work together on research and development. Sandia signed 237 during the past five fiscal years, from October 2012 to September 2017; 152 were new and 85 were amendments adding tasks or funding to existing agreements. October 2007 to September 2017, 268 new agreements were signed and 233 were amended.

Strategic Partnership Projects, Non-Federal Entity Agreements

These are bilateral contracts that let Sandia do work for a non-federal entity sponsor, making the labs' resources available to private industry and individuals, state and local governments, colleges and universities, nonprofit organizations, international organizations, foreign governments and foreign companies. From 2006-2017, Sandia signed 873 new agreements and 812 amendments.

Intellectual property licensing

Partners can license Sandia's IP, including patents, copyrights, trademarks and mask works, for commercialization or private use. From 2006-2017, patent activity included 3,616 invention disclosures, 2,350 patent applications and 1,165 patents issued. There were 1,520 copyright submissions and 3,942 commercial and non-commercial technology licenses granted.

University partnerships

Sandia partners with key universities to do cutting-edge science, hire the best scientists and engineers and develop strategic collaborations in focused research areas. From 2006-2017, investments in research totaled \$340.6 million at all universities and \$65.6 million at New Mexico universities. ■

A DIFFERENT

The LED revolution started with a white paper and became a multibillion-dollar business. And it's not over. The paper's authors say every light will be an LED someday.

LIGHT

By Sue Major Holmes

Light-emitting diodes — LEDs — are changing how the world lights homes and factories. Within a couple of decades, solid-state lighting technology is expected to displace traditional lighting in virtually all uses — from grid-dependent incandescent and fluorescent lights to off-the-grid camping lanterns.

Solid-state lighting, based on compound semiconductors, got a boost with a technology transfer initiative at Sandia Labs in the early 1990s, an influential white paper in 1999 and timely industry interest and research.

field. “In 1999, the blue LED — which all of this is based on — was so wimpy. It was so inefficient,” Tsao recalls. White light was a more challenging scientific problem than single-color LEDs because white light requires multiple colors. Developing a more efficient blue LED was critical since white LEDs are based on adding phosphors to a blue LED, which convert some, but not all, of the blue to green and red, Tsao said. Combining blue, green and red make white.

A leap forward

LEDs became cost-competitive with incandescent



Scientist Andy Allerman works on ultraviolet light-emitting diodes with a short wavelength and high power output.

The white paper, “The Case for a National Research Program on Semiconductor Lighting,” was written by Sandia researchers Jeff Tsao and Jeff Nelson with Roland Haitz and Fred Kish of the Hewlett Packard Company spinoff Agilent Technologies. At the time, a white LED only recently had been created in the laboratory and people were still debating what to call it, said Sandia fellow Jerry Simmons, a now-retired long-time researcher in solid-state lighting.

The paper presented a vision of energy-efficient solid-state lighting and called for a national research and development initiative in the new

lighting about a decade ago and competitive with fluorescent and similar lighting in 2011. Today, high-brightness LEDs are a \$15 billion worldwide business that also represents substantial energy savings. LEDs are in everything from lamps and flashlights to large-scale lighting in factories, restaurants and theaters; from consumer electronics and automotive lights to smart road signs that flash warnings to speeding drivers.

The Department of Energy’s June 2016 research and development plan predicted solid-state lighting would dominate lighting technology in five to 10 years in sales, amount of light generated and



MEET

Jeff Tsao

For Jeff Tsao, learning has a purpose.

“My parents taught me that I should always do my best to contribute to the world, and that creating lasting knowledge, not gathering money or status, is the most profound way of doing that. My grandparents — my mom’s father was a close comrade of Sun Yat-Sen during the revolution against the Qing dynasty — went further and instilled in me a sense of obligation to contribute to the world.”

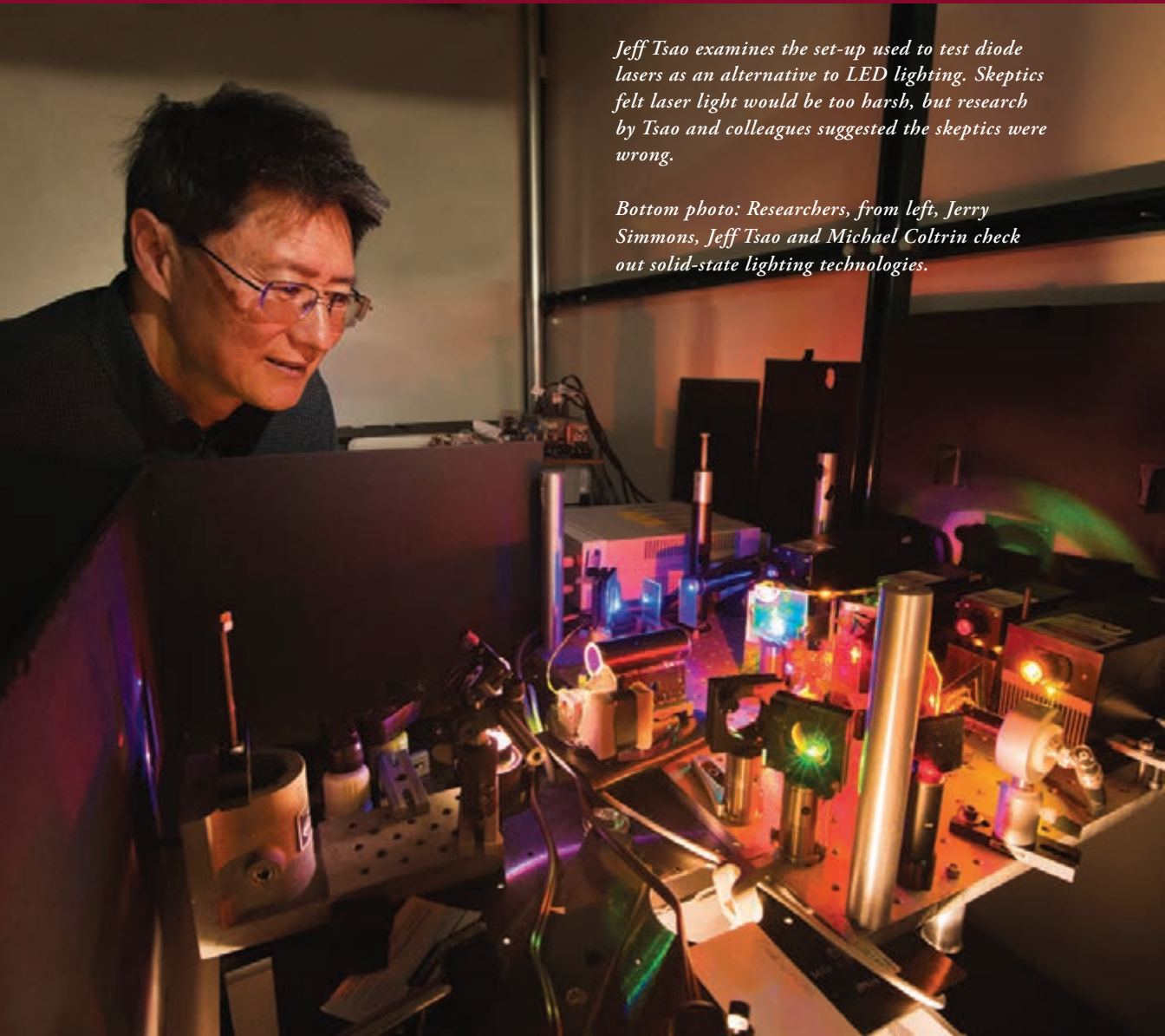
Over the course of 30-plus years at Sandia, Tsao has worked on so many projects that have been memorable that he’s hard-pressed to name favorites. “In general, projects are most rewarding to me when there is an open question, often one no one has thought to ask yet but whose answer could change how people think and add to humanity’s knowledge,” he said. “Then there’s the digging and thinking deeply about the question amid the uncertainty of whether you’ll be able to find an answer or not. Sometimes you succeed, sometimes you don’t, but if you succeed after having gone through all of that, wow, it’s super rewarding.”

Right now he’s working on several projects. They’re all interesting, and he likes to think they’re all important, but said one can’t really know until many years have passed.

“I’m working on new ways to think about how to manage and nurture research itself, both in individuals and in teams, and on new ways to think about creativity and learning, both in humans and machines. My work also focuses on new ways to think about the ‘new world of lighting’ enabled by solid-state lighting but that goes way beyond solid-state lighting. There can be new ways to think about the future of energy and its possible large-scale electrification via free-fuel sources.”

On top of it all, he said, “I’ve been blessed with a wonderful family. My wife gives me so much support it’s incredible. My children have given me so much joy.”

— Sue Holmes



Jeff Tsao examines the set-up used to test diode lasers as an alternative to LED lighting. Skeptics felt laser light would be too harsh, but research by Tsao and colleagues suggested the skeptics were wrong.

Bottom photo: Researchers, from left, Jerry Simmons, Jeff Tsao and Michael Coltrin check out solid-state lighting technologies.

installations, and would account for the majority of installations by 2030. The plan noted, however, the industry faces challenges: continued improvements in efficiency and price reduction, manufacturing scale-up and further energy savings. Tsao and Simmons predict every light will be a light-emitting diode someday.

“It’s clear now that solid-state lighting has been phenomenally successful,” Simmons said. “You can now buy white LED bulbs at home improvement and grocery stores with efficiencies that are more than six times better than incandescents, lifetimes of 50 times more than a typical incandescent and at prices close to that of incandescent bulbs. Solid-state lighting is rapidly penetrating the market, and we believe that in our children’s lifetimes it will completely displace all

other forms of general illumination so that incandescents and fluorescents will simply become museum pieces, like Victrola record players.”

The impetus for solid-state lighting came from the huge potential for energy savings. Commercially available white LEDs today are about 30 percent efficient, with 50 percent efficiency on the horizon, Tsao said. Potentially, they could reach 70 to 80 percent efficiency.

That was not the case in the early 1990s when Congress created the Technology Transfer Initiative, which funded national labs to collaborate with industry partners. Sandia worked on several collaborations, including one with Hewlett Packard in the area of compound semiconductors. That eventually led to the intellectual collabora-

tion of the white paper, which gained traction with industry when it was promoted by the Optoelectronics Industry Development Association.

The white paper also was the foundation of a three-year Sandia Grand Challenge Laboratory Directed Research and Development project, “A Revolution in Lighting — Building the Science and Technology Base for Ultra-Efficient Solid-State Lighting.” The LDRD, launched in 2001 and spearheaded by Simmons, coincided with the solid-state lighting community’s support of a national initiative.

Sandia’s work has earned more than 20 patents, led to numerous strategic partnership projects and Cooperative Research and Development Agreements with industry and generated 41 LDRD projects since 2001.

Different routes to impacting industry

While Sandia has had technology transfer agreements with individual industry partners and has licensed patents in solid-state lighting, “I think our other routes, where we have had industry-wide impact, have been even more important,” Tsao said.

He believes Sandia’s influence has been broad, through its many publications, the impact of the white paper, Sandia’s leadership of workshops

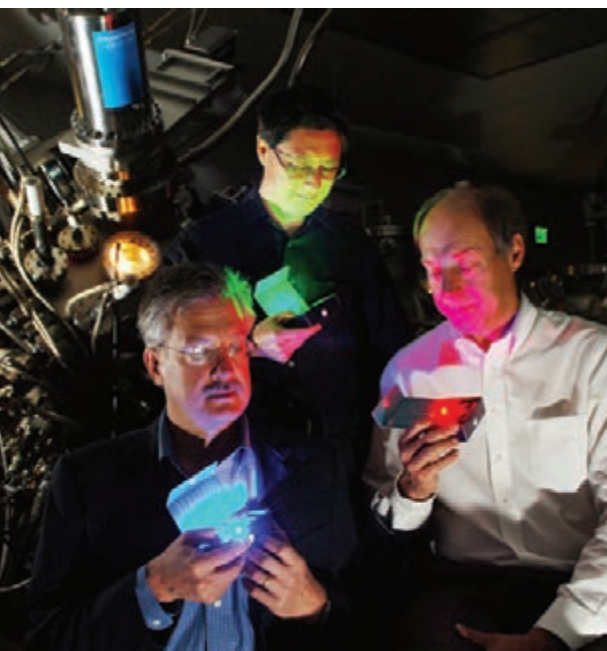
that developed roadmaps for the future direction of the technology and the labs’ ongoing contributions to solid-state lighting research and development plans from the Energy Department’s Office of Energy Efficiency and Renewable Energy.

The original goal was to save energy by creating efficient LEDs and helping get them to market. “If you don’t have the commercialization piece, then you don’t save energy because people aren’t installing the lights,” he said. “You need both.” Reaching that goal also led to unanticipated spin-off developments now coming to the fore. For example, the emerging field of wide bandgap power electronics relies on semiconductors such as gallium nitride or GaN, the same semiconductor needed for blue LEDs.

“There are so many companies that are feeding the different levels of the food chain in GaN-based devices,” Tsao said. “Whether it’s a substrate, processing equipment or other equipment, there this whole industry centered around blue and white LEDs. You can leverage a lot of that for power electronics. Power electronics will be important for solar power, for wind power, for renewable energy, for the smart grid of the future, for all these things where you have to transform voltages and switch currents.”

Now, with the onset of the internet of things, people want everything connected to the internet. Light fixtures — the most ubiquitous grid-connected appliances on the planet — could be an important path, Tsao said. Sandia has started exploring integrating more functions into lighting with an industry partner, Lumileds.

“You want those fixtures to communicate, so add WiFi to them. You might want to speak to them, so have a microphone in there. You could turn them into a speaker so they can speak back,” Tsao said. “You might want them to sense chemicals or biochemicals that you want or don’t want nearby. Perhaps they could sense humidity and temperature, or people, like who’s in the room, and if there’s nobody in the room, why don’t we turn off the lights? And, depending on who’s in the room, tailor the lighting levels to their individual preferences.” ■





CATCH A
Wave

With technical help from Sandia Labs, a Santa Fe company uses the motion of the ocean to bring fresh water to coastal communities

By Nancy Salem

Hurricane Katrina whipped up huge, powerful waves that caused severe destruction in 2005 along the U.S. Gulf Coast. Their size and strength convinced Phil Kithil of Santa Fe there had to be a way to harness that energy.

His first thought was a device that would use wave action to pump deep, cold seawater to the surface to dampen the intensity of hurricanes, which thrive on warm water. He proved the concept with a simple tube and one-way valve attached to a buoy, but the idea had no commercial potential as hurricanes are unpredictable.

He thought of a second use because the wave-action pump also brought to the surface concentrated ocean nutrients such as phosphate and silicate that promote the growth of phytoplankton. “Phytoplankton take in carbon dioxide to metabolize nutrients and give off oxygen,” Kithil said. “We felt the pumps had a role to play in climate change mitigation.”

But, again, the business potential evaporated when governments participating in the 2009 United Nations Copenhagen Climate conference did not take action that would open carbon markets for the device.

The third idea was the charm. Kithil and his company, Atmocean Inc., founded in 2006, partnered with the Albuquerque engineering firm Reytek Corp. in 2010 to produce a pump system that uses wave power to send pressurized seawater onto shore where it is desalinated without the use of external energy. Kithil said the system has a simple design and can be set up cheaply and in rural settings to provide fresh water for drinking and farming in coastal cities.

Working with scientists at Sandia Labs through the New Mexico Small Business Assistance (NMSBA) program, the two companies have tested and advanced the technology and moved it close to market by attracting significant investment. “We wouldn’t be where we are today without Sandia’s help through NMSBA,” said Chris White, Atmocean’s chief operating officer. “It provided us with the backbone of validating our technical improvements so we could go forward.”

A hand with R&D

NMSBA is technology transfer at a grassroots level. The public-private partnership among Sandia, Los Alamos National Laboratory and the state of New Mexico lets small business owners who have a technical challenge work with scientists and engineers at the national labs. Created in 2000 by the state

legislature, the program brings world-class technology and expertise to small companies and promotes economic development with an emphasis on rural areas. NMSBA has provided 2,648 small businesses in all 33 of the state’s counties with more than \$53.3 million worth of research hours and materials.

“Many small companies don’t have the resources to do advanced research and development. NMSBA is a great way to give them an R&D hand,” said Jackie Kerby Moore, manager of Technology and Economic Development at Sandia. “National laboratory expertise helps these people realize their dreams and build their businesses, a win-win for the economy.”

Kithil and Phillip Fullam, chief engineer of Reytek, first worked with Sandia’s Rick Givler, a specialist in modeling physical systems, to assess the feasibility of their near-shore wave energy system. Givler proved that, using typical waves and a set number of seawater pumps, considerable pressurized water would reach an onshore reverse osmosis water purification system.

“We needed to know if we would get a dribble at the end or a gusher of pressurized water,” Kithil said. “Rick came up with the answer — a gusher. If it was a dribble we’d have no business. With a gusher we could estimate expenses and profit. That’s how important the Sandia research was. We could take an interesting idea to business feasibility.”

Sandia’s findings have helped Atmocean attract about \$3.5 million in investment to continue product testing, add staff and boost component manufacturing at Reytek. The company built full-size seawater pumps and tested the system off the coast of Oregon in 2011 and off Peru for six months in 2015. “The first Peru tests were a big success,” Kithil said. “Other small communities want to see if it will work for them.”

Demonstrated in an operational environment

Atmocean in 2017 signed a fourth NMSBA agreement — small businesses can apply for help through the program once a year — and is working with Sandia engineer Tim Koehler on computational modeling of the wave energy system. Following trials in a test tank at the Texas A&M University Haynes Laboratory, the system will be deployed later in the year off the coast of Newfoundland for a third round of testing, bringing it to a technology readiness level, or TRL, of seven. There are nine levels in the TRL method of estimating technology maturity. Level seven means the prototype has been demonstrated in an operational environment.



Mechanical engineer Tim Koehler uses computational fluid dynamics to help the Santa Fe, New Mexico, company Atmocean with the design of a buoy.

Atmocean’s current system is a 200-foot by 200-foot array of pumps floating on the ocean. “Each pump is a buoy on a piston,” Koehler said. “As a wave passes, the buoy ingests sea water, and as the buoy settles, it pumps seawater through hydraulic lines back to shore where it enters the zero-electricity desalination process.”

Water arrives onshore at about 180 psi, or pounds per square inch of pressure. Atmocean uses energy recovery devices — essentially spinning mechanical wheels — to boost 14 percent of the arriving seawater to 900 psi, the pressure needed to run reverse osmosis. The RO system is the size of a shipping container and is manufactured by Atmocean industry partners. “We supply the pressurized seawater and we work with standard industry-proven technologies on the desalination,” White said.

The system runs 24/7 and production depends on wave action. White said that in southern Peru, in typical ocean conditions, 50 million cubic feet of pressurized water is pushed to shore in a year. Fourteen percent of that is desalinated, producing 5 million cubic feet of fresh water annually that can be used for agriculture or consumption.

Kithil said the system is inexpensive to operate, offers local employment and helps the environment. “Each array of pumps creates a defacto marine protected area with artificial structures that see marine growth,” he said. “The system uses small boats operated by local fishermen who get consistent work. During our full-scale pilots in Peru in 2015, we saw a huge outpouring of support from the local fishing community.”

Ocean forces on buoys

Kithil and Fullam are working with Koehler to

improve the pump design. “They want to know what forces the ocean, through the passage of waves, puts on the buoys, so they can optimize their performance and be as efficient as possible,” Koehler said. He is using computational fluid dynamics modeling to evaluate various buoy designs engineered by Reytek and narrowed down through wave pool tests. “It will give them an idea of ocean forces on various pump designs,” he said.

Koehler’s first foray into NMSBA has been eye-opening, he said. “It’s a different application than what I typically work on and uses different software, so it adds some breadth to my experience,” he says. “It’s been a good process in terms of my personal and professional growth. I’m learning more, and it’s nice to help a small business. I like the idea. It’s a good way to help rural communities with clean energy technology.”

After the final demonstration in Newfoundland, Atmocean, which presented the technology at the 2016 United Nations Solutions Summit, will seek a commercial partner. “If all goes well, we’re looking at a year and a half after the tests to reach commercialization,” White said.

Fullam said NMSBA has been critical to the success of Atmocean. “Sandia has resources and experience in areas we don’t,” he said. “The computer modeling tools are something a small company could never afford. We’ve been able to use those resources to answer some rather esoteric questions and generate more questions. The people we’ve dealt with really know what they are doing, and we were able to pinpoint early in the development some key technical issues we wouldn’t have seen. We would have spent a lot of time spinning our wheels. It cut years off the development cycle.” ■

FUELING THE FUTURE

For more than 10 years, an institute full of dogged scientists has been working to free the energy stored in plants and use it to power transportation and create renewable products. The results are finding their way from the lab to the marketplace and into peoples' lives.

BY JULES BERNSTEIN



T Imagine a world where many of our country's cars, trucks and airplanes run on fuel derived from plants instead of petroleum. Further imagine a world where many common household products such as plastics, medications, adhesives and fabrics currently made from petroleum are derived from plants as well. In this vision, these plants are grown domestically, require little water or fertilizer and do not compete for resources with food crops. This is the vision that the Joint BioEnergy Institute (JBEI) in Emeryville, California, is working to realize.

JBEI is a Department of Energy Bioenergy Research Center founded in 2007. Since then, significant progress toward its petroleum-free vision has become evident in many respects. As of April 2017, new inventions from its research have led to 261 invention disclosures (a first step in the patent process), 174 patent applications and 89 patents licensed to companies both in the U.S. and around the world. Additionally, JBEI scientists' 704 articles published in peer-reviewed publications have been cited by researchers more than 26,100 times. All these accomplishments are partly a result of the way the institute is set up. JBEI is a consortium of

seven organizations: Sandia, Lawrence Livermore, Lawrence Berkeley and Pacific Northwest national laboratories; the Carnegie Institute for Science; and the Berkeley and Davis campuses of the University of California. Scientists from each of these organizations are housed together under one roof, divided into four main departments that mirror the production process from sunlight to biofuels: feedstocks, deconstruction, fuel synthesis and technology.

Growing plants for gas

Sunlight energy is stored in plant cell walls as chemical energy, which JBEI is working to convert into transportation energy and green products. To release chemical energy, mostly in the form of sugars, scientists need to deconstruct lignin, the other component of plant cells, which guards the sugar. Lignin is shockingly tough to break down by design. It is essential for plants, giving them structure, allowing them to transport water against gravity, and protecting them from microbial attacks. However, getting past lignin to extract sugars for biofuels is essential for JBEI. Toward this goal, the feedstocks department is breeding plants that produce less lignin, and is working to make the remaining lignin easier to break down.

Inside the Joint BioEnergy Institute in Emeryville, California, researchers use the latest tools in molecular biology, chemical engineering, and computational and robotic technologies to transform biomass into fuels.





JBEI is working with the San Mateo, California, company Afingen on bioengineered switchgrass as a source of fuel.

JBEI scientists also found a clever way to rewire the signals plants send themselves to sprout and grow each season, resulting in crops that are better for biofuel production. This technique copies a small piece of the plant's own DNA and reinserts that piece elsewhere in the plant cell. One start-up company now using JBEI's technique is Afingen.

CEO Bill Shelander explains the benefit of this new process for engineering crops: "Most other DNA modifications require larger DNA fractions that are randomly inserted and typically result in a very weak plant that doesn't survive well in the field. This technique is specific to one part of the plant and doesn't require DNA from any other organism."

Afingen received Department of Energy Small Business Innovation Research funding to demonstrate these and other proprietary insights in switchgrass, a native American prairie grass. By September 2016 enough of this grass had been grown in a greenhouse to allow transplanting to a test field. All of the plants in this field trial were cut to the ground in February 2017 for testing. For now, the Afingen team is excited to see the obvious difference in growth between Afingen's grass and non-bioengineered switchgrass.

Plant deconstruction and fuel synthesis in a single pot

With bioengineered plants in hand, JBEI's deconstruction department is dedicated to developing

technologies that can extract fermentable sugars. Plant cell walls are made of cellulose — long chains of glucose sugars linked together — and lignin. The bonds between glucose chains can be difficult to break apart. Deconstruction scientists are developing multiple means of breaking the chains to release 6-carbon sugars (the type of sugar most microorganisms prefer) from plant biomass.

One such method is pre-treating the biomass with organic salts that exist as liquids at temperatures below 100 degrees Celsius, called ionic liquids. These liquids dissolve the complex biomass cell walls so enzymes can access their sugars. Led by JBEI's director of Biomass Pretreatment, Seema Singh of Sandia Labs, the deconstruction scientists have filed multiple patents on new ionic or "bionic" liquids made from recycled biofuel production byproducts such as lignin. They are also engineering new enzymes and microbes to be able to break down glucose while in the presence of ionic liquids.

Some of these discoveries have been licensed to companies like Ilium Technologies. Singh, along with former Sandians Blake Simmons and Aaron Socha, formed the company around JBEI's bionic liquids. There are many applications for the bionic liquids they produce, including biofuels and the production of batteries and greenhouse gas-reduction devices.

The sugars and lignin monomer molecules left after deconstruction are then ready for the final step in the biofuel production process. In the fuel synthesis group, JBEI scientists engineer microbes such as yeast and *E. coli* that consume the sugars and turn them into advanced fuels that are compatible with current engine technologies and, hopefully, with the more efficient engines of the future. The microbes also could be engineered to convert the sugars (and lignin) into industrial chemicals such as solvents or synthetic textiles like polyester and plastics. This is one of JBEI's goals going forward.

In the past two years, JBEI has made a lot of progress developing what it calls an "integrated one-pot process" that takes biomass from deconstruction to fermentation of sugars in one tank. This reduces the number of steps involved in production, reduces water usage, brings down the cost of making biofuels, and thus brings them closer to being commercially viable.

The digital backbone of the operation

Creating and screening thousands of molecules with conventional methods would be expensive and extremely time consuming, so a fourth JBEI department develops technology and software enabling such large-scale DNA design and molecular analysis.

If an organism like yeast or *E. coli* that makes alcohol as part of its metabolism is going to produce other useful chemicals, scientists must reprogram the organism's DNA. For example, with DNA modification, *E. coli* might be able to produce adipic acid, which can be made into a renewable product like nylon.

Teselagen, another startup company, uses JBEI's patented automatic protocol generation technology to produce DNA modification instructions. Founder and CEO Mike Fero explains the role of protocols this way: "Molecular bio labs are essentially kitchens. You have freezers and stoves and things for dispensing liquids, and protocols. Protocols are the recipes. They even have a list of ingredients at the top, and the same kinds of instructions."

From fuels to the future

While continuing its focus on making biofuels competitive with petroleum, many consider the numerous JBEI patents, intellectual property licenses, industry partnerships and multiple spin-off

JBEI is funded by the Department of Energy and is a partnership of Lawrence Berkeley National Laboratory, Sandia National Laboratories, Lawrence Livermore National Laboratory, University of California at Berkeley and Davis, and the Carnegie Institute. Its goal is to develop advanced biofuels – liquid fuels derived from the solar energy stored in plant biomass that can replace gasoline, diesel and jet fuels.

companies to be signs of the institute's success. This success didn't happen by accident. JBEI founders created a one-stop shop for IP and licensing to facilitate work with interested industry partners.

However, others, like JBEI Director of Commercialization Peter Matlock, argue that the institute's most potent agent of influence is its workforce. "Our most effective technology transfer is through our people. We've had hundreds come through here as students and postdocs in the past decade who then have gone on to academic posts, government labs and to industry around the world," he said.

Thanks to JBEI's work, the world may one day operate on biofuels and consume more renewable products. But the work done to date has indisputably contributed to better use of biology for industrial purposes. "We've done a lot to move bioengineering forward in a more sophisticated way," said Matlock. "Many of us grew up with the saying 'better living through chemistry' but given all of JBEI's progress I'd retool this to 'better living through biology.'" ■





MEET

Traci Lopez

Having a piece of New Mexico in Northern California's Bay Area was a selling point for software engineer Traci Lopez. The Santa Fe native and granddaughter of a former Sandia electrical engineer knew she wanted to be part of a lab working toward a sustainable and clean-energy future.

"When I saw that Sandia was hiring a software engineer at the Joint BioEnergy Institute, I immediately jumped at the opportunity. I wanted to apply my skills with a lab that has ties to my home," she said. "My interest and excitement for what we are doing and how we are changing energy as we know it have only continued to grow."

At JBEI, Lopez works on the Experiment Data Depot, an online application designed as a repository for storing, sharing, viewing and visualizing experiment data and metadata. "We are bringing an engineering approach to synthetic biology research with the goal of increasing the reproducibility of experiments," she said.

Lopez is interested in applying machine learning models to experiment data to better predict and optimize how scientists might run future experiments.

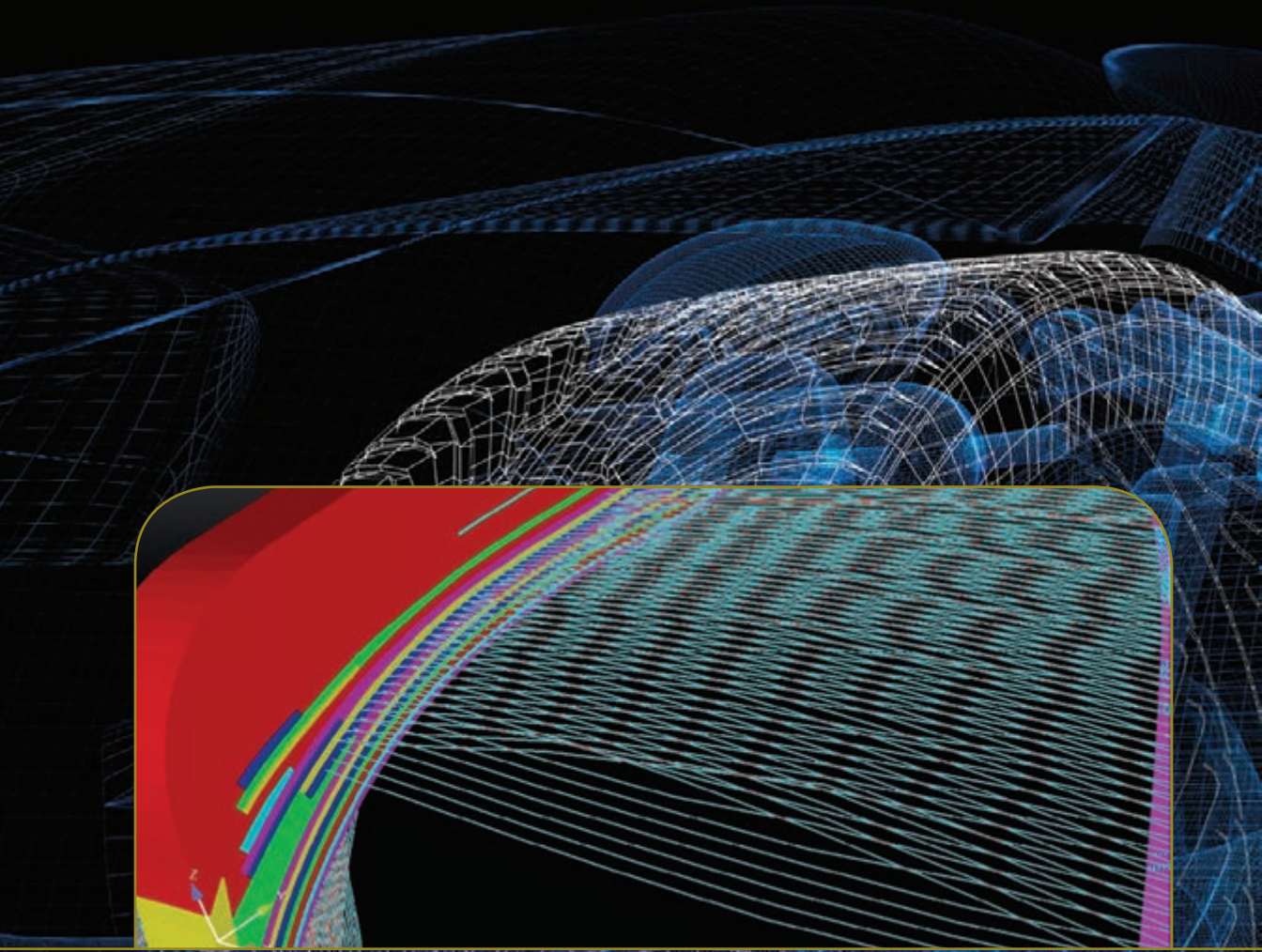
After receiving a degree in mathematical economics from Pitzer College in Claremont, California, she moved to the Bay Area where she discovered a passion for building software. She started her tech career working for a solar company in Oakland as a project manager while spending free time taking online courses, attending Meetups and writing computer code. The company recognized her passion for and growing expertise in building software and gave her a full-time software developer position.

Lopez said people interested in a STEM (science, technology, engineering and math) career should not be intimidated and instead take advantage of all learning opportunities. "There are a lot of passionate people trying to make a difference and innovate. It's just a matter of jumping on board," she said. "My best advice is to be confident and don't be afraid to ask questions."

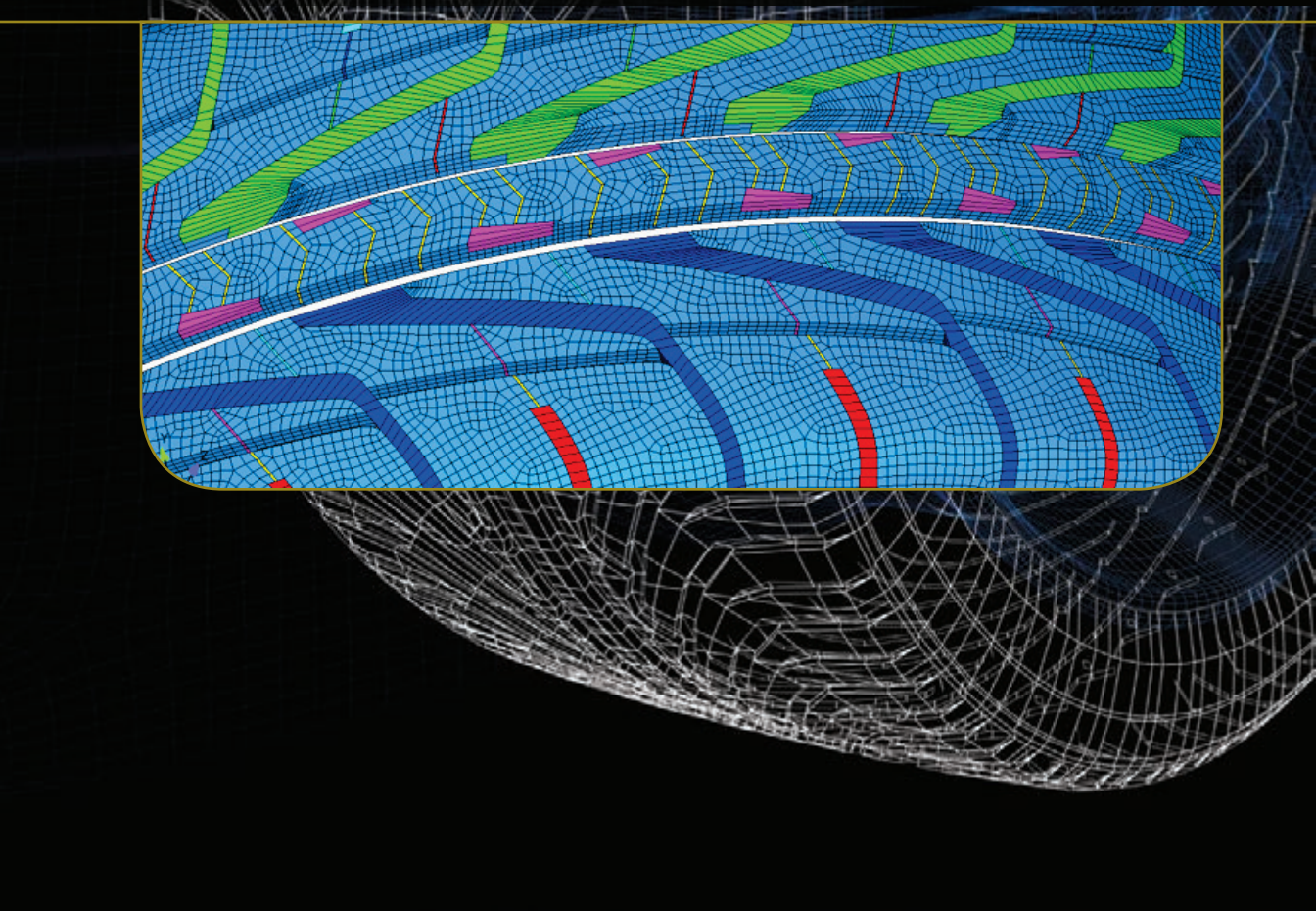
Lopez gravitates to the outdoors and enjoys skiing, biking, climbing, kayaking and discovering new places to visit around Northern California.

— Michael Padilla





STREETSMART



In a collaboration almost as old as technology transfer itself, Sandia and The Goodyear Tire & Rubber Company have worked together for 25 years to create better vehicle tires and more advanced computational mechanics.

“You might wonder how national defense systems relate to tire engineering,” said Susan Seestrom, Sandia’s chief research officer. “But a tire is a complex system – one of the most formidable challenges in computational mechanics – and that’s something Sandia knows well.”

The joint work allows Sandia to enhance its software toolkits and improve its capabilities for mission applications while simultaneously addressing Goodyear’s proprietary challenges. “It is remarkably complicated to model and simulate tire performance, let alone under varying temperature, pressure and wear conditions,” said Chris Helsel, Goodyear’s chief technology officer. “Our computational work with Sandia is a continuous source of competitive advantage for Goodyear, helping us design and deliver high-performance products and services in a digital economy.”

back when technology transfer from the national labs was in its nascent stage. In 1980, the Stevenson-Wydler Technology Innovation Act was signed into law by President Jimmy Carter, becoming the first major U.S. technology transfer legislation. It required federal laboratories to actively participate in and budget for technology transfer activities.

Stevenson-Wydler was followed by the Federal Technology Act of 1986, the second major piece of legislation focused on tech transfer from federal government agencies to the private sector. It established the Federal Laboratory Consortium and let federal labs enter into CRADAs with private industry.

“Tech transfer was an exciting new opportunity for the labs,” said Mary Monson, senior manager of Technology Partnerships at Sandia. “The Department of Energy really embraced the tech transfer concept for federal agencies in the late 1980s and early 1990s. Part of the defense programs budget was put aside for U.S. economic security as well as enhancing the capabilities of the labs through solving complex real-world problems.”

Tires and national security might not seem to have a lot in common. But for 25 years, Goodyear and Sandia Labs have worked together and raised each other's game.

By Nancy Salem

Goodyear’s engineers design every tire with Sandia-developed tools. The company credits its work with Sandia for reducing new product development times, improving manufacturing methods, and lowering both technical and operational costs, all contributing to a competitive advantage in a complex industry.

Ted Blacker, Sandia’s manager of Simulation Modeling Sciences, said the partnership has been successful because it is strategic. “We focus on strategic technical challenges where advanced technology from both sides can change the future,” he said. “Almost without fail, the new capabilities they commission us to develop, for example, to model rotating, twisting and deforming tires, help us with simulations in our national security work.”

Sandia and Goodyear signed a Cooperative Research and Development Agreement, or CRADA, in 1993,

Designing the ideal tire

Goodyear took note, reaching out to Sandia in 1992, with the two organizations forging a relationship through back-and-forth visits to each other’s sites.

“They looked at our advanced computational mechanics software developed for nuclear weapons programs after the government halted underground testing and saw that they could be applied to tires. Instead of building and testing three to five prototypes before a tire was ready for manufacture, they could use our computer codes to develop one,” Monson said. “Time to market a new design was dramatically reduced, by half or more.”

Sandia’s tools went to work on the many components of a tire system. “Modeling the pneumatic tire for performance and handling predictions was a challenge in several computational mechanics areas,



Sandia computer scientists Vicki Porter, left, and Byron Hanks, second from left, and Antonio Recuero, second from right, and Mohammed Sobhanie of The Goodyear Tire & Rubber Company study images of tire technology.

including composites modeling, contact mechanics and rubber material behavior,” said Sandia technical lead Martin Heinstein. “The mechanics and solvability challenges aligned well with Sandia’s need to develop code for large-scale, massively parallel platforms.”

“It’s often surprising to people to learn just how complicated it is to model and simulate tire performance, considering millions of material combinations and permutations and blending structural mechanics, rigid body and fluid dynamics under varying temperature, pressure and wear conditions,” said Dale Moseley, Goodyear’s global project manager.

Generate buzz

An early victory for the collaboration was the Assurance TripleTred, a unique all-weather tire with a three-part tread compound. Goodyear wanted a visually distinctive tire that would generate buzz and demonstrate its best technology. The Assurance line was launched in 2004, and in 2005 Sandia and Goodyear won a joint R&D 100 Award for the tires, particularly the TripleTred, which was brought from concept to market in less than a year. Goodyear said the tire could not have been produced without modeling and predictive testing tools developed with Sandia.

A wide range of lab technologies have played a role in the CRADA including advanced computational mechanics, sophisticated geometry and meshing, computational simulation and verification, elastomeric materials, structural and tire dynamics, advanced manufacturing of rubber products, efficient characterization methods for structural dynamics, reliability tools for manufacturing processes, sensor systems, data science, human reliability and engineered products.

“Our relationship with Sandia has been very beneficial in our competitive success in the global automotive

industry, allowing us to begin submitting ‘virtual tires’ to automakers that can be incorporated into their vehicle models early in the development process as they tune the vehicle designs,” Moseley said.

The CRADA has been renewed repeatedly since 1993 and Goodyear continues to produce innovative products developed in collaboration with Sandia. Much research done under the CRADA has been applied to Sandia’s science-based nuclear weapons stockpile stewardship mission.

“So many good things have come out of this enduring partnership,” Monson said. “It has worked both ways. We were able to apply our codes to a real-world problem, and improve our codes. And Goodyear was able to develop revolutionary products.”

The work with Goodyear led to a deeper appreciation at Sandia of the value of computer modeling in the early stages of development.

“We showed that modeling and simulation made a difference in developing better products faster,” Blacker said. “Our computational tools typically were used late in the process to understand why something broke and how to fix it. Now we use modeling more in the up-front stages, such as in the early design, to reduce testing.”

Monson said CRADAs are an important technology transfer tool. “They help us sustain and improve our capabilities because we’re applying our technology to a company’s pressing problems,” she said. “There’s an urgency. It’s not abstract.”

She said the Goodyear CRADA has allowed Sandia researchers to work with peers in industry and share best practices. “It really is collaborative,” she said. “Both teams bring a different way of looking at a problem. We have learned a lot through those interactions about how to approach problems differently.” ■



MEET

Jason Martinez

As a prosecutor in the Sandoval County District Attorney's Office, Jason Martinez got a lot of experience in the courtroom. He tried dozens of cases with a conviction rate of 94 percent. "It's like playing chess in front of 50 people," he said. "They're all watching every move."

Raised in Albuquerque, Martinez was the first in his family to graduate from college. He earned bachelor's degrees in economics and political science from the University of New Mexico and interned summers with then-Sen. Pete Domenici and in the White House, where he worked in President George W. Bush's Office of Strategic Initiatives. "It was an exciting time," he said. "I did research on the Energy Policy Act of 2005 for Senator Domenici and worked in foreign affairs at the White House in 2006 at the height of the Iraq War and Russian invasion of Georgia. I was 20 and 21 those summers. It was an honor to be exposed to that level of staff."

It left Martinez with a desire to go into law. He entered a four-year program at UNM that gave him the dual degrees of master of business administration and juris doctor. He joined the prosecutor's office and describes his 18 months as a trial attorney as "tremendous."

Martinez got to know Sandia Labs the summers he wasn't interning in Washington, D.C. "My first position was picking up tumbleweeds when I was a junior in high school," he said. He later interned in radiation protection and sample diagnostics, and did research on congressional bills, committees and appropriations.

When he heard the lab was looking for a specialist in Cooperative Research and Development Agreements, or CRADAs, he was intrigued. "I saw that I could use my MBA and law degree in a single position," Martinez said.

He signed on in June 2013 and was given the chance to develop the position. He seeks out researchers, technologies and industry partners that could benefit from CRADAs, negotiates agreements, improves and streamlines the process and expands on program successes.

Martinez, who in his spare time enjoys watching and playing sports including basketball and golf, has seen Sandia's CRADA portfolio grow and set records each of the past three years. "This is a great mechanism for getting national laboratory technology into the private sector," he said. "CRADAs have impact on our national security mission and on local and national economies."

— Nancy Salem



Cool, calm & reflected

Nanoparticles in a thin window film can beat the heat

By Mollie Rappe

It is a truth universally acknowledged, that a car sitting in the sun on a summer day must be sweltering. However, thanks to a partnership between Sandia Labs and the Albuquerque company IR Dynamics, that truth might not be so universal.

Together they are turning nanoparticles that reflect heat, infrared radiation, into window films for offices, houses, and even cars.

The partnership started in the fall of 2013 through the New Mexico Small Business Assistance (NMSBA) program, a partnership among Sandia Labs, Los Alamos National Laboratory and the state of New Mexico that lets small business owners who have a technical challenge work with scientists and engineers at the national labs. Paul Clem, a materials physicist at Sandia, was studying films 25 times thinner than a human hair that switch between being an insulator and a metal depending on the temperature for

possible use in electronics. William Kurtz was heading a company making energy efficient aerogel insulated windows and skylights. They met in a tech park in Santa Fe and started to discuss the need for windows that could let heat in during winter months and keep it out in the summer months.

Some materials, like aluminum foil, reflect light and heat. Other materials are transparent to light, like glass and plastic. A few rare materials can be both depending on their temperature. Vanadium dioxide is one such material.

In fact, vanadium dioxide is thermochromic. At cooler temperatures it is transparent to infrared light. When it heats up, it becomes a metal that reflects IR radiation while still letting visible light through. This dynamic switch between IR transparent and IR reflective gave rise to the company name IR Dynamics.



Materials physicist Paul Clem holds a sample of nanoparticle coated glass. Thermochromic nanoparticles switch from infrared transparent to infrared reflective when they heat up, which will help to keep office buildings, homes and even cars cool.



These materials switch due to temperature instead of applying external electricity like electrochromic materials. Electrochromic glass is a growing sector of the window industry but is expensive and requires infrastructure like wires and switches. Thermo-chromic materials are autonomous, making them interesting scientifically and commercially.

Tunable and reflective nanoparticles

With help from NMSBA and a Cooperative Research and Development Agreement, or CRADA, a team of researchers including Clem spent several years trying to develop easy-to-apply polymer films with thermo-chromic vanadium dioxide nanoparticles.

Sandia materials chemist Nelson Bell was primarily responsible for designing and implementing a

multi-stage process of making nanoparticles. He also determined the best way to disperse the nanoparticles in a spray-paint-like mixture, which led Bell to call himself a paint chemist.

The biggest challenge, said Kurtz and Clem, is figuring out how to scale up the synthesis to make the pounds of nanoparticles needed to manufacture commercial products.

In addition to figuring out how to make larger quantities of vanadium dioxide nanoparticles, the team worked on how to tune the switching temperature. For example, it might be best for car windows to start reflecting heat at 78° Fahrenheit but another temperature might be better for other applications. By tweaking the “recipe” and adding tiny amounts



William Kurtz, left, president of IR Dynamics LLC of Santa Fe, works with Sandia's Nelson Bell on developing thermochromic materials to control infrared transmission.

of different metals, the team was able to make nanoparticles that could switch at any temperature from 200° to -40° Fahrenheit.

Characterizing these “batches” of nanoparticles to make sure they had the correct properties was the responsibility of Sandia materials scientist Raegan Johnson. She used high-end equipment such as a Fourier transform infrared spectrometer, X-ray diffraction instrumentation and a transmission electron microscope to determine the infrared absorbance, chemical structure and physical structure of the nanoparticles.

“A start-up the size of IR Dynamics can’t afford to purchase the diagnostic equipment that is available through Sandia Labs. Through the NMSBA and CRADA programs we are able to use those resources to de-

velop the technology,” said Kurtz. “It is important for small technology companies like ours to be able to partner with the national laboratories. I think that it is part of what keeps us competitive as a nation with the rest of the world.”

Nanoparticles for retrofitting windows

The first product Kurtz hopes to get to market is a film to retrofit windows; something homeowners could apply to their existing windows to reduce their heating and cooling bills. Future applications include incorporating the nanoparticles into new windows and adding them to architectural plastics such as the kind used in the Water Cube of the 2008 Beijing Olympics, or to high-performance athletic clothing.

In June 2016, IR Dynamics received a \$1.95 million grant from the Department of Energy’s Advanced Research Project Agency-Energy SHIELD program to bridge the “valley of death” and make retrofit window films a reality. The goal of the ARPA-E program is to make single-pane windows as energy efficient as double-pane windows. If every single-pane window in the country was upgraded, it would save about 1.3 percent of all U.S. energy, or roughly the amount needed to power 32 million homes.

Most of the other projects funded through the program focus on reducing heat loss, which is a key concern nationwide. However, in some areas of the U.S., cooling requires more electricity than heating, which makes windows that can reduce both real winners.

Kurtz hopes to have the film to retrofit windows on the market by late 2018. The company has filed several patents. IR Dynamics is also partnering with a leading corporation in the window film and structural plastics industries and a leading company in the high-performance fabric industry.

“Usually the things we do are in technical journals or they’re presented at conferences. It’s rewarding to see things go from idea to a commercial product,” said Clem. “For this company we can point to five new jobs that all started from the first NMSBA agreement. Seeing new companies start up and grow knowing you’ve given them a technical leg up on the competition is satisfying.” ■



**T
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— By Heather Clark —

Understanding the human gaze can help data analysts sort through mountains of information, and make the right decisions.

Intelligence analysts trying to identify national security threats often work with radar or photographic-like images, while others analyze information in abstract forms such as complicated scatter or bar graphs. Some analysts flip through, pan or zoom in and out of multiple images at lightning speed, creating a video-like environment.

The complexity of images, the multitude of tasks analysts must complete and the quickly changing national security environment demand software and hardware that will help viewers analyze images more thoroughly and efficiently to extract useful information. “We want to provide the right information at the right time and in the right format so they can make the best decisions possible,” Sandia Labs cognitive psychologist Laura Matzen says about research on ways to help humans better interact with visual data.

Sandia has combined the expertise of visualization researchers and cognitive scientists, and access to national security analysts and their data to make decisions, to provide new tools and models to advance the field. “Our core problem is designing computational information systems that make people better at getting meaningful information from those data sets, which are large and diverse and coming in quickly in high-stress environments,” said Laura McNamara, an applied anthropologist at Sandia who has studied how certain analysts perform their jobs with radar imagery.

These researchers want to better understand how humans extract information from visual displays so they can make visual designs more useful. They also are working to develop tools and models for academic researchers and industry experts in the field.

Several Laboratory Directed Research and Development projects are working on various aspects of

visual cognition. These include tools that track both where and when a viewer is looking, software that models how eyes dynamically recalibrate their trajectories when tracking moving targets and models that describe how humans scanning a screen with a goal in mind change the way they interact with different types of visual data.

Partner to produce GazeAppraise

Eye tracking, which has been used for years to measure where the eye is looking mainly on static computer screens, is one tool researchers use to determine how humans use visual data. In 2015, Sandia signed a Cooperative Research and Development Agreement with EyeTracking Inc. of Solano Beach, California, a partnership that led to the development of award-winning eye-movement analysis software.

GazeAppraise won a regional Federal Laboratories Consortium award in 2016 for software that characterizes eye movements when people are interacting with dynamic data. GazeAppraise can be used to improve performance in dynamic image analysis in medical diagnostics, airport security, nuclear nonproliferation and other areas where people work with soft-copy, or digital, images.

GazeAppraise also fills a gap in eye-tracking research by creating a new way to analyze data by where and when the viewer looks, Matzen said.

GazeAppraise applies Sandia’s Tracktable code, which automates the observation of motion and trajectories, said researcher Mike Haass. One early example of Tracktable was an analysis of air traffic patterns over a day across the U.S. Like Tracktable, GazeAppraise uses geometric descriptors to cluster similar scan paths to speed software processing, Haass said. Scan paths are ways humans scan for information on displays. For example, a well-understood scan path is that Latin-language readers scan pages from left to right.

To GazeAppraise, eyes scanning screens can be understood as trajectories, just as flying aircraft are, though with different properties, Haass said. “Your eyes can stop and turn 180 degrees on a dime and an airplane can’t. So the algorithms that work for airplanes don’t work for eyes,” he said, explaining that his team created new software features to capture the trajectories of human gazes on screens.



This award-winning image by Sandia researcher Andy Wilson shows PANTHER’s geometric and temporal trajectory analyses of air traffic patterns from 43,000 flights over the U.S. on April 4, 2014. White lines represent level flight, orange lines indicate ascent and blue lines show descent.

EyeTracking provided a deep knowledge of eye-tracking systems and a task and data to test GazeAppraise, Haass said. The two partners are working to make the tool commercially available.

GazeAppraise has been used on several projects at Sandia. For example, it analyzed eye-tracking data from neutron generator engineers to find consistent patterns used by the most efficient employees. The analysis led to a redesign of the software that helped the engineers complete the task more quickly. In doing so, GazeAppraise meant the end of a tedious task for the cognitive and visualization researchers, Haass said. Before GazeAppraise, “you were limited by your working memory and your ability to proceed in the face of monotony. Depending on your data set, it could take days, weeks or months to complete,” he said. “Things that would have taken months are better suited to GazeAppraise.”

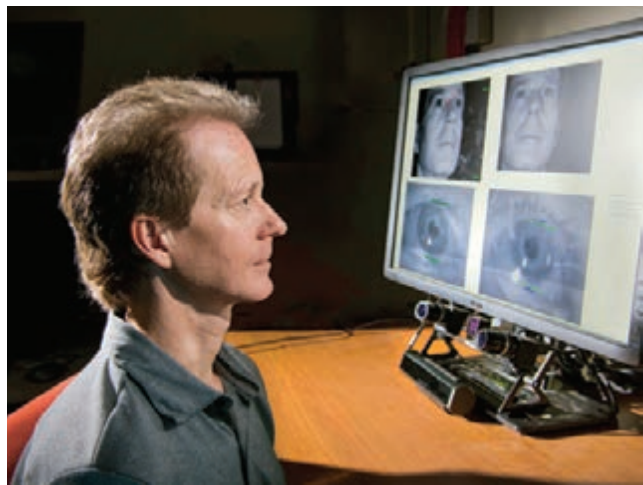
Toward a top-down model of eye tracking

Until now, eye-tracking research has shown how viewers react to stimuli on the screen. For example, a bare, black tree against a snow-covered scene will naturally attract attention. This type of bottom-up visual attention, where the viewer is reacting to stimuli, is well understood, Matzen said.

But what if the viewer is looking at the scene with a task in mind, like finding a golf ball in the snow? They might glance at the tree quickly, but then their gaze goes to the snow to search for the golf ball. This type of top-down visual cognition is not as well understood and that’s where Sandia’s researchers have focused their efforts. Matzen said a recent realization was that top-down visual cognition works differently for photographic-like images than it does for abstract images such as bar graphs.

Matzen’s current research builds on Sandia’s Pattern Analytics to Support High-Performance Exploitation and Reasoning (PANTHER) Grand Challenge LDRD, which developed a method to compare saliency maps of an image with eye-tracking data from a viewer. The maps are colorful images that show which objects in a display were visually salient and important to the viewer’s goal. “Ideally, you want the things that are important to be the most salient,” Matzen said. “You don’t want people to have to waste a lot of time hunting for them or ignoring things, like a flashing red light that’s not important.”

By isolating top-down features, the researchers can quantitatively determine how efficient or useful analysis tools are, Haass said. By comparing a saliency map of where experts in the field find the most useful information with a fixation map that details eye-tracking data showing where viewers are looking, you can create a computer model to predict how people with a goal in mind make sense of the visual information they receive.



Mike Haass demonstrates how an eye tracker under a computer monitor is calibrated to capture his eye movements on the screen. Haass and others are working on the technology with EyeTracking Inc.



MEET

Laura Matzen

A high school term paper on the use of cryptography during the Civil War helped cognitive scientist Laura Matzen land her first Sandia internship. A teacher submitted her paper to the *Concord Review*, a quarterly journal that publishes high school students' work. American Airlines reprinted a photo of the article and a Sandia employee who wanted to work with a student in cryptography read it. Matzen was hired.

After a summer learning how to code, Matzen, then a chemistry major, spent a second summer at the Applied Materials Laboratory where she synthesized a variety of zinc-oxide nanoparticles for thin-film battery research. The paper about that summer project is still one of her most cited, even after nearly a decade working in Sandia's Cognitive Sciences & Systems department.

Matzen earned a doctorate in cognitive neuroscience from the University of Illinois and in 2008 was hired full-time at Sandia. Laura isn't the first Matzen to work at the labs. Her father, Keith Matzen, is director of the Pulsed Power Sciences Center.

When not at work, Matzen spends time with her husband and three daughters. "Sandia is really supportive of that work-life balance, and that's really important to me," she said.

With her young family, Matzen said she hasn't been able to enjoy her artistic hobbies, like mosaics and beadwork, as much as she'd like. An artistic interpretation of an iconic Z machine photograph and a mosaic of Sandia's thunderbird logo hang in her father's office.

Keith Matzen said Laura was asked many times early in her Sandia career if they were related, but he's noticed the tenor of the questions changing. "At this point in time the shoe is often on the other foot; sometimes I'm asked if I know Laura or if I am related to her!" he wrote. "Very cool (spoken as a proud father)."

— Heather Clark

The team hopes to publish a top-down model as open source software, so someone with a mockup of a graph can use it to determine the best design based on the users' goals, Matzen said. Sandia is working with the University of Illinois to develop the new model and Georgia Tech to develop a questionnaire that will help designers determine users' needs.

These and other visual cognition projects at Sandia ultimately seek to strengthen the connections

between humans and technology and to design systems, McNamara said.

"Where this could end up going is ensuring that as we invest money on information and analysis environments for intelligence analysts who are facing this firehose of information, we don't give them software that increases their cognitive and perceptual load or that they just can't use," she said. ■

More *Star Trek* than *ER*, Sandia's lab-on-a-disk quickly tests for diseases, public health threats and chemical and biological attacks, when seconds count.

SPIN DOCTOR

By Jules Bernstein



In the 1960s, *Star Trek* debuted the tricorder, a handheld scanner Dr. “Bones” McCoy would wave over his patients’ bodies to instantly detect disease. Today, Sandia Labs has come close to realizing that futuristic vision with SpinDx, a four-pound lab-on-a-disk that can simultaneously test for up to 64 markers of diseases and of chemical and biological attacks.

SpinDx can be manufactured more inexpensively than traditional laboratory testing equipment, and reliable results of its tests on biological samples such as blood, saliva and urine are ready within 15 minutes. But its greatest strength is versatility. SpinDx can be adapted to detect an almost limitless number of public health problems, including food-borne bacteria, viruses, toxins, small molecules and deadly white powders. It can differentiate between types of cells, allowing a doctor to see, for example, whether a patient has decreased levels of certain white blood cells, a hallmark of radiation exposure.

“In the past you needed a gigantic lab with lots of people in white coats making these tests work. We’re trying to bring the tests into a format that can be run in any doctor’s office or clinic anywhere in the world,” said Sandia chemist Chung-Yan Koh.

The evolution of micro-diagnostics

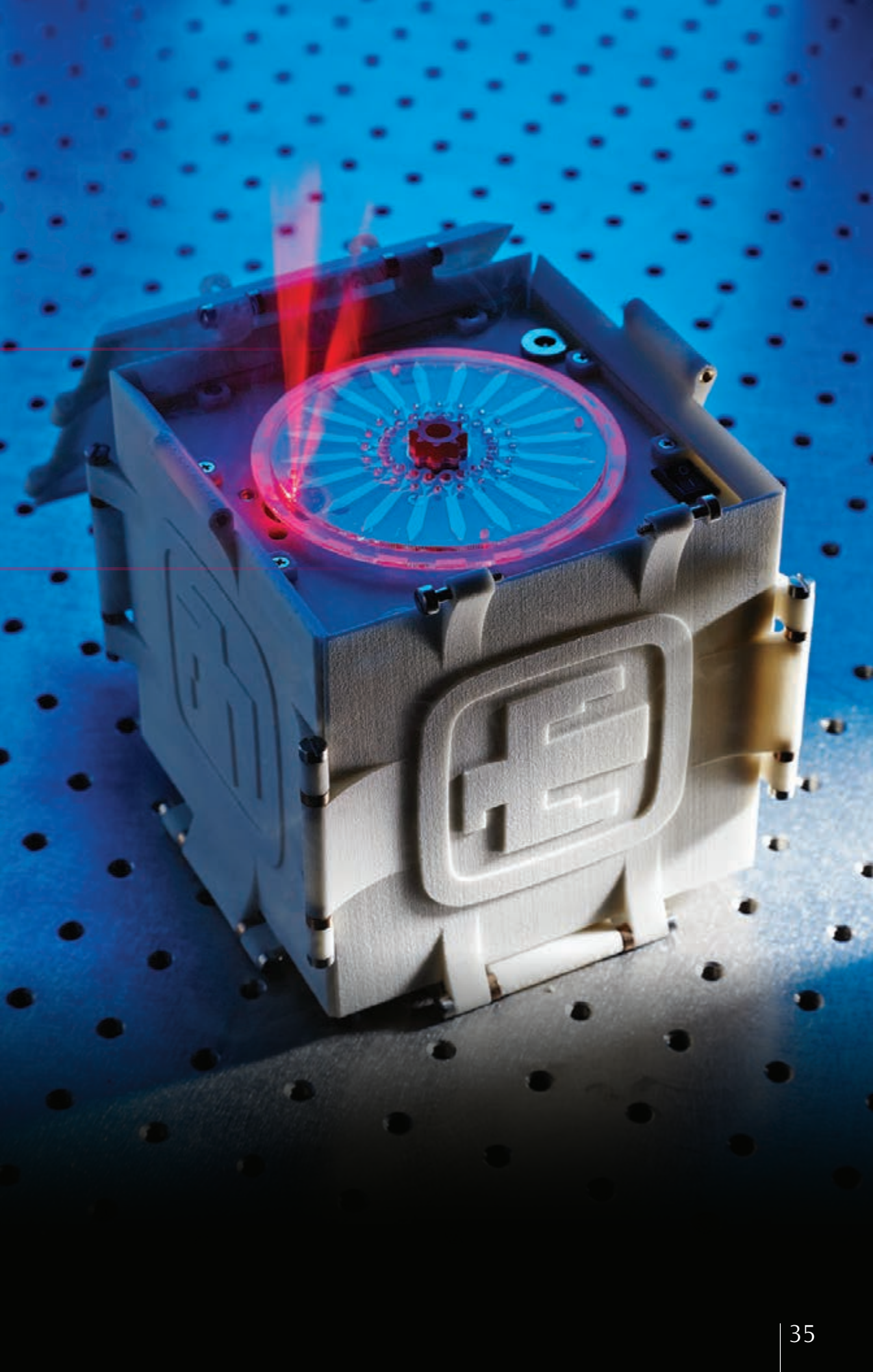
SpinDx looks and functions a bit like a DVD player. A disposable disk can send drops of raw, unprocessed

biological samples into 64 different channels that function, according to Koh, like “dozens of tiny test tubes.” The disk spins and the samples interact with test reagents inside the channels. If there is a reaction between the sample and reagent, a red laser causes the tip of the channel to glow, signaling the presence of an infectious agent.

The system evolved from protein detection work done at Sandia by Koh alongside engineers Greg Sommer and Ulrich Schaff. The team needed the ability to test different types of cells and proteins in blood. The tests, called biodosimetry, could show how much radiation a person had been exposed to and how long ago. The work coincided with the 2011 Fukushima Daiichi power plant accident in Japan and led to the development of SpinDx.

Initial funding came from Sandia’s Laboratory Directed Research and Development, a program established in 1990 by Congress to let scientists at national labs do innovative, independent research. Building off the successes of SpinDx under Sandia’s internal funding, the National Institute of Allergy and Infectious Diseases, part of the National Institutes of Health (NIH), invested in the research.

This new avenue focused on developing point-of-care diagnostic tools for public health concerns such as toxin exposure. SpinDx can detect highly lethal protein toxins like botulinum neurotoxin, a teaspoon



of which has the potential to kill 100 million people. NIH also has provided funding to develop SpinDx from a prototype into a more robust point-of-care tool.

A versatile system

In the past two years, Sandia researchers have added even more ways for SpinDx to identify acute viral infections such as Zika or chikungunya. Earlier versions performed tests that look for pathogen-specific proteins and antibodies. Antibodies are proteins manufactured by immune systems that recognize and bind to infections. At later stages of infections, when viruses have disappeared from the blood, the antibodies that flushed them are still detectable.

Now SpinDx also can perform nucleic acid tests, which detect pathogens present in a sample at the time of the test, increasing confidence in the technology's ability to make a diagnosis.

Both the protein and nucleic acid tests have existed separately for some time. SpinDx combines both in one small package to give medical professionals

a more complete picture of a patient's current and previous exposures to diseases, infections and chemicals.

Results from SpinDx diagnostic tests are also more reliable now. Sandia's team uses glass inside the plastic disks, which helps increase the stability of samples placed on the disc and generates signals that are easier to read. The test chemistry has improved, boosting the reliability rate of the results from around 90 up to higher than 95 percent. With reliability that high, the system is ripe for commercialization.

Consumer products on the market

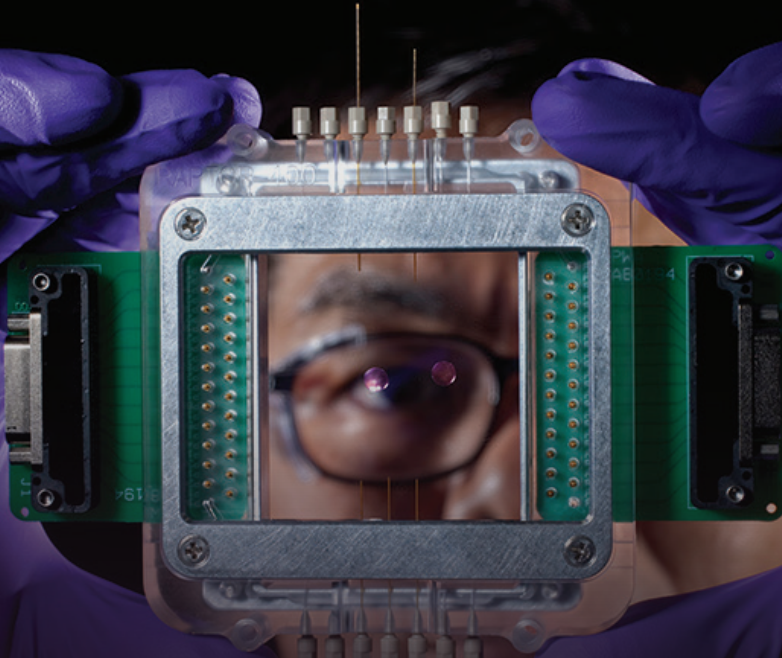
Industry partners have licensed the SpinDx technology for widely different uses. Two members of the original development team left Sandia to form Sandstone Diagnostics in Livermore, California. The company uses SpinDx technology in its recently launched Trak Male Fertility Testing System — a consumer device that lets men measure and track sperm count at home to improve a couple's chances of conception. Sandstone has been awarded NIH Small



From left, researchers Matt Piccini, Chung-Yan Koh and Anup Singh led the SpinDx team. The technology can determine a patient's white blood cell count, analyze important protein markers and process up to 64 assays from a single sample, all in a matter of minutes.



SEE VIDEO



A bundle of BUSINESS

Microfluidic devices dramatically shorten the cycle time from tests to results to clinical action. Using small biological sample sizes in mobile devices that deliver fast, accurate results also delivers significant cost savings over traditional laboratory testing methods. Sandia Labs has been a leader in developing microfluidic component technology for more than 20 years. Now, companies working in

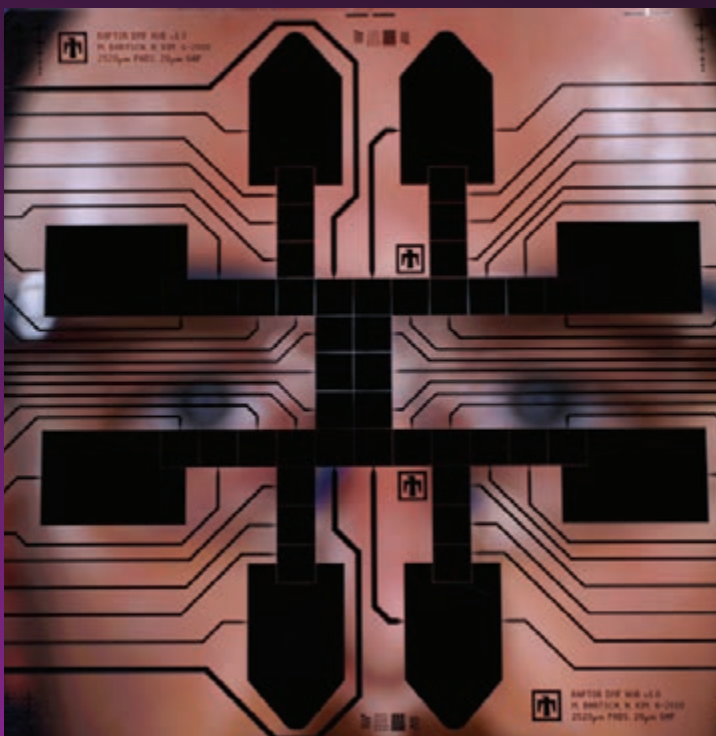
diagnostics can license more than 50 of Sandia's foundational microfluidic patents for one simple fee.

As a federal research laboratory, Sandia relies on companies to license and commercialize its technology, thereby amplifying its impact. This is the first time Sandia has bundled such a large number of related patents in a ready-to-sign license, to stream-

line the process of transferring taxpayer-funded technology into the private sector.

The patents in Sandia's microfluidics portfolio can be used to develop devices that are portable and faster while providing quantitative results. Many of these microfluidic technologies have undergone extensive testing and evaluation by Sandia's federal and university partners and can have applications in biomedical diagnostics, environmental sensing, sample preparation, food and water testing, pharmaceutical R&D and veterinary medicine.

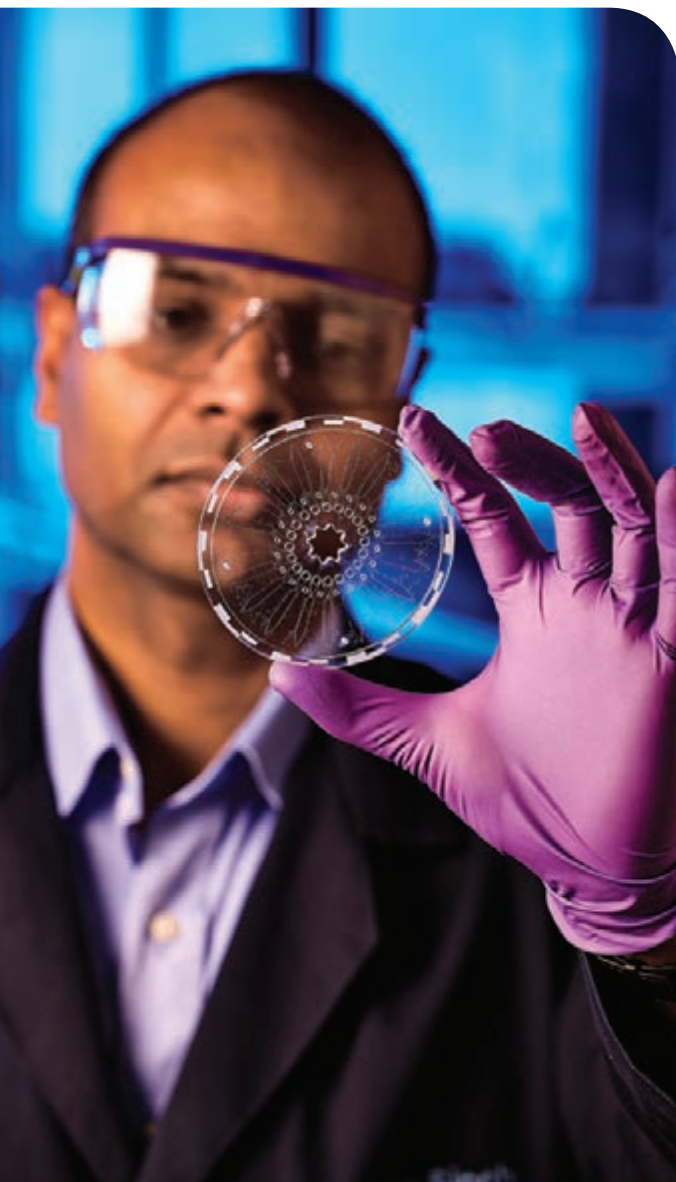
For more information, visit Sandia's ready-to-sign licenses page at ip.sandia.gov. ■



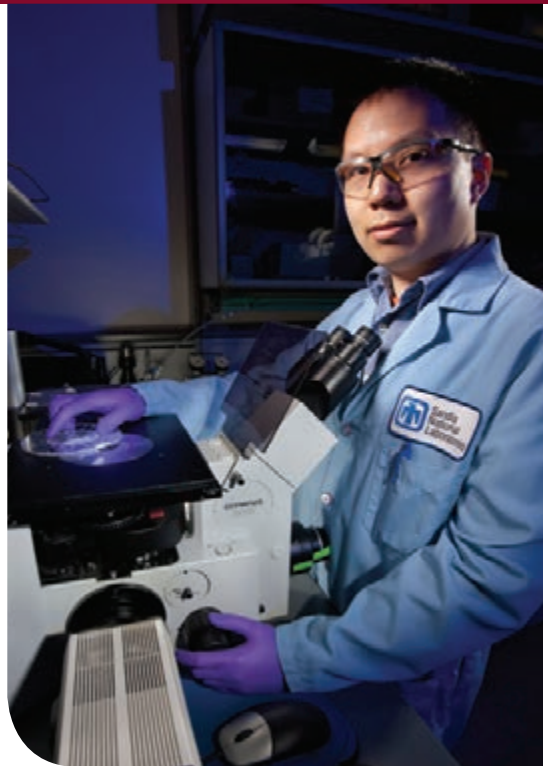
Sandia researchers have probed the physics of microfluidics and developed high performance transport-based microfluidic and nanofluidic systems.

Business Innovation Research funding to develop devices based on SpinDx technology to monitor bacterial bloodstream infections in newborn babies and diagnose toxin levels in adults.

Another market for the technology is water supply monitoring agencies. Safe-H2O of San Francisco makes rapid diagnostic systems for these agencies, allowing them to find and eliminate water-based pathogens like Giardia, Legionella and E. coli. The company's devices help public sector water utilities



SpinDx, shown in both photos, features centrifugal microfluidics, or “lab-on-a-disk” technology, which uses centrifugal forces to manipulate samples and reagents through microfluidic channels implanted on disks that are of the same size as a standard CD or DVD.



and commercial water systems protect people from these common illnesses.

Food poisoning can be detected with SpinDx. There is a type of E. coli that produces Shiga toxin, which gets inside a person's cells and shuts down the ability to produce proteins. SpinDx protein tests can confirm the presence of Shiga in a sample, as well as other common food-based toxins like botulinum.

A third licensee in Colorado, Lifeloc Technologies Inc., is working with Sandia to develop tests for drugs commonly abused by addicts.

By allowing screening for threats not currently part of routine screening protocols, SpinDx could be used to thwart bioterrorism. “If public health professionals test for less commonly monitored biological threat agents like anthrax or viruses like Ebola, then you could identify it with this technology and do something about it, potentially before a lot of people get sick,” said Koh.

These markets indicate only a small sample of the possible uses for the technology. Biodefense applications could include allowing a first responder in the field to test white powders to see if they are harmless, or deadly substances like such as ricin or anthrax. With continued improvements to the platform and an expanding number of commercial licensees, SpinDx will enable humans worldwide to, as Star Trek's Spock would say, “Live long and prosper.” ■



Sandia Labs has expanded
the fundamental knowledge
of combustion processes
for four decades, pioneering
research into new science
and applied concepts
while helping the
automotive industry
produce cleaner,
more efficient
vehicles

WHERE RESEARCH MEETS THE ROAD

By Michael Padilla



Research. Collaboration. Impact.

These three words capture the essence of experiments that use new facilities and techniques to solve high-priority combustion problems. Bob Hwang, director of Sandia's Combustion Research Facility (CRF) and Transportation Energy Center attests that every vehicle built today is cleaner and more efficient due to work done at the CRF. "We have been at the forefront of improving the understanding of combustion science for more than 37 years," he said. "Sandia's strong engagement with industry continues to help shape national research to meet critical energy and fuel standards."

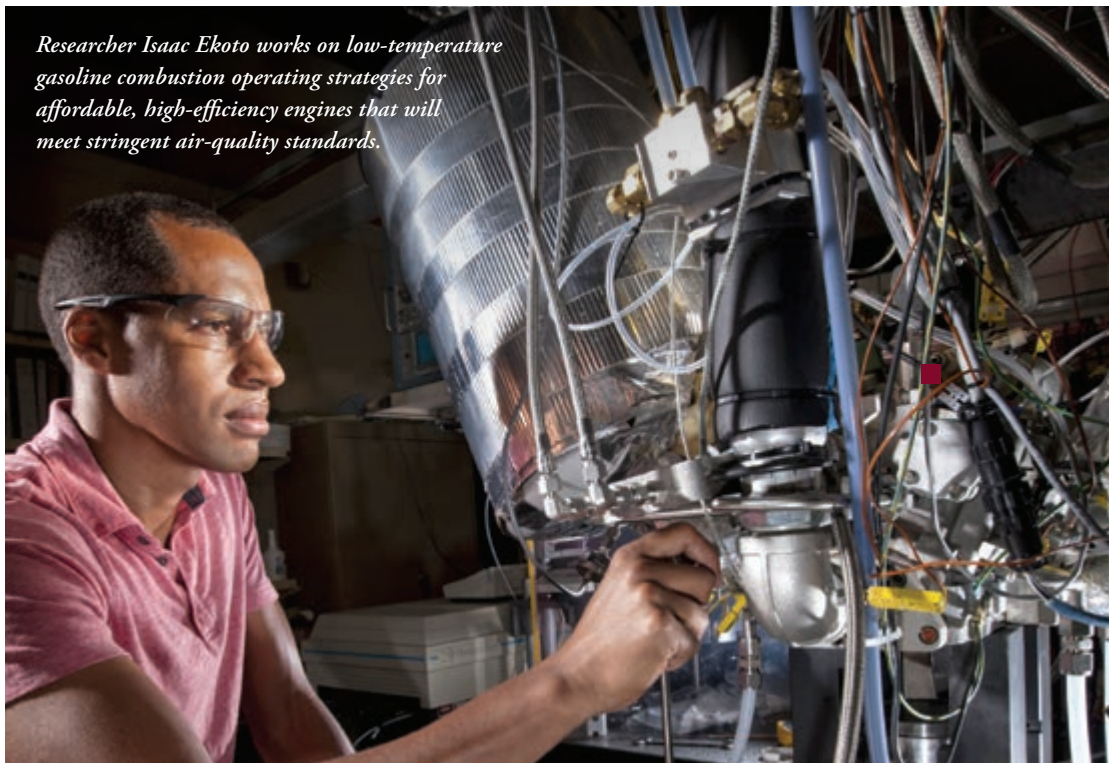
Partnerships with industry

Hwang said the CRF, located at Sandia's Livermore, California, site, doesn't develop or optimize hardware but provides the fundamental understanding needed to guide private-sector engineers and develops the

Trucks and John Deere & Co. Chevron Corp. funded an ongoing project, and other energy companies are exploring ways to work with the CRF on combustion experiments. Most recently, Toyota and Hyundai Motor Co. auto executives visited the site to explore and expand upon working relationships.

One of the most significant agreements was with Cummins and helped change the way engineers think about and model the diesel combustion process. In 2007, Cummins produced the world's first diesel engine designed entirely on a computer. A multi-institution collaboration led by CRF developed the physically accurate modeling approaches. The design reduced by 10 percent the time and cost of producing a new, more robust, fuel-efficient engine that met all expectations for performance and emissions.

The Cummins agreement, a joint CRADA that included Lawrence Livermore and Los Alamos national labo-



Researcher Isaac Ekoto works on low-temperature gasoline combustion operating strategies for affordable, high-efficiency engines that will meet stringent air-quality standards.

numerical optimization tools they need. With this in mind, various Cooperative Research and Development Agreements, or CRADAs, and Strategic Partnership Projects are in place to drive CRF research in areas important to industry. Agreements have involved engine industry giants, including General Motors Co., Ford Motor Co., Chrysler, Toyota Motor Corp., Caterpillar Inc., Cummins Corp., Detroit Diesel Corp., International

laboratories, led to a better understanding of the physics and chemistry of combustion and emissions formation in heavy-duty vehicle diesel engines as a prerequisite to meeting stringent standards for nitrogen oxides and soot.

Under the CRADA, which grew to include General Motors, Caterpillar and Detroit Diesel, the CRF conducted in-depth measurements over several years using



MEET

Steve Busch

While many people have looked under the hood of a car, few get to look inside a roaring diesel engine. Steve Busch is one of those lucky few.

“Not too many people get an opportunity to actually see what is happening inside engines,” he said. Busch conducts research inside operating diesel engines and takes optical measurements to understand fuel injection, mixing, combustion and pollutant formation.

Busch said that although internal combustion engines are mature in terms of their technology, learning and understanding the detailed physics in the combustion chamber that are needed to eke out further benefits in emissions and efficiency are difficult. “The dynamics in an engine are complicated,” he says. “Combustion takes place on a wide range of space and time scales and that creates open-ended problems that we are working to solve.”

Busch joined Sandia as a postdoctoral scientist in 2013 and became a member of the technical staff at the labs’ Combustion Research Facility in 2014. He has a doctorate of engineering science in mechanical engineering from the Karlsruhe Institute of Technology in Germany and a master’s degree in mechanical engineering from the University of Michigan. He received his bachelor’s degree in mechanical engineering from Colorado School of Mines.

He considers himself both an engineer and a scientist. Even though Busch went to school to become an engineer, his research experience led him to grow into the role of a scientist. “Setting up and conducting an experiment requires a lot of engineering but to understand the results of the experiment and to make an interpretation, you have to be a scientist,” he said.

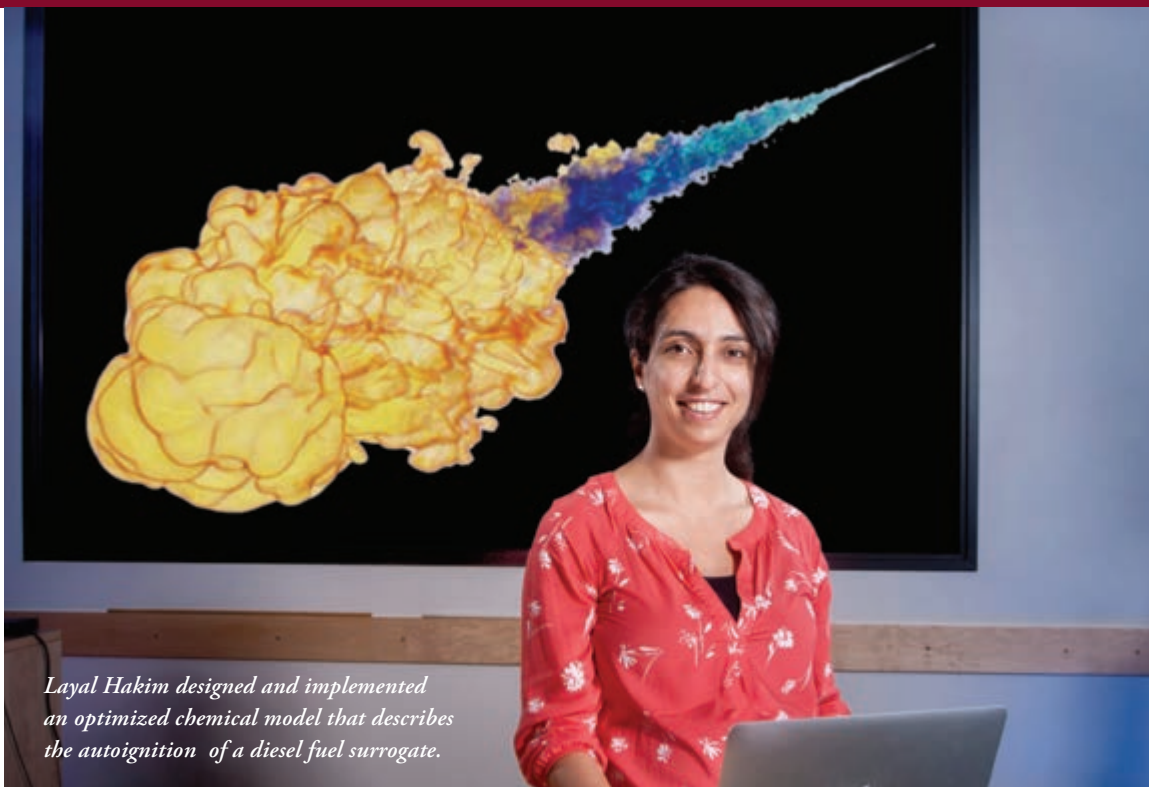
Busch is an expert in digital-image processing, optical combustion diagnostics and data acquisition. With his diverse educational background and extensive research experience, he doesn’t give up easily and is resilient even in changing environments.

“The challenge of working in this field,” he said, “is that anyone can take a picture of something but to interpret those pictures is the most challenging thing I’ve ever had to do.”

That grit has come in handy in and outside of research. He’s currently tackling a major landscaping project at his home and said he finds similarities between the project and his work at Sandia.

“What I like about landscaping is that I am developing a vision into a reality,” he said. “There are instances here at Sandia where I have to envision an experiment and make it happen. Lots of planning and preparation.”

— Michael Padilla



Layal Hakim designed and implemented an optimized chemical model that describes the autoignition of a diesel fuel surrogate.

advanced laser diagnostics applied in a new-generation optically accessible engine. Researchers at Los Alamos and the University of Wisconsin improved computational fluid dynamic models and developed new submodels that enabled the numerical simulations to match the CRF's experimental data.

Understanding supercritical fuel mixing

Liquid and gas molecules behave in unconventional ways in the high-temperature and pressure conditions in the cylinder of a diesel engine. The CRF's computational experts have developed a theoretical model that captures the physics of fuel/air mixing processes under supercritical conditions, and images from CRF experiments have corroborated the mixing behavior predicted by the model. These findings help engine-makers redesign fuel-injection and fuel/air mixing strategies to achieve lower emissions and higher efficiency.

In-cylinder carbon monoxide emissions control

To help industry understand the sources of carbon monoxide (CO) emissions, CRF researchers performed laser-sheet imaging that showed the evolution of the in-cylinder CO distribution. Using quantitative spectroscopic information developed under the Department of Energy Basic Energy Sciences program at the CRF, researchers quantified the image data to provide accurate measurements of the in-cylinder CO concentration. Comparison to tailpipe CO measurements taken using well-established methods verified the optical measurements, giving industry confidence to use those optical

measurements to validate their proprietary models and ultimately decrease engine emissions.

Spray combustion consortium

A newly formed, industry-funded Spray Combustion Consortium is working to better understand fuel injection by developing modeling tools. Control of fuel sprays is key to the development of clean, affordable fuel-efficient engines. Intended for industry, software vendors and national laboratories, the consortium provides a direct path from fundamental research to the validated engineering models ultimately used in combustion engine design. The consortium agreement builds on Department of Energy research projects to develop predictive flow models for engine fuel injector nozzles and couple these models to spray development outside the nozzles.

Consortium participants include Sandia and Argonne national laboratories, the University of Massachusetts at Amherst, Toyota, Renault, Convergent Science, Cummins, Hino Motors, Isuzu and Ford Motor Co.

More collaboration ahead

As the nation continues to move toward cleaner, more efficient, low-carbon modes of transportation, the CRF will expand and enhance its collaboration processes with industry. "We continue to share and transition our knowledge to industry with the idea that it will benefit the public for decades," Hwang said. "Our strong engagement with industry is helping to shape national research agendas toward the achievement of critical goals." ■

On the
Trail of
a
Killer

By Nancy Salem



Anthrax is deadly and hard to detect. BaDx – a mini-lab the size of a credit card – makes it easier and cheaper to pinpoint the bacteria. And that's good.

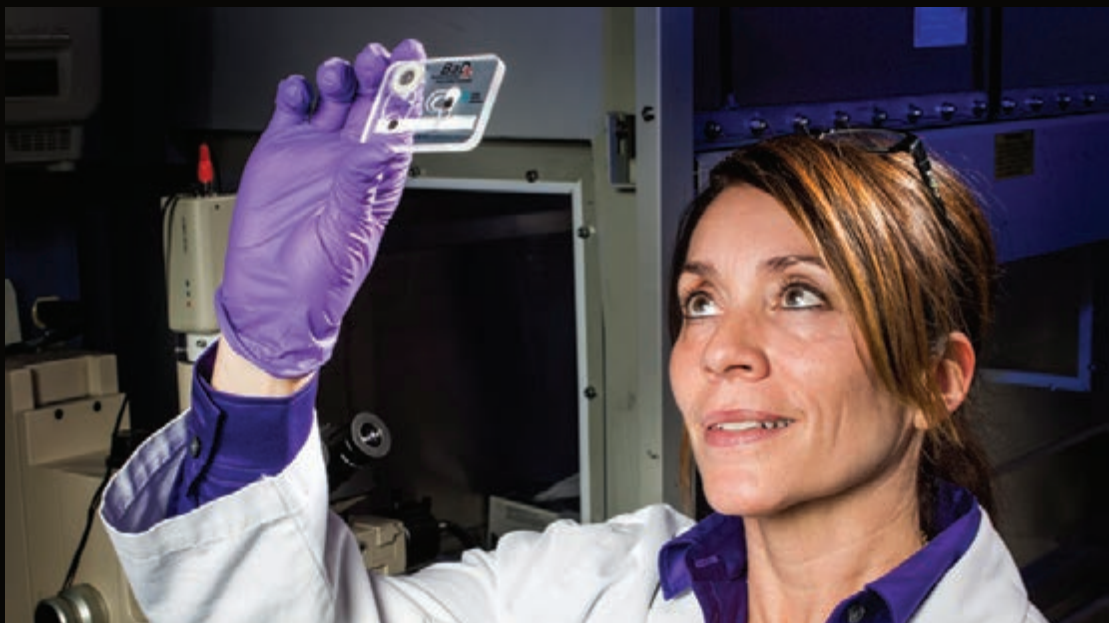
One of the world's most common bacteria is also one of the deadliest. *Bacillus anthracis*, the bacteria that causes anthrax, is found in soils all over the world and can cause serious, often fatal, illness in humans and animals. It can survive in harsh conditions for decades, and people can be exposed through skin contact, inhalation of spores or eating contaminated meat.

Detecting anthrax is challenging because samples for testing must be propagated in a laboratory that uses specialized tools requiring a consistent power supply, something often unavailable in the developing world. "Working with dangerous samples like *B. anthracis* spores places laboratory staff at risk," said Melissa Finley, a veterinarian and member of Sandia's

International Biological and Chemical Threat Reduction organization. "Concentrating many positive test samples in a lab could also tempt someone to steal positive anthrax samples for nefarious uses."

Another barrier is cost. "Farmers in many developing countries don't make a lot of money, so they don't pay for diagnostic testing often," Finley said. "When they do, they can't afford to pay a lot for it." The most common diagnostic test for anthrax costs around \$30, which is out of the reach of many farmers, perhaps discouraging them from testing animals they suspect are infected, Finley said.

Sandia has developed a safer, easier, faster and cheaper way to detect anthrax and is working with an



Sandia veterinarian Melissa Finley helped develop the BaDx anthrax detector based on her experience working with animal and public health agencies in Afghanistan.



MEET

Melissa Finley

Melissa Finley's credibility was on the line as she worked, surrounded by skeptics, to save the life of a dehydrated calf in rural Afghanistan. As a woman and a foreigner she had to earn the trust of the villagers she was trying to help. "I sent them to the market to get dextrose solution, a baby bottle, catheter and antibiotics. I had to reassure them I wasn't going to kill the calf, that they could trust me," she said. "When the calf started to come around I had instantaneous respect."

Finley has been working in Afghanistan since 2009 as a member of Sandia's International Biological and Chemical Threat Reduction organization. A seasoned veterinarian, she travels throughout the country teaching safe laboratory practices, providing continuing veterinary education to reduce the spread of infectious disease and collaborating with the government's animal health agencies. Veterinary medicine is linked to biological threat reduction because about 75 percent of the agents that can be used as biological weapons are animal in origin.

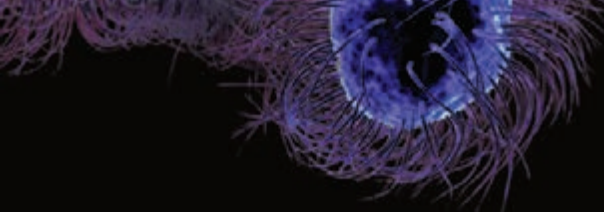
Finley is an Albuquerque native who grew up around animals. In high school Finley decided she wanted to be a vet. She completed a three-year pre-veterinary program at New Mexico State University then went to Colorado State University where in four years she earned a Doctor of Veterinary Medicine.

She did a two-year residency in large-animal internal medicine at Cornell University in Ithaca, New York, and later joined the University of California, Davis, as a post graduate researcher studying the impact of *Neospora caninum*, a protozoan, on bovine abortions. Finley moved on to Kansas State University as an assistant professor in clinical sciences in the College of Veterinary Medicine and became a teaching assistant in the college's department of anatomy and physiology, pursuing her doctorate. Finley's postdoctoral fellowship was at the Salk Institute for Biological Studies in La Jolla, California. "I was shaping my career to balance clinical relevance and research," she said. "I wanted to bridge fundamental science and clinical practice."

On a visit home to Albuquerque, Finley's mom suggested she look into jobs at Sandia. "I told her it's an engineering laboratory, there's nothing for a veterinarian," she said. "I decided to look and show her." But there was one job. Sandia wanted someone with a biosciences background to work in global security and biological weapons nonproliferation. Finley was hired in 2005. She has traveled to about two dozen countries but spent most of her time in Afghanistan and Iraq.

She said she wouldn't trade her Sandia work for anything else the veterinary world has to offer. "I never dreamed I would have a job like this," she said. "It's been exciting for me as a veterinarian and as a person who works in global security. I've watched areas like Afghanistan and Iraq transition from war to sovereignty. It's part of history."

— Nancy Salem



Albuquerque company to commercialize the technology. Dubbed BaDx (Bacillus anthracis Diagnostics), the credit-card-size device, a mini-laboratory, can detect the anthrax bacteria in places with no power, refrigerated storage or lab equipment. It could cost around \$5-\$7 and requires no specialized tools and minimal or no training.

The technology was licensed in late 2013 to Aquila, a New Mexico woman-owned small business that specializes in the design and manufacture of technologies and services for nuclear security and international safeguards. Aquila is working with Sandia through a Cooperative Research and Development Agreement to complete testing with external partners and begin marketing BaDx.

“This is a wonderful example of where very sophisticated technology has enabled a practical solution to a very important problem” said Mary Monson, senior manager of Technology Partnerships at Sandia.

Complex and sensitive, but simple to operate

A Laboratory Directed Research and Development project launched in 2011 in Sandia’s International Biological Threat Reduction Program led to BaDx. While a large team helped develop the detector, the drivers were scientists Jason Harper, Thayne Edwards and Finley.

BaDx needs no battery, electric power or special lab equipment. It’s hardy against wide temperature variation and can detect very small numbers of B. anthracis spores. A field technician puts a sample swab into the amplification chamber, which contains selective growth media. The device then uses a lateral flow assay, similar to a common pregnancy test, to detect B. anthracis. Magnetically operated valves allow the sample to advance from stage to stage to complete the testing process. A colored line appears on the device several hours later if the test is positive for the bacteria.

The technician can then initiate a chemical process that sterilizes the device, avoiding the risk of positive samples accumulating and falling into the wrong hands. “The device amplifies the B. anthracis so it can detect as few as 100 spores instead of the typical 1-10 million required for detection,” Harper said.

Developed with commercialization in mind
BaDx builds on Sandia’s long-standing expertise in



From left, Markku Koskelo, chief scientist of Aquila Technologies, and Judy Beckes Talcott, company president, meet with Sandia’s Thayne Edwards, a developer of the labs’ BaDx anthrax detector. Aquila, an Albuquerque company, licensed the technology.

bioforensics, most visible in the work the labs did in response to the anthrax spores mailed to media offices and two U.S. senators in the fall of 2001, killing five.

Harper said BaDx was developed with commercialization in mind. “All the design considerations and performance standards were pointed toward getting BaDx out into the world,” he said.

Edwards was working with Aquila on sensors through another Sandia tech transfer program, New Mexico Small Business Assistance, and mentioned BaDx. “We were about a year into the project and already had a prototype that demonstrated proof of concept,” Harper said. “We set up meetings and brought the prototype. They liked it, and we were off and running.”

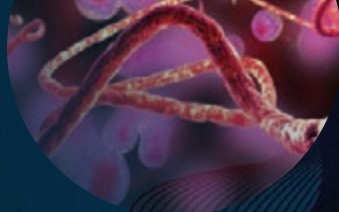
Aquila was manufacturing within six months and is well into final external testing. “We see a lot of potential for government customers and nongovernmental organizations as well as commercial markets,” said Aquila’s chief scientist Markku Koskelo. The company anticipates future models of the device that will detect *E. coli*, salmonella, valley fever and group A strep.

In 2015, BaDx was recognized by the Federal Laboratory Consortium with its national Award for Excellence in Technology Transfer. It also won an R&D100 Award in 2014, a TechConnect World 2015 National Innovation Award and was named by Popular Science magazine as one of the greatest innovations of 2015. “Aquila has been a great partner and their commercializing of this technology will help us fulfill our mission of serving the public good,” Monson said. ■

GENIE IN A BOTTLE

By Mollie Rappe

Micro chemistry lab puts the power to detect biological and chemical threats in the palm of a hand





It was an ambitious goal: to make a handheld device with the power of a full chemistry lab.

It was a grand goal.

It was a grand challenge.

It was Sandia Labs' first Grand Challenge.



Grand Challenges are Laboratory Directed Research and Development (LDRD) funded projects that set out to tackle bold technical issues with national security applications. The MicroChemLab Grand Challenge ran from the fall of 1996 to the fall of 2000 with the initial focus of detecting chemical threats. It was later expanded to include detection of biological toxins.

“The technology from the μ ChemLab Grand Challenge developed years ago is still relevant today and it jump-started microfluidics research at Sandia leading to other innovative microfluidic devices such as RapiDx, BaDx and SpinDx,” said Tristan Mahyera, a business development specialist who works with the μ ChemLab IP portfolio. “Those technologies have really done a great job of making their way into the public or into public-private collaborations. Further development of μ ChemLab intellectual property and such collaborations have been the real return on investment for the labs and for the public.”

Patents granted, companies founded

The initial Grand Challenge generated over 70 patents related to collecting, separating and detecting tiny samples in microelectronic mechanical systems, or MEMS. The project helped establish an entire specialty at Sandia using miniaturized systems to detect and monitor chemical and biological signals. Several hundred patents indirectly stem from the project.

The Grand Challenge involved about 40 researchers with 90 more contributing to patents. Two researchers left Sandia and founded Defiant Technologies to design and manufacture hand-held gas-phase chemical detection systems. Several others started Eksigent Technologies to develop tiny high-pressure pumps.

The μ ChemLab Grand Challenge also led to a few Cooperative Research and Development Agreements, or CRADAs. The project brought in more than double the LDRD investment with funding from external sources such as Department of Energy and Department of Defense programs during the final two years and CRADAs after the Grand Challenge ended.

From drinking water to crops

In addition to next-generation biological detection systems such as SpinDx and BaDx built upon MEMS and microfluidics research, the Grand Challenge led to some less conventional projects.

Sandia researchers teamed with Parker-Hannifin to develop a better way to detect carcinogenic disinfection byproducts in drinking water. They used the MEMS-based sensor from the Grand Challenge along with a super-absorptive kind of carbon to form the heart of an easy-to-use, table-top tool that quickly and cheaply detects extremely low levels of disinfection byproducts. The Parker-Hannifin Water Analyzer has been on the market since 2011.

Sandia recently received an Advanced Research Projects Agency-Energy grant to adapt a miniature gas detection system to monitor plant health and breed better crops. The micro-GC system has roots in the μ ChemLab Grand Challenge and can measure volatile organic compounds indicative of drought stress or attacks by pests. The detector could monitor these stress signals practically in real time, better informing farmers of their crop health.

“It is exciting to see how far this work on miniaturized sensing technologies for detection of chemical and biological agents has spread,” said Anup Singh, director of Sandia’s Biological and Engineering Sciences Center. “Being repurposed for real-time monitoring of hard-to-access root systems has led to building a microfluidics competency at Sandia. This has resulted in devices that can enable faster medical diagnostics in doctors’ offices with SpinDx, even safer drinking water.” ■



Technology from the μ ChemLab is still relevant today. It jump-started microfluidics research at Sandia leading to other innovative microfluidic devices such as RapiDx, BaDx and SpinDx.



A Sandia Labs researcher helped develop tiny, flexible solar cells that can power devices of any shape and size. He took the technology to the private sector and is poised to change the way solar energy is collected and used.



THE NEXT SMALL THING

By Neal Singer

Leaving the position of researcher at a national laboratory to be president of a tiny start-up is like emerging from a secure harbor onto a turbulent ocean in a tiny skiff. Instead of a weekly paycheck and paid utilities, there are rising production costs, customer whims, the distraction of partners, possible invasions by enemy hackers, advertising costs and decisions between spending time on research or serving as your company's public face.

For nearly two years, Murat Okandan, Sandia Labs employee-on-leave and current president of the photovoltaic start-up mPower Inc., has thrived on the transition. Supported by his technical background and buoyed by his belief that much of the world's energy needs one day will be provided through photovoltaics, he says that the most usable form of energy emanates free of charge from the solar system's major energy provider: the sun.

"The sun is a perfectly placed, wireless provider of energy," he said. "And you don't have to worry about radiation byproducts, containment of spent nuclear fuel and other challenges that face our human-made nuclear reactors."

Payback in less than two years

The construction of photovoltaic cells requires a little bit of aluminum and/or copper, he said, but most cells are basically silicon, an inexpensive material. "In energy payback, a PV panel pays back in less than two years the energy it took to build it. With fossil fuels, there are mining costs, the cost of an engine to burn

the fuel, CO₂ reclamation difficulties ..." his voice trails off; the list apparently stretches on.

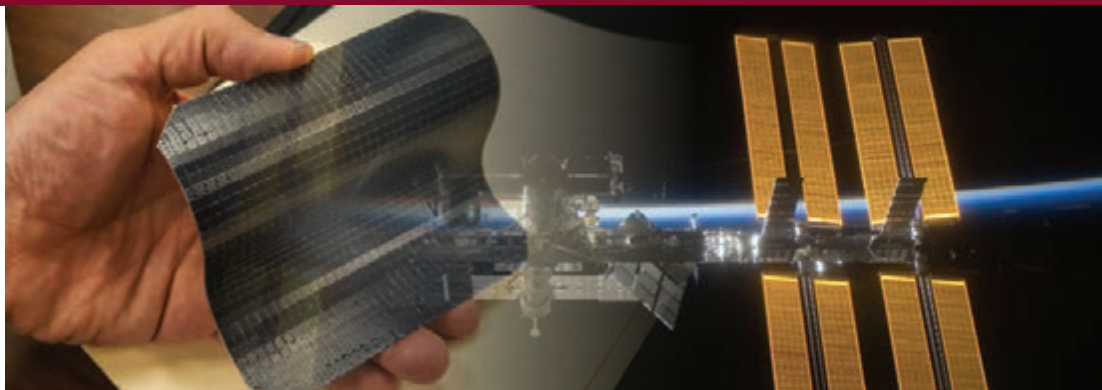
"This is a somewhat new idea, but not a radical one," he said. "People have been considering photovoltaics for a long time but in the past few years it has become much more attractive."

Unlike the Soviet Union's first satellite, which used short-lived batteries as a power source for its communications, the first American satellite's radio output was powered by a photovoltaic system that lasted much longer, Okandan said. "It was a good idea, but expensive. Still, photovoltaics' main application at the time was satellites, and NASA was there to support research at companies working to improve the technology."

Government investment helps new technologies along until they blossom, at which point cost becomes an issue, he said. Okandan has taken advantage of that government interest in the past, and is seeking in part to do that now.

A radical idea

He was serendipitously in the right place when he connected with a small group of Sandia researchers to pursue an idea radical in 2013: Instead of using brick-sized silicon solar cells for rooftop solar, why not micro-size components each the size of a piece of glitter, created in mega-batches in computer-chip or solar-cell fabrication facilities? Their surface could capture photons and release electrons with less



material. The tiny units would be light enough that less support structure would be needed, which would be another cost savings.

The technology, called microsystems enabled photovoltaics, or MEPV, could be used to power cell phones, tablets or laptops by being embedded in their outer shells. Or the tiny cells could be put on a flexible base and worn on clothing or put on tents. Military folk on bivouac, hikers or hunters could recharge their electronics in the field. If part of a group of micro-cells was in shade, the rest would still operate, unlike a collection of solar cells where one "shaded" cell in shadow could stop the whole process of electricity collection.

So Okandan and two other Sandia researchers, seeing the difference the various inventions surrounding solar glitter might make to society, made the jump to the private sector in 2015 through the Labs' Entrepreneurial Separation to Transfer Technology program and renamed the array of tiny solar components "Dragon SCALEs." In early 2017, mPower licensed MEPV technology from Sandia. The license applies to a portion of Sandia's MEPV intellectual property portfolio associated with silicon solar cells.

Race to deliver something of value

Now occupying an office in a building designed for start-up entrepreneurs, he holds meetings in its conference rooms with team members who are excited about the potential of the technology.

There's a lot of competition.

"Our challenge is being able to deliver something of value," he said. "There are things our solar technology can do, and there's only a limited time to bring it to a certain level of maturity."

Surprisingly, prototypes he is providing aerospace colleagues for testing and possible sale are not tiny integrated circuit wafer-cut samples formed in a micro-electronic foundry — a version of the Sandia technology used to build earlier prototypes — but instead are using conventional photovoltaic industry processes.

The individual cells, roughly 4 millimeters on a side, are somewhat larger than the micron-sized pieces — popularly termed "solar glitter" — that were the object of Sandia research and an early version of the company's technology since its inception in 2015. "The integrated-circuit fab-based process is a more expensive pathway we're not exercising right now," Okandan said. For the aerospace projects and other markets, the conventionally formed photovoltaic pieces will provide the necessary testing capability, he said, and are connected in a square array of 24 by 24 individual cells, forming roughly a 10 cm square that matches the size of a solar array elements for cube-sats or other aerospace applications.

And the early work plays a crucial part in his offering. There are key features that were developed during the project at Sandia that underlie the current photovoltaic elements. "Our interconnection, resilience and new integration options are critical to our prototype's value," Okandan said. About other factors, he said, "Our array can generate higher voltages. It's also cheaper, lighter, packs more densely, and is more resilient than what's currently available."

Easy to deploy in every object

Tests are ongoing with potential customers and partners in aerospace and in other markets.

The outlook is promising, he said. "Potentially the big payoff with our technology is how easy and fast it is to integrate and deploy solar, ideally in every object — buildings, planes, consumer electronics, sensors," he said.

Mary Monson, Sandia's senior manager of Technology Partnerships, said companies like mPower take the labs' technology and further develop it so it can be manufactured for widespread use in the energy and defense sectors. "Sandia's partnerships with industry play an integral role in our mission success," she said.

She said the license is special to Sandia because the technology is homegrown. "To have it blossom in Albuquerque is something we can be proud of," Monson said. "We'd love to see it grow and become part of the country's solar-energy infrastructure." ■

Greg Sommer co-founded the startup Sandstone Diagnostics. The Livermore, California, company licensed Sandia's SpinDx technology, which Sommer helped invent when he worked at the labs. Sandstone is developing commercial diagnostics instrumentation for clinical and life science research markets.



SEE VIDEO

Turning scientists into ENTREPRENEURS

Sandia's Entrepreneurial Separation to Transfer Technology (ESTT) program lets labs' employees leave to start or expand technology companies. ESTT encourages researchers to take technology out of the labs and into the private sector by guaranteeing their jobs back if they return within two years. They can request a third-year extension.

Since the program began in 1994, 157 Sandia employees have left, 70 to start a company and 87 to expand one. About a third returned to their Sandia jobs. "This is an innovative technology transfer tool that has endured," said Jackie Jerby Moore, Sandia's manager of Technology and Economic Development. "Not only do we

have many success stories, but we've measured the economic impact, which shows job creation and other positive benefits to the local community. Furthermore, entrepreneurs who return to Sandia bring new experiences that benefit the labs."

Kerby Moore said one of Sandia's hottest technologies, the medical diagnostic lab-on-a-disk SpinDx, is being commercialized using ESTT. Greg Sommer, a former Sandia researcher who helped develop SpinDx, co-founded and is chief executive officer of Sandstone Diagnostics in Livermore, California, which is bringing the technology to market.

"The high-tech environment at Sandia is ripe

for innovation and game-changing technologies," he said. "The ESTT program allowed us to launch Sandstone and develop cutting-edge medical products based on technology we originally developed for Sandia's biodefense missions."

Genaro Montoya, the ESTT program leader, said entrepreneurial training is offered to help researchers considering ESTT. "Anyone at the labs can take the training," he said. "It gives an idea of what's involved in starting a small business." ■

Murat Okandan left Sandia to found mPower Technology Inc. and commercialize the labs' solar glitter technology.

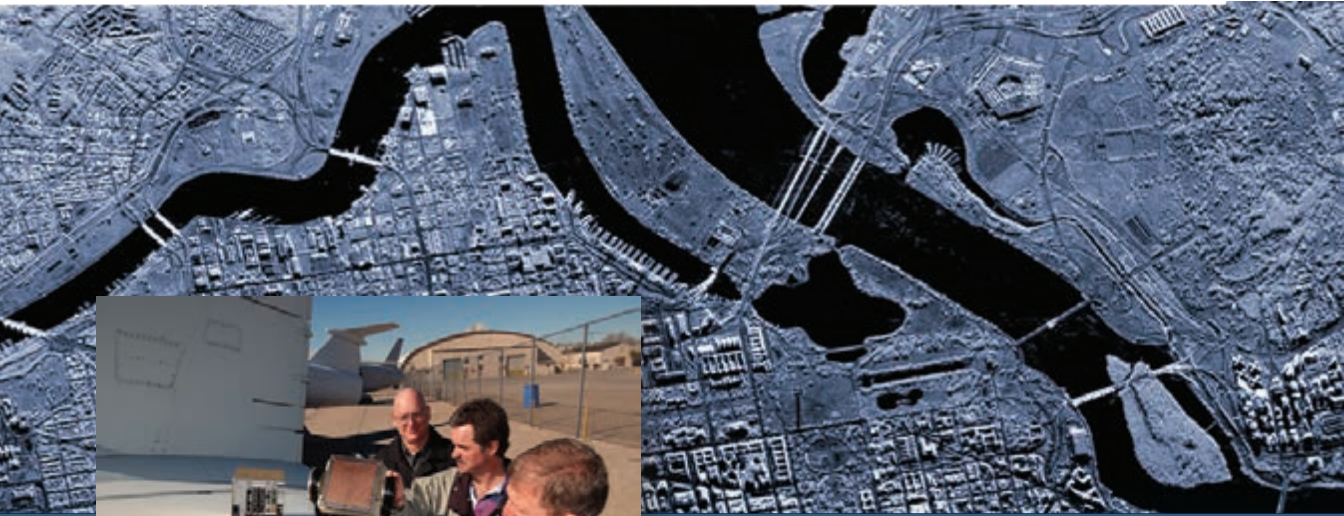


Sandia

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LOOKING BACK



*Washington D.C. SAR image.
Sandia researchers, from front to back, George Sloan, Dale Dubbert and Armin Doerry, check out an early version of MiniSAR.*

Synthetic Aperture Radar, or SAR, was developed in the 1950s to meet a U.S. military need for all-weather, day or night imaging. It creates two- or three-dimensional images of objects, such as landscapes, using the motion of a side-looking radar antenna over a target region to provide finer spatial resolution than conventional beam-scanning radars. SAR, typically mounted on an airborne moving platform, and has been used to image the moon and other planets, and produce high-fidelity topographic maps. It's a key technology in the nation's portfolio of Intelligence, surveillance and reconnaissance sensor systems.

Sandia Labs got involved in SAR as it was being developed to meet the labs' nuclear weapon-related responsibility to design, engineer, test, integrate and produce interfaces for non-nuclear components, including radars. Sandia pioneered advances such as the first real-time, ultra-fine resolution SAR; interferometric radar systems producing the first real-time 3-D digital elevation maps of

terrain; and a system that produces strip-map imagery at both 10-foot and 4-inch resolution. Sandia not only improved radar performance but shrunk the size of the sensor. In 1991, a SAR radar system weighed 500 pounds and in 2005 a miniature system weighed 27 pounds.

Through intellectual property licensing and other technology transfer, SAR has improved the quality of life of citizens and soldiers. In one instance it was used by the Secret Service, FBI and other agencies to map terrain at the 2002 Winter Olympics in Salt Lake City to help prevent terrorism. "Sixty-five years after its invention, Sandia continues to innovate around the fundamental SAR technology and its application to a wide variety of national security mission work," said Steve Castillo, Sandia senior manager of Airborne ISR Systems who has worked on SAR technology the past six years.

— Nancy Salem