

**Sandia
National
Laboratories**

TECH TRANSFER
SUCCESS
STORIES
2020





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◀ *Image of a test apparatus for Sandia's WeaselBoard which helps critical infrastructure owners protect their systems against zero-day exploits, representing Sandia's dedication to national security challenges.*

The Cleanroom Invented 58 Years Ago Still Used Today

The cleanroom, invented by a Sandia physicist, is used all over the world today in hospitals, electronic and pharmaceutical industries, and space exploration to provide a clean, decontaminated space.

PROBLEM

Prior to the 1960s, cleanrooms were an emerging technology aimed at creating optimal environments in which to manufacture items sensitive to environmental contaminants, such as pharmaceuticals and batteries. However, historical cleanrooms commonly suffered from issues such as contamination from microscopic dust particles and unpredictable airflows, which interfered with manufacturing processes. An innovative laminar-flow cleanroom developed at Sandia National Laboratories solved these pervasive issues. Sandia's cleanrooms are widely in use today in applications as diverse as electronics manufacturing and hospital operating rooms.

INNOVATIVE EDGE

Willis Whitfield, who is credited as the physicist that invented the modern-day cleanroom, was asked in the early 1960s to find a solution to improve the reliability of miniature mechanical components for Sandia systems. At the time, nuclear weapons components — mainly mechanical switching parts — were becoming smaller and microscopic dust particles were preventing Sandia from achieving the quality the laboratories needed. Engineering concepts for his initial invention center around highly filtered air that is constantly flushing out the room in a sweeping motion. In the first cleanrooms, air was circulated in the room at a rate of 4,000 cubic feet or about 10 changes of air per minute, resulting in dust counts decreasing to an almost unbelievable zero. The subsequent invention created a work environment that was more than 1,000 times cleaner than the cleanrooms in use at the time.

IMPACT

Today the use of cleanrooms is commonplace. In fact, within only a few years of its invention, \$50 billion worth of laminar-flow cleanrooms were installed worldwide. The original cleanroom's construction and engineering blueprints remain the standard for today's cleanrooms, with only a few minor modifications. The cleanroom has revolutionized manufacturing in electronics and pharmaceuticals and helped further space exploration. Early adopters of the technology included the US government, which first used the design to standardize cleanrooms for the federal government in 1963, as well as RCA and General Motors Co. Additionally, Willis Whitfield eventually worked with NASA on adapting cleanroom technology to provide planetary quarantines during missions to the moon and Mars and sterilization techniques for spacecraft.

Cleanroom technology has also resulted in significant breakthroughs in the semiconductor, biotechnology, nanotechnology, health sciences, and healthcare industries. For example, in the medical field, Bataan Memorial Methodist Hospital in Albuquerque, New Mexico, which later became Lovelace Medical Center, was the first hospital to use laminar-flow technology in its operating rooms. Cleanrooms are now used in many hospitals to maintain a clean environment and prevent infections.

◀ *Cleanroom inventor Willis Whitfield stepping out of one of Sandia National Labs' mobile cleanrooms.*

Making Affordable Hydrogen Economy a Reality

BayoTech is using licensed Sandia technology to enable modular, on-site hydrogen production.

PROBLEM

Energy consumption around the world is migrating to new alternatives due to the extensive environmental impact of current energy sources. Hydrogen, a promising alternative, is costly to produce, transport, store, and dispense, making it less commercially viable than conventional energy technologies. Based on a Sandia-developed technology, New Mexico company BayoTech is developing modular, scalable, and rapidly deployable platforms that produce hydrogen, at or near the point of consumption, at a significantly lower cost with less greenhouse gas emissions than currently available production sources.

INNOVATIVE EDGE

Hydrogen is typically produced in large refineries and later transported over significant distances to the point of use via a combination of rail and large tube trailers. The process is expensive and can negatively impact the environment. BayoTech's modular distributed chemical reactors convert natural gas to hydrogen utilizing a modified steam methane reformer that is significantly more efficient than traditional reforming units. The original design was developed by Sandia in collaboration with General Atomics and the French government to improve hydrogen production for alternative energy.

COMMERCIALIZATION AND INDUSTRY IMPACT

While the company's initial focus has been on agricultural applications, Bayotech's systems will enable on-site hydrogen production for a variety of consumers, including the agricultural industry for on-site ammonia production; the energy sector for cleanup of heavy crudes; and the hydrogen fuel sector for fueling stations, distribution centers, and ports. BayoTech is contributing to the New Mexico economy by providing highly paid technical, financial, and administrative jobs. The company is partnering with Process Equipment & Service Co., based in Farmington, New Mexico, to manufacture its reactor systems.

Representative image of hydrogen fuel. Bayotech's modular hydrogen production unit, with underlying Sandia technology, could decrease the economic and environmental impact of hydrogen production.





Resilience for Water Distribution Systems

Sandia's Water Network Tool for Resilience (WNTR) identifies critical challenges faced by water distribution systems.

PROBLEM

Water distribution systems, a crucial component of urban infrastructure, deliver safe drinking water to support human health, the economy, and the environment. These distribution systems face challenges such as aging infrastructure, water quality concerns, uncertainty in supply and demand, natural disasters, environmental emergencies, and cyber and terrorist attacks. These incidents have the potential to disrupt water service for extended periods of time. To help minimize disruptions, the United States Environmental Protection Agency (EPA) funded efforts at Sandia to develop the Water Network Tool for Resilience (WNTR), a software package designed to simulate and analyze a water distribution networks' resilience. The software analyzes water distribution system performance during disruptive incidents and helps prioritize recovery options.

INNOVATIVE EDGE

Utilizing Sandia's expertise in simulation, resilience analysis, and software development, WNTR integrates critical aspects of resilience modeling for water distribution systems into a single software framework. The software's simulation and analysis capabilities help water utilities predict how their system will respond to expected and unexpected incidents and inform decisions that improve overall resilience. The software includes capabilities to generate water network models, simulate hydraulics and water quality, and evaluate resilience considering a wide range of disaster and recovery scenarios. As water distribution systems grow more complex, evaluation under adverse conditions requires advanced modeling, complex controls, and dependency on other critical infrastructures. The WNTR software framework helps support this type of resilience analysis.

COMMERCIALIZATION AND INDUSTRY IMPACT

WNTR is an open-source Python package that evaluates how a system will respond to a wide range of disruptive incidents, such as earthquakes, power outages, water quality concerns, supply and demand uncertainty, and cyber-attacks. The software, which has been downloaded over 27,000 times, has been applied to a wide range of infrastructure resilience projects such as hurricane preparedness in the US Virgin Islands, earthquake preparedness in Seattle, and power outages in New York. Users of the software have included Arcadis, Xylem, Mott McDonald, Los Alamos National Laboratory, and Naval Postgraduate School. These users leverage the software for activities such as classic water systems analysis, network analysis for infrastructure, and to assist in their own code development. The software provides the water distribution systems analysis community a rich set of tools to predict how water distribution systems will perform during various incidents, and understand how to absorb, recover from, and adapt to disruption to enhance resilience.

◀ *Representative of Sandia's WNTR software which can simulate natural disasters, power outages, shifting population centers, or other challenges to analyze the resilience of water distribution networks.*

Novel Technology Allows for Rapid Diagnostics

Commercialization of Sandia's SpinDx has created a unique diagnostic tool to track male fertility.

PROBLEM

Current laboratory analysis tools for evaluating male fertility can take many days or weeks to supply test results. These tests can be expensive, and in some cases, they may not be covered by medical insurance. For couples trying to conceive a child, the cost and time spent waiting for results can be taxing. Realizing there was only one device on the market for real-time male fertility testing at home, the founders of Sandstone Diagnostics recognized an opportunity and licensed SpinDx to create the Trak Male Fertility Testing System.

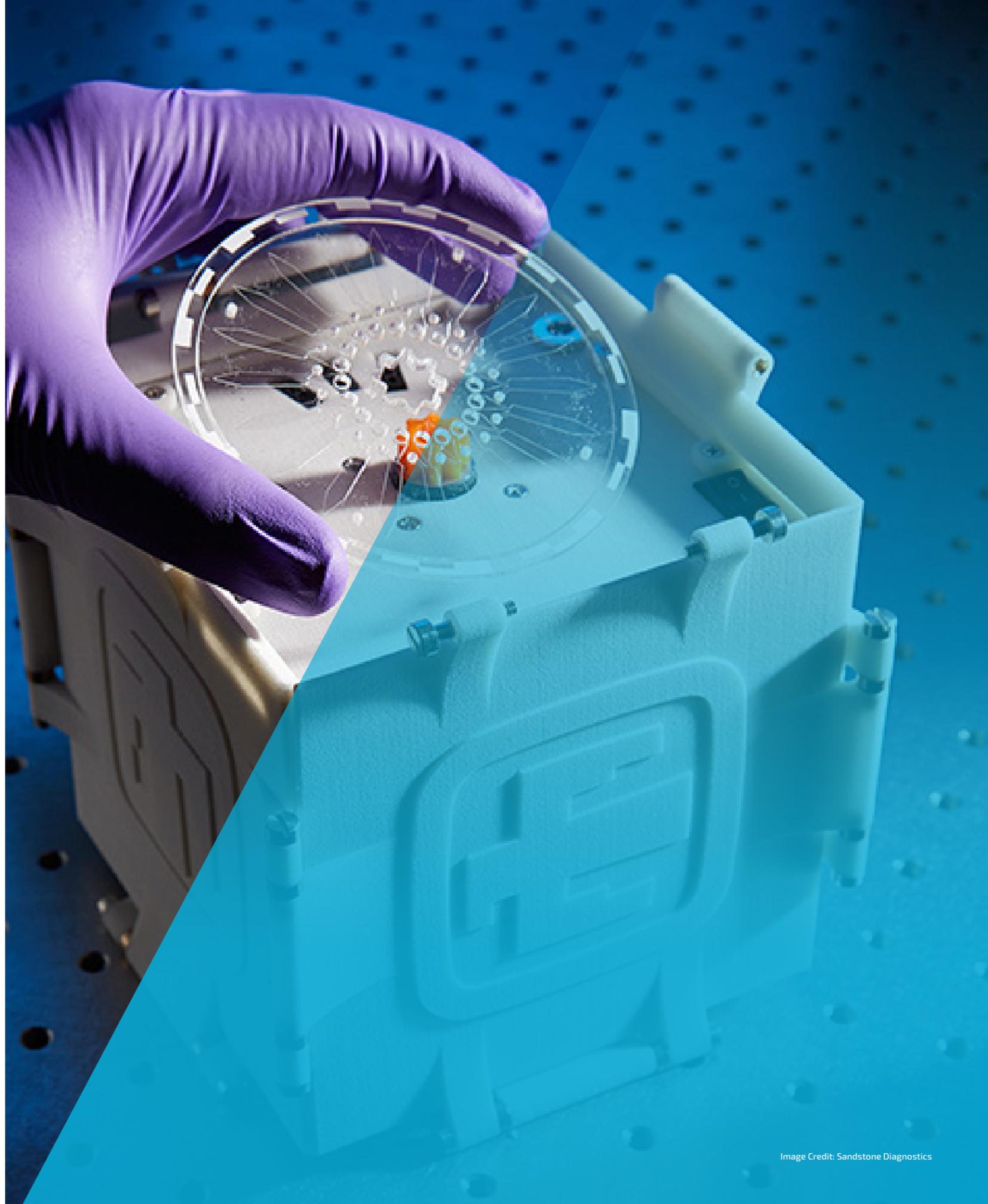
INNOVATIVE EDGE

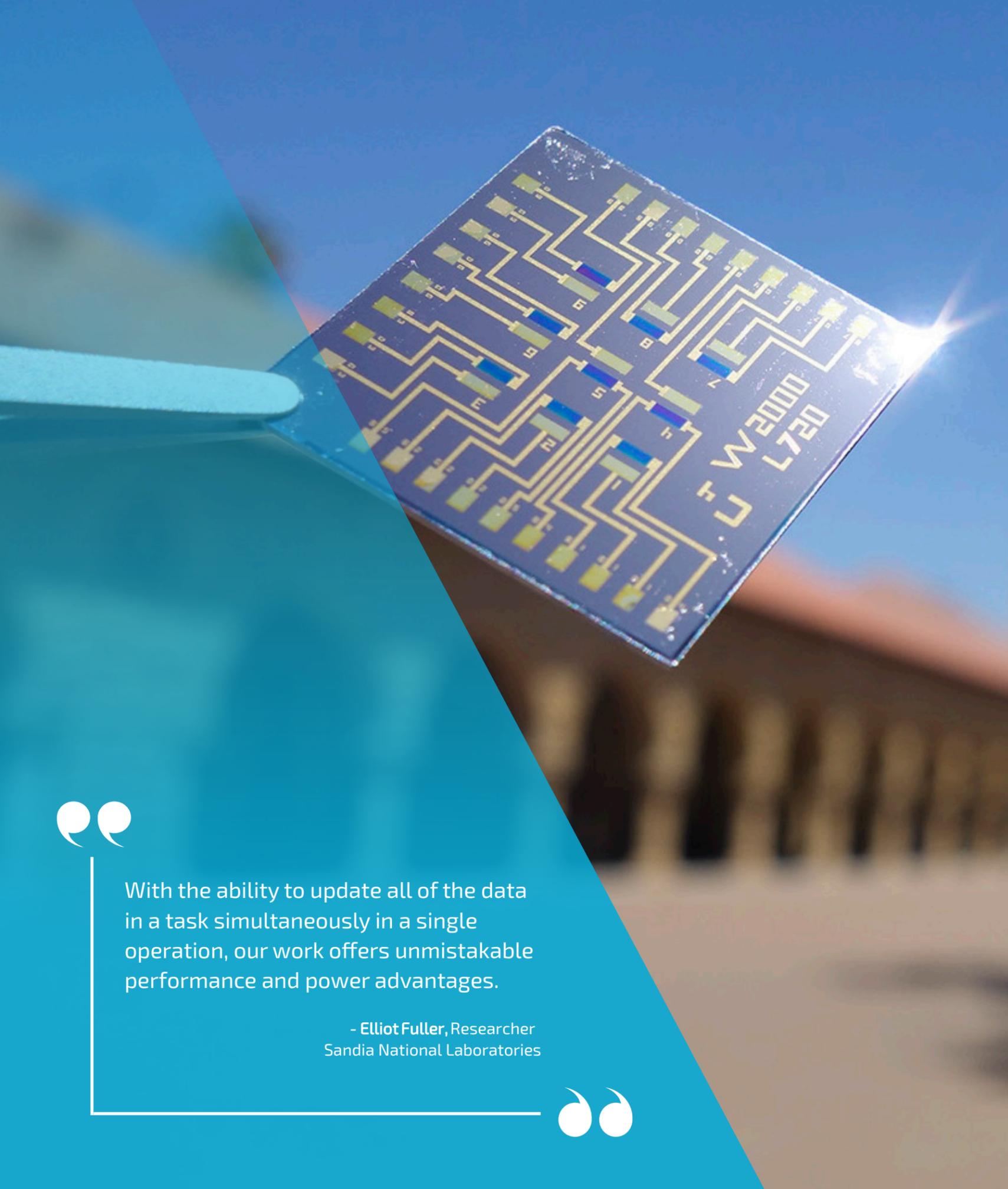
Sandstone Diagnostics, founded by two former Sandians, developed Trak Male Fertility Testing leveraging Sandia's SpinDx technology, a portable lab-on-a-disk diagnostic device that was originally developed using Sandia's Laboratory Directed Research and Development funding to identify trace levels of biotoxins to combat terrorism. Unlike many other diagnostic devices in the market, Sandia's SpinDx technology can perform either protein or nucleic acid tests using a heating element. Control of heat flow allows for different temperature zones inside SpinDx, enabling simultaneous nucleic acid and protein tests. Nucleic acid tests require a temperature that would ordinarily destroy a sample's proteins. The Trak Male Fertility test utilizes this specialized diagnostic process to enable men to measure, track, and improve their sperm count in the comfort of their own homes. Users simply place a small test sample into a four-inch plastic disk etched with microfluid channels containing beads designed for specific assays. The disk is spun in the battery-powered SpinDx for an assay reaction and a quick count, providing results within 15 minutes rather than several days or weeks.

COMMERCIALIZATION AND INDUSTRY IMPACT

After receiving FDA clearance in 2016, the Trak Male Fertility System was commercialized and can now be purchased from Sandstone online or through other online retailers, including Amazon. Sandstone is also exploring other applications for SpinDx, including ultra-sensitive toxin detection for neonatal sepsis, and is currently developing the Torq, a zero-delay centrifuge system that produces clean plasma within minutes of collection. Plasma, which is the most frequently tested specimen in clinical diagnostics, requires separation from the rest of blood for testing purposes, but prediagnostic errors can occur before blood is analyzed due to a delay in blood separation. Sandstone's Torq may help limit those issues. In addition to Sandstone, Sandia has licensed SpinDx to seven other entities, including a licensing agreement with Lifeloc Technologies to use SpinDx for the detection of drugs of abuse.

Sandia's SpinDx technology was licensed to create Sandstone's Trak Male Fertility Testing System and will be used by Lifeloc Technologies to detect drugs of abuse. ►





With the ability to update all of the data in a task simultaneously in a single operation, our work offers unmistakable performance and power advantages.

- Elliot Fuller, Researcher
Sandia National Laboratories



Improving Neuromorphic Computing Efficiency

Allowing computers to learn and process information with orders of magnitude greater efficiency.

PROBLEM

Machine learning algorithms are demanding larger amounts of data storage and power to complete increasingly difficult tasks, like voice recognition, robotics and autonomous driving. However, today's computers are now reaching performance limits as Moore's Law ends and transistors can no longer be reduced in size. Such performance limits are severely inhibiting the impact of the machine learning to our society. To address this issue and increase computing performance, scientists and commercial manufacturers have focused on the field of neuromorphic computing, which is inspired by the way the human brain carries out data-centric tasks. Neuromorphic computing aims to engineer new computing devices, materials and computer architectures that work collectively to execute machine learning tasks with orders of magnitude greater efficiency than today's computers.

INNOVATIVE EDGE

To meet this challenge, scientists at Sandia National Laboratories along with researchers at Stanford University and the University of Massachusetts, Amherst designed a prototype array of artificial synapses that loosely mimics the way the brain processes and stores information. The team reports that in testing the prototype, a three-terminal design called an ionic floating-gate (IFG) memory, the artificial synapses performed even better than anticipated in processing speed, energy efficiency and durability. The IFG, similar to biological synapses, relies upon ion motion and chemical reactions to store and process information. IFG demonstrated processing and storing information in parallel (or in one action) by the memory elements, thereby reducing energy consumption and increasing efficiency. In contrast, traditional computers must take many extra steps to sequentially transfer information back and forth between the memory and processor.

COMMERCIALIZATION AND INDUSTRY IMPACT

These findings were published in Science Magazine in May 2019 in an article titled "Parallel programming of an ionic floating-gate memory array for scalable neuromorphic computing." Researchers reported that the projected energy efficiency of the developed IFG surpasses that of its digital counterparts by nearly three orders of magnitude. Widespread applications of these developments include those in mobile and wearable devices, and will enable continuous learning by computers and similar devices over their lifecycle.

◀ *An array of artificial synapses designed by researchers at Stanford and Sandia National Laboratories can mimic how the brain processes and stores information.*

Image Credit: Armantas Melianas and Scott Keene, Stanford University

Experimental Strategy Games

New technologies are making wargames more accessible and repeatable, allowing for data analysis to provide increased insight and understanding of strategic risks and opportunities.

PROBLEM

International relations are increasingly interconnected and complex, and researchers are seeking insights into conflicts, disputes, and escalation dynamics. Traditional approaches include observing strategies and tactics of high-ranking experts in seminar-style wargames simulating scenarios of interest. While the expertise of participants in these traditional scenario-based wargames is valuable, the data generated cannot support statistically significant conclusions. Sandia is working with UC Berkeley and Lawrence Livermore National Laboratories (LLNL) under a Berkeley-led project titled the Project on Nuclear Gaming (PoNG). The resulting game, Strategic Interaction Game between Nuclear Armed Lands (SIGNAL), offers players a chance to make strategic game play decisions using political, economic, and military tools. With this new approach, the project has created a way to observe thousands of playthroughs by different players in a game involving cyber, conventional, and nuclear capabilities, thus allowing for machine learning and data analytics to study conflict escalation.

INNOVATIVE EDGE

SIGNAL, available online, serves as the first example of a large-scale, experimental gaming approach for examining nuclear deterrence and conflict escalation dynamics and will allow researchers to analyze players' strategies. The project seeks to better understand how new experimental gaming techniques can deepen insight into conflict escalation and the potential implications of new weapon types and technologies.

COMMERCIALIZATION AND INDUSTRY IMPACT

The game allows the collection of data that can be used to explore new questions, such as how the broader population would react in certain types of conflict situations. The PoNG team recruits early-career security specialists and graduate students in related fields to play the game, giving them a chance to practice real-time strategic decision making. This has inspired some contributors to pursue public sector careers. In addition, several academic and international organizations are interested in partnering with the project team on the pedagogical value of this new gaming approach.

Signal is a next-generation game designed to represent hypothetical countries and help future strategists make strategic decisions using modern political, economic, and military tools.



“What we're working towards is being able to better understand how different force structures, like what types of weapons you have in your arsenal, might change how people act in a crisis. The more we can understand that, the better we can inform policymakers on possible options for reducing the risk that those weapons pose to the world.”

- Bethany Goldblum, *Researcher,*
UC Berkeley Department of Nuclear Engineering

Reducing Uncertainties in the Cosmos

Sandia's Z helps astronomers understand the physical environments of our Earth-Moon system, white dwarf stars, black holes, and the Sun.

PROBLEM

Scientists at the University of California Davis (UC Davis) and Harvard are studying the origin and evolution of our Earth-Moon system. Primary methods to study such systems include computer simulations of planetary impacts and experiments at UC Davis' Shock Compression Lab. The simulations suggest a new model to explain why the Earth and Moon are nearly identical in chemical makeup: our Moon originated from an impact between the Earth and a large object that left the Earth rotating rapidly, much faster than previously modeled. The impact was strong enough to create a hot, donut-shaped structure composed of rocky vapor that eventually evolved to become our present-day Earth-Moon system. UC Davis' experiments launch projectiles at seven to eight km/s that compress and heat material samples from deep in the Earth's core to conditions reminiscent of such planetary impacts. However, higher impact velocities are needed for improved understanding of conditions that are created post-impact; such velocities can only be achieved on Sandia's Z pulsed power facility, commonly referred to as Z.

INNOVATIVE EDGE

Sandia's Z is the largest and most powerful pulsed power facility in the world. Z uses intense magnetic fields associated with high electrical currents for high energy density science applications. Z can recreate the extreme pressures and temperatures that occurred during formation of the Earth-Moon system at velocities of up to 40 km/s, like those predicted by the UC Davis Earth-Moon computer simulations. Related to this research, Sandia is also part of the new DOE-NNSA Center for Matter at Extreme Conditions (CMC). CMC, headquartered at UC San Diego and led by Farhat Beg, is partnered with three other UC campuses (Berkeley, Davis, and Los Angeles) as well as the University of Chicago and Florida A&M in close collaboration with General Atomics and four DOE national labs (Los Alamos, Lawrence Livermore, Sandia, and the SLAC National Accelerator Laboratory). Sarah T. Stewart, a UC Davis professor and Director of the Shock Compression Lab, is a co-principal investigator for the Center; Sarah, who continues to work with Sandia, received a 2018 MacArthur "genius" Fellowship for "advancing new theories of how celestial collisions give birth to planets and their natural satellites, such as the Earth and Moon."

COMMERCIALIZATION AND INDUSTRY IMPACT

Sandia's partnerships with leading science and engineering universities are critical to national research and development priorities. Drawing on the universities' research, talent and experience and Sandia's unique facilities and expertise, the partnership between Sandia, UC Davis, and Harvard is enabling novel research on the physical properties of planetary minerals and gases at extreme pressures and temperatures. By using Z's unique capabilities, researchers will address questions and uncertainties about the origin and early evolution of our solar system, super-Earths outside our solar system, and the universe.



◀ *Sarah Stewart in her lab at UC Davis with students, where two powerful gas guns simulate conditions in the early solar system.*

Image Credit: Deborah Netburn's 2018 piece in LA Times



▲ Sandia's Z machine contributes to a fundamental understanding of nature, fusion research in the laboratory, and a greater understanding of the safety, security, and reliability of our nation's nuclear weapons stockpile.



Algorithm Library for Software Developers

Sandia's innovative approach facilitates software integration for development algorithms.

PROBLEM

In the dynamic world of software development, developers must construct codes that address unique subjects, such as materials physics or cardiac dynamics. The individual, distinct software capabilities required can be time-intensive to implement. Although the end users and applications of these codes are unique, there are generic aspects of software construction that developers can build upon to expedite the development process. Sandia's Trilinos framework – an architecture to enhance the research, development, and integration of new algorithms for software development – facilitates code creation and decreases overall programming time.

INNOVATIVE EDGE

Trilinos grew out of a group of established numerical algorithm efforts at Sandia that aimed to have a large positive impact on the quality and usability of the software Sandia produces. Trilinos' solver library traces its roots to Sandia's Aztec software. Originally created to solve materials physics problems, study human physiology, and address real-world issues, researchers further developed the Aztec library in Trilinos, which offers an enhanced version of Aztec, AztecOO. Trilinos serves as both a production tool for software performance improvement and as a research testbed for developing and evaluating capabilities on future applications and platforms.

Trilinos is a library of software with components, or 'packages,' that can be adapted by application programming interfaces (APIs) to run as solvers, high-performance data structures, and parallel algorithms for various scientific and engineering applications. The software offers a variety of ways for a package to interact with other packages, such as stringing object-oriented packages together. It also offers developers a set of tools for building on multiple platforms, generating documentation, and conducting multi-platform regression testing. Current Trilinos development efforts are focused on preparation for Exascale platforms, systems capable of a billion-billion operations, expected to arrive in 2021.

COMMERCIALIZATION AND INDUSTRY IMPACT

Trilinos is one of the largest and most complete scalable solver capabilities in the world and is freely available to the public as open-source software. With over 50 unique packages, Trilinos has been tremendously successful, becoming a critical enabler of the diverse simulation codes that support most engineering disciplines within the Department of Energy's (DOE) Advanced Simulation and Computing (ASC) program and many Federally Funded Research and Development Centers (FFRDCs). The software continues to be leveraged at Sandia in software packages, such as Goma, Dakota, Xyce, and Sierra, which are utilized in range of areas, from national security to manufacturing processes. In addition, various academic, industrial, and government entities, such as Boeing and Goodyear, are Trilinos users.

Lowering Emissions for Diesel Engines

Ducted fuel injection improves the atmosphere and economy by reducing emissions.

PROBLEM

Soot and carbon dioxide are the largest contributors to climate change. Engine designs have consistently failed to remove soot from emissions due to the physical limitations of fuel combustion chemistry. Injectors in traditional diesel engines create local igniting mixtures that contain two to ten times more fuel than necessary for complete combustion, which results in excessive amounts of soot. At Sandia's Combustion Research Facility (CRF), new innovations for engines have the potential to reduce emissions of soot and nitrogen oxides (NOx) in a cost-effective manner while encouraging the use of renewable fuels and improving engine performance. In particular, Sandia's ducted fuel injection technology, which could be retrofitted into existing diesel engines, eliminates the soot-NOx trade-off, greatly reducing diesel engine emissions.

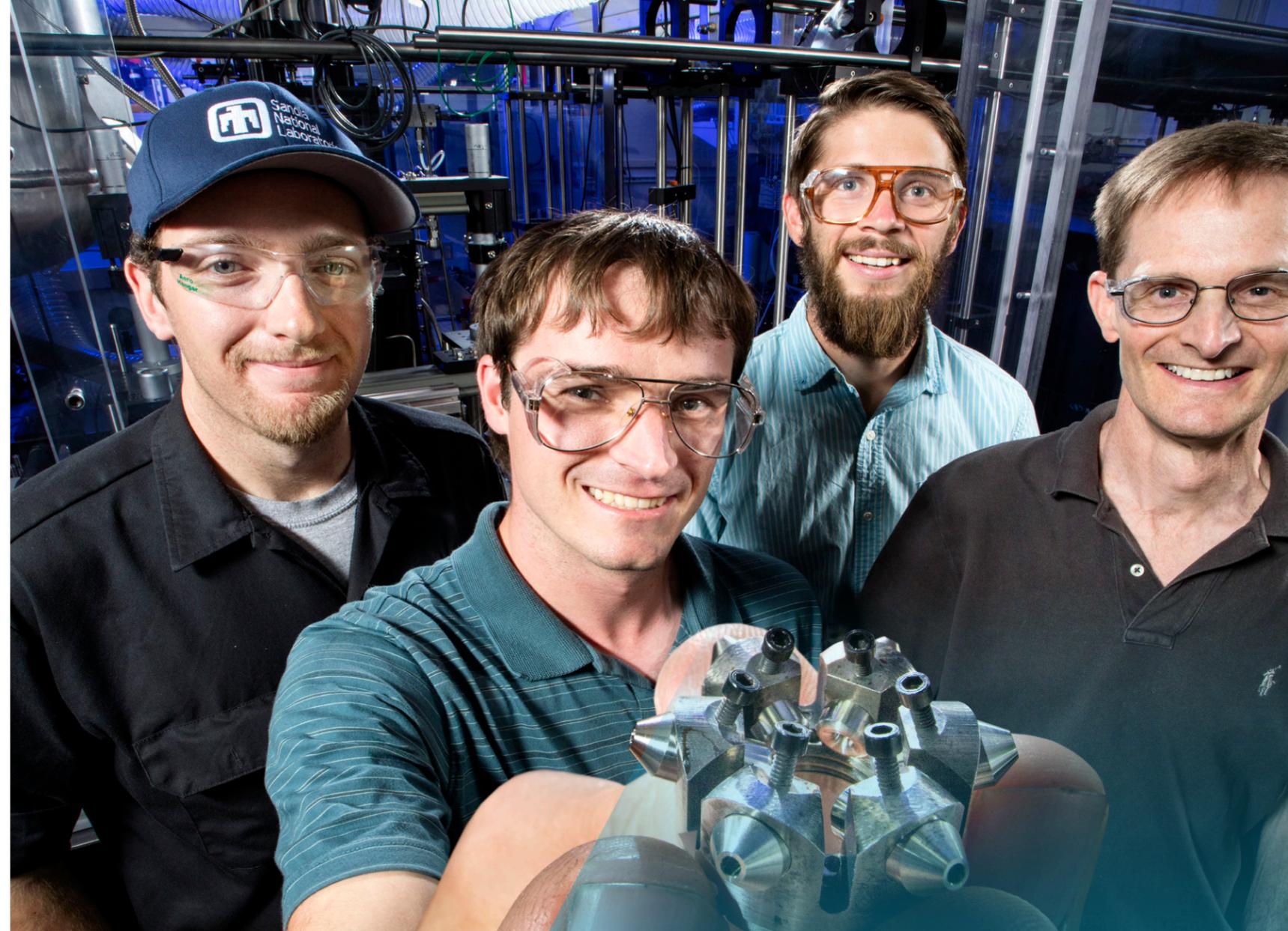
INNOVATIVE EDGE

Sandia's CRF – a highly-specialized suite of laboratories that includes laser-based diagnostics, a computer-controlled safety system, and combustible and toxic gas handling capabilities – is an established leader in combustion research and development. Ducted-fuel injection was born when CRF scientist Charles Mueller and his team found inspiration in a Bunsen burner, which eventually led to the assembly of four to six ducts directing the fuel mixture from the injector to the points of ignition. The ducts can be constructed from low-cost materials and enable diesel combustion with minimal soot levels, because the local igniting mixtures contain less excess fuel. Depending on an engine's instantaneous speed and power level, ducted fuel injection can fine-tune the fuel-air mixture in an engine to reduce between 50%-100% of the soot and NOx emissions.

COMMERCIALIZATION AND INDUSTRY IMPACT

Industry has taken note of this technology, which will enable a less-expensive engine system because less exhaust aftertreatment would be required. Ford and Caterpillar signed a Cooperative Research and Development Agreement (CRADA) with Sandia in 2019 to help enhance the technology. The patented technology has also attracted the attention of Toyota, General Motors, and Georgia Tech.

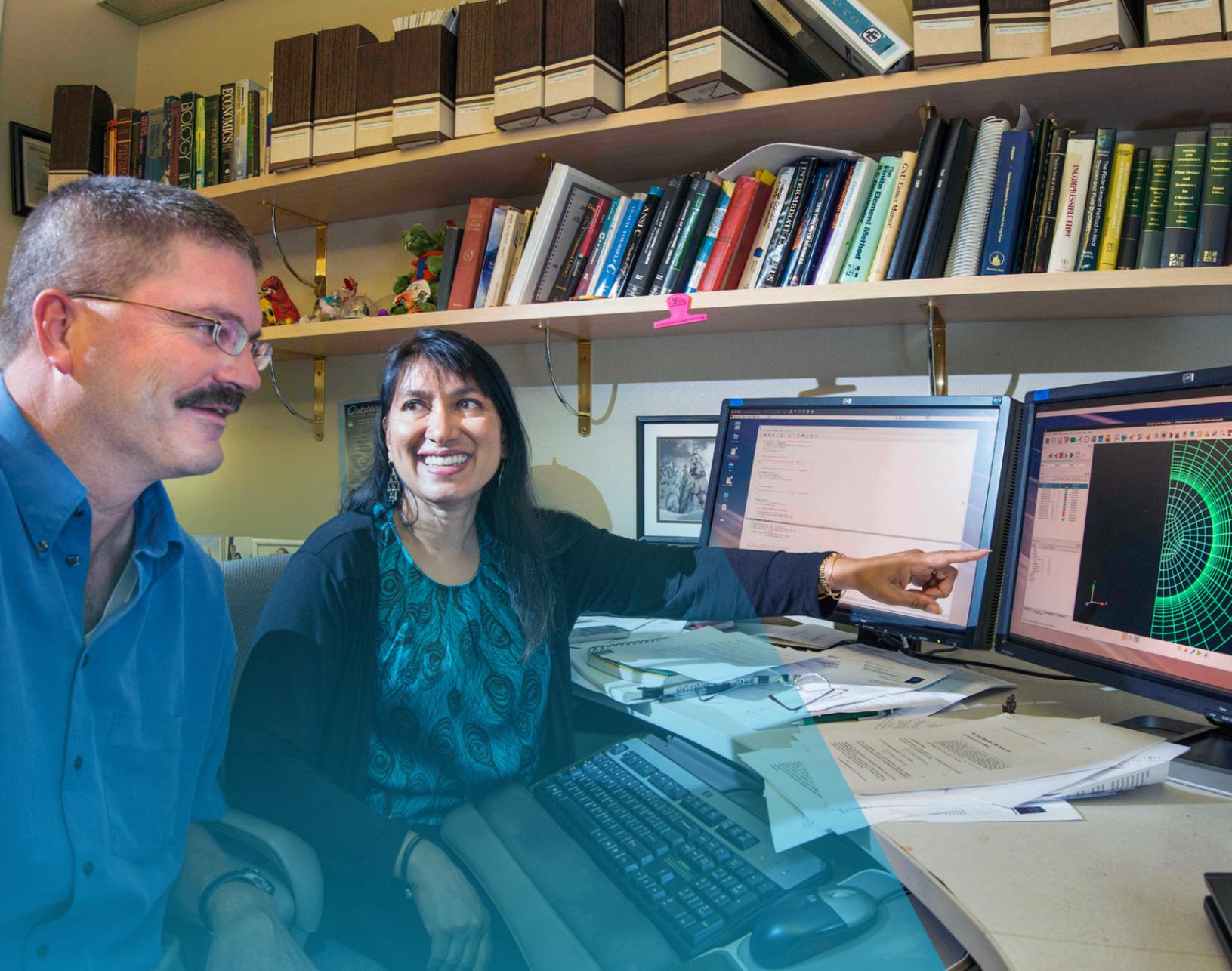
From left, Sandia National Laboratories researchers Nathan Harry, Christopher Nilsen, Drummond Biles and Charles Mueller show off the prototype ducted fuel injection module.



Breaking the trade-off between soot and nitrogen oxides is a research area of highest priority for diesel engine development. This is an example of the key role of government supported research — to identify and demonstrate the potential of innovative, high-risk technologies to reshape the landscape for an industry, our transportation infrastructure, and our society, and then to work alongside commercial partners to get the technology into the marketplace.

- Paul Miles, CRF Engine Research Program Manager,
Sandia National Laboratories





Reducing Manufacturing Process Development Time

Sandia's open-source software, Goma, benefits industry through cost savings and improved product design.

PROBLEM

Large corporations face the challenge of remaining competitive in the global marketplace while increasing market share. These corporations rely on product creation and improvement to serve existing markets and capitalize on new opportunities. Developing new or improved products requires creating or reevaluating manufacturing processes and demands significant time and capital investments. While there is commercial software available for modeling and simulating physical processes, it can be expensive and difficult to use. Several large manufacturers have collaborated with Sandia National Laboratories for many years to improve their manufacturing processes utilizing Sandia's Goma software to reduce process-development time, understand fundamental processes, and educate computational mechanics experts.

INNOVATIVE EDGE

Goma was originally developed at Sandia in the 1990s to solve free and moving boundary problems. The software, which has applications in industrial modeling and simulation processes, is a novel algorithm where boundary motion is accommodated by allowing mesh nodes to move as if they were a pseudo-solid rubbery material. Compared to other software applications, Goma allows for rapid response modeling due to its flexible structure by mixing and matching physical-chemical interactions and developing specialty physics models.

Over the course of its development, Goma benefited from early use and input from more than 26 industry and university users and partners, creating a more robust software. Since it was released as open-source software in 2013 it has been widely used by commercial manufacturers. It is the first finite-element code with multiphysics mechanics and production capabilities to be freely available for users. In 2014, Goma received an R&D 100 Award for both its capabilities and its ability to be used as an educational tool. The University of New Mexico now manages the external repository for the software.

COMMERCIALIZATION AND INDUSTRY IMPACT

Goma has been used for over a decade in commercial manufacturing processes. Projects at 3M have helped advance manufacturing process technologies and product design through faster and more uniform production of adhesive tapes and abrasive materials. Additionally, Corning has used Goma simulations to gain deeper insight into flat panel glass processing and Procter & Gamble has used the software for porous adsorbent media applications. Academic institutions utilize the software for graduate students learning numerical methods. Sandia received the R&D 100 Award in 2014 due in part to Goma's educational opportunities. The University of Minnesota is currently researching a path forward in which the software can be utilized for high tech materials manufacturing.

◀ *Sandia National Laboratories researchers Randall Schunk and Rekha Rao discuss an image generated by the Goma 6.0 program.*

The Goma 6.0 software has been a critical component of our computational suite leading to process knowledge creation and we look forward to future collaborations with the open-source Goma community.

- Dr. Robert Secor, Staff Scientist,
Corporate Research Process Laboratory

Advanced Monitoring System for Supercomputing Performance

Sandia's Lightweight Distributed Metric Service (LDMS) monitors and enables diagnosis of crucial performance issues in supercomputers.

PROBLEM

Regular home and office computers typically support a single user and failures are rare. In contrast, high-performance computers have vastly more components and support multiple concurrent users running complex applications on the latest hardware technologies, making failures common and improvements in operational efficiency difficult. Sandia researchers and their collaborators – including the University of Illinois at Urbana-Champaign (UIUC), Boston University, and Open Grid Computing (OCG) – are replacing traditional, manual methods for performing supercomputer diagnostics and using machine-learning analytics to monitor and automatically diagnose performance issues within supercomputers. Efforts have resulted in the creation of an advanced monitoring system called the Lightweight Distributed Metric Service (LDMS).

INNOVATIVE EDGE

LDMS – the only HPC monitoring tool to provide continuous high-fidelity, system-wide platform awareness – offers a new, high-quality source of data for systems analysis. Multiple collaborations are furthering this work, including the following:

- **OCG:** Sandia and collaborative partner OCG have developed fundamental design and implementation features that enable the collection, transport, and storage of data at greater scales, at higher fidelity, and with lower impact to the system than other monitoring tools. Sandia's exposure to the latest HPC systems technologies in processing, memory, and interconnects ensures that LDMS collects data necessary for understanding aggregate HPC systems.
- **Boston University:** Sandia and Boston University are collaboratively tackling automated anomaly detection and root-cause diagnosis. The collaborators have written a suite of synthetic performance anomaly injectors based on issues seen in production. Through the use of machine learning techniques, the partnership is training models to automatically recognize problem signatures in new scenarios and provide automated diagnoses. Such performance issues include memory imbalance, poor cache utilization, memory leaks, and others.
- **UIUC:** Sandia and UIUC, one of Sandia's academic alliance schools, are collaboratively researching automated detection of and responses to network congestion. The partnership uses an ensemble of machine learning techniques to discover congestion-related indicators and quantify their impact on application performance. The team is developing experiments to assess the most effective responses, both manual and automated, to mitigate performance degradation.

COMMERCIALIZATION AND INDUSTRY IMPACT

LDMS is a freely-available, open-source, and platform-independent software with low overhead demands, allowing it to collect hundreds to thousands of metrics on a greatly diminished timescale without compromising application performance. As a result, the software is currently part of the NNSA's Tri-Lab Operating Software Stack, which is the base software stack for all high-performance computing systems at Sandia, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory. Large-scale deployments of LDMS include the Cori supercomputer (12,067 nodes) at the National Energy Research Scientific Computing Center and the National Center for Computing Application's Blue Waters (27,648 nodes) at UIUC. Data collected from these computers is improving performance through providing near real-time data and is improving architects' next-generation HPC system designs through data-driven understanding of how applications interact with the resources of current generation systems. Other benefits include improved system performance through low-latency diagnoses and situation-based resource allocation.



Sandia computer scientists Ron Minnich (foreground) and Don Rudish utilize Sandia's Thunderbird supercomputing cluster to demonstrate running Linux kernels as virtual machines, an achievement that will allow cyber security researchers to more effectively observe behavior found in malicious botnets.



Broadly, these large-scale, high-performance computing systems are very critical for scientific progress. The Department of Energy, for example, has a number of supercomputers where all the scientific computing applications workloads are run, and these include lots of different topics...People write simulators or applications to do scientific discovery or to evaluate something they are doing, and these are typically complex applications that run on many servers, many nodes, many computers, essentially, for a long time.

*- Ayse Coskun, Assistant Professor and Lead Principal Investigator,
Boston University*



Zero-Emission Ferries: from Vision to Reality

Bringing zero-emission, high-speed passenger ferries to Bay Area waters.

PROBLEM

Traditional diesel-powered ferries emit 10 times more air pollution than cars, and 23 times more than buses. In cities like San Francisco with heavy roadway traffic, ferry services shuttle commuters across the Bay daily, decreasing automobile congestion on the streets while simultaneously increasing air pollution. Years of research conducted around systems for reducing carbon emissions have emphasized road transportation applications, with little focus in the maritime industry.

INNOVATIVE EDGE

Sandia has a robust hydrogen program, first created in the 1960s, with extensive experience in hydrogen production, storage, and delivery, as well as fuel cell development and systems engineering. In 2014, Sandia's hydrogen expertise led the Red and White Fleet, a Bay Area ferry operator, to approach Sandia to help determine the feasibility of a zero-emission ferry using hydrogen fuel cell technology. While smaller hydrogen-powered boats do exist, they are designed to operate on calmer waters and at much slower speeds. Red and White Fleet required a high-speed alternative with the capability of ferrying large numbers of passengers quickly across the Bay multiple times throughout the day. The project, led by Sandia and sponsored by the Department of Transportation's Maritime Administration (MARAD) through MARAD's Maritime Environmental and Technical Assistance (META) program, commenced with the San Francisco Bay Renewable Energy Electric Vessel with Zero Emissions (SF-BREEZE). Conceptual feasibility was confirmed for a 150-passenger commuter ferry capable of daily traveling two 50-mile round-trips at top speeds of 35 knots (at least 60 percent of the time) before needing to be refueled with liquid hydrogen. Sandia collaborated with the naval architect Elliott Bay Design Group, the class society ABS, the US Coast Guard, and industrial hydrogen suppliers to determine that a hydrogen-fueled ferry and associated hydrogen fueling infrastructure were feasible and posed no "show-stopping" regulatory challenges.

COMMERCIALIZATION AND INDUSTRY IMPACT

The SF-BREEZE feasibility study created the launching point for the production of the first commercial hydrogen fuel-cell ferry by startup Golden Gate Zero Emission Marine (GGZEM) in partnership with SWITCH (Switch) Maritime, an impact investment fund focused on vessels. Construction of the first of this new fleet of hydrogen-fueled maritime vessels is currently underway in Alameda California at Bay Ship and Yacht Co., thanks in part to sponsorship from the California Air Resources Board (CARB). The resulting vessel, the "Water-Go-Round", once complete, will undergo several months of testing, commencing with a demonstration lead by project partner and sightseeing ferry operator, Red and White Fleet, prior to its launch as a commercial commuter service in the San Francisco Bay.



Image Credit: GGZEM

Helping the maritime industry as a whole implement zero emissions drive technology will not only add operational benefits to the myriad of business owners but also have a profound impact on the reduction of global pollution and CO2 emissions.

- Joseph Pratt, Ph.D., CEO & CTO
Golden Gate Zero Emission Marine (GGZEM)

Ensuring Cybersecurity in Solar Energy Systems

As a member of the SunSpec Alliance, Sandia is creating cybersecurity standards and best practices for distributed energy resources.

PROBLEM

The US power system is currently undergoing a transformation through the integration of renewable resources such as wind and solar. Distributed Energy Resources (DER) – energy generation and storage technologies which include fuel cells, grid-tied batteries, solar, and wind systems – are a rapidly growing part of the US energy portfolio as they are adopted by utilities and consumers. These systems require proven regulations to ensure attack-resilient devices and networks to protect against cyber threats. At the request of the Department of Energy's Solar Energy Technologies Office, Sandia recently created a roadmap to improve cybersecurity for solar DER; the roadmap includes needs for cybersecurity research and development, standards development, and industry best practices.

INNOVATIVE EDGE

Executing on this vision and leveraging more than a decade of cybersecurity research and development expertise, Sandia has assembled a workgroup to create standards and best practices in cybersecurity for DER. The workgroup is a part of the SunSpec Alliance, a trade alliance of over 100 solar and storage distributed energy industry participants that aims to ensure safe and secure system interoperability. As part of this goal, the SunSpec Alliance's DER Cybersecurity Workgroup is helping to define standardized certification procedures for DER and server vulnerability assessments, as well as creating DER control network topology requirements and interface rules. In the next two years the group will recommend comprehensive data-in-flight requirements for DER communications, establish patching requirements, and create recommended auditing practices for DER networks.

COMMERCIALIZATION AND INDUSTRY IMPACT

The SunSpec Alliance DER Cybersecurity Workgroup is creating a path forward for the secure usage of renewable energy systems and outlining actionable improvements to the DER cybersecurity standards landscape. The alliance strives to enable standardized systems that will ultimately reduce costs, accelerate industry growth, and secure critical infrastructure. Better protected and standardized systems will improve protection for critical energy infrastructure in the US and ensure that consumers' lights, water, and other utilities are functioning properly.

◀ *The SunSpec Alliance strives to protect distributed energy resources from cyber incidents through improved standards.*

Interoperable Distributed Energy Resources are rapidly becoming a large portion of the nation's power generation portfolio. These devices have the ability to provide grid services but also pose a risk to critical infrastructure if not properly secured. We established the DER Cybersecurity Workgroup to provide guidance, best practices, and cybersecurity standards for secure DER communications and control.

- Jay Johnson, *Principal Member of Technical Staff,*
Sandia National Laboratories

Preparing the Next Generation of Computer Scientists

Sandia's Jess software allows university students to develop expert systems to solve real world problems.

PROBLEM

Solving difficult or ill-defined problems, like job applicant qualification or transportation scheduling, can be time-consuming and create significant bottlenecks in an organization's operations. Expert systems, an early example of artificial intelligence, allow computers to help solve these problems using "if...then" rules. Sandia developed an easy-to-use expert system shell called "Jess" that enables users to create customized expert systems for logistics, planning, order processing, data mining, and optimization. A programmer simply defines a problem and Jess determines the necessary steps to solve it.

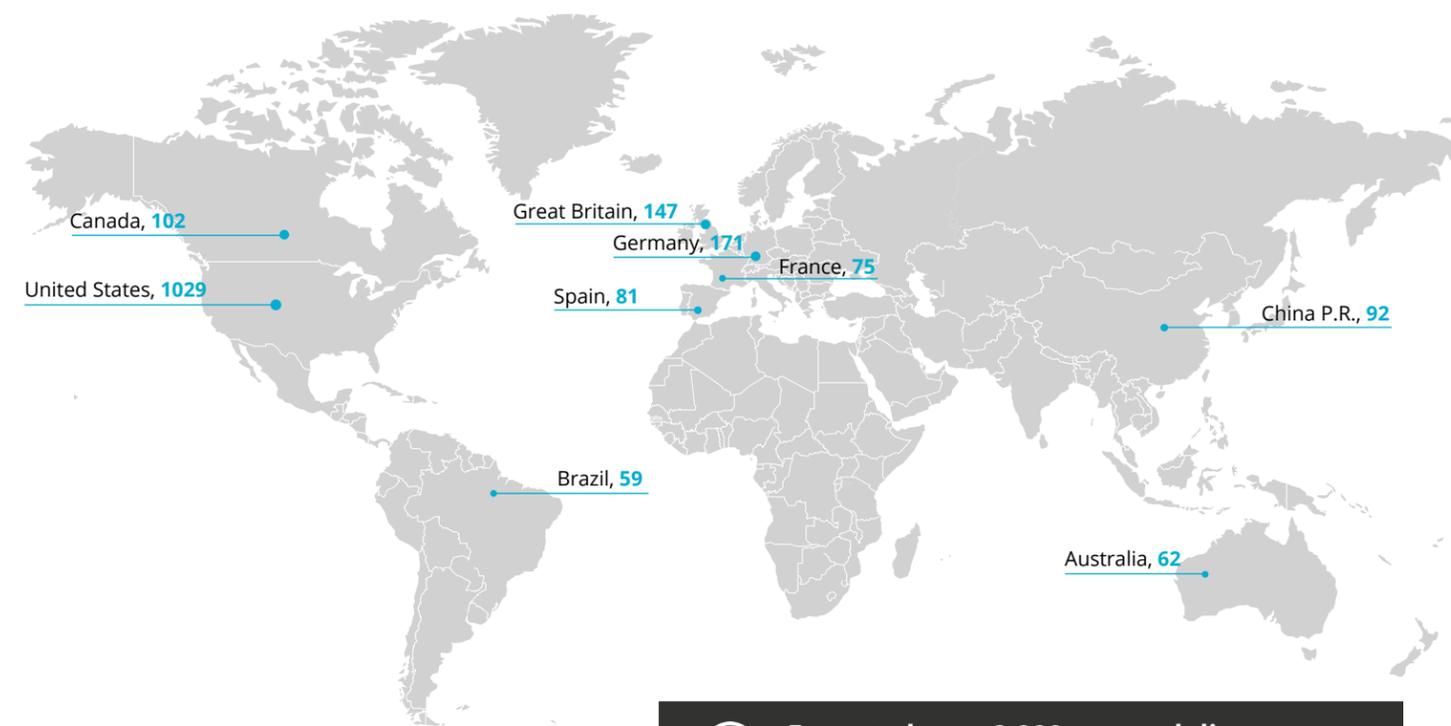
INNOVATIVE EDGE

The initial creation and subsequent release of Jess coincided with the development of the Java programming language—one of the most popular and widely used programming languages in the world. Since Jess was written in Java, any program developed using Jess has the ability to run on a wide variety of platforms, from cellphones to supercomputers. Java's popularity has optimized easy adoption of the program in industry and academia. The software has benefited from a large, active user network that helped shape development of multiple versions of the software program.

COMMERCIALIZATION AND INDUSTRY IMPACT

Since releasing Jess in 1997, Sandia has executed over 370 commercial licenses to large corporations including many in finance, insurance, security, transportation, and manufacturing. While Jess has experienced a great deal of commercial success, its ongoing legacy is training the next generation of computer scientists.

Sandia has executed nearly 2,000 research licenses with universities around the world since Jess was originally released and continues to execute new research licenses on a monthly basis. Universities are provided access to the full source code with permission to modify at no cost. In addition to free access to the code, a corresponding textbook was written by Jess's creator and published by Manning Press in 2003. The combination of textbook and source code has enabled students and professors to develop their own fully functional expert rules systems for real world applications.



Executed over 2,000 research licenses with universities around the world

TOP LICENSES BY COUNTRY

United States	1029	United Kingdom	49
Great Britain	147	Italy	48
East Germany	112	Netherlands	46
Canada	102	Republic of Korea	41
China P.R.	92	Taiwan	41
Spain	81	India	31
France	75	Greece	28
Australia	62	Japan	26
Brazil	59	Poland	26
Germany	50	Switzerland	26

Enhancing Aviation Safety

Sandia's expertise in structural health monitoring is enhancing structural integrity for commercial airlines.

PROBLEM

The aging fleet of aircraft in the United States amplifies the probability of structural integrity issues and accompanying complications. Inspection systems and repair practices are being developed to help enable the aviation community to maintain the commercial aging fleet more safely and cost effectively. These improved technologies will provide constant monitoring for the structural integrity of aircraft to ensure passenger safety and security. Sandia National Laboratories has worked in aviation safety for over 25 years in conjunction with the Federal Aviation Administration (FAA). Sandia began its long history in the field when the FAA, in response to several aviation incidents, increased its research efforts to improve inspection, maintenance, and repair of commercial aircraft.

INNOVATIVE EDGE

Sandia's Airworthiness Assurance Center (AANC), which is operated for the FAA by the laboratory, conducts independent inspection and maintenance development, reliability, flight testing, and technology transfer activities to facilitate the use of improved practices into the industry. Areas of expertise for the laboratory include nondestructive inspection (NDI), advanced materials, engines, structural integrity, and a wide range of other airworthiness assurance areas.

A structural health monitoring program at AANC has collaborated with the Boeing Corporation, Delta Air Lines, Structural Monitoring Systems, Anodyne Electronics Manufacturing Corp, and the FAA to understand the technical gaps of implementing structural health monitoring on commercial aircraft and the potential effects on FAA regulations and guidance. Recent activity has included the development of built-in sensors that automatically and remotely assess an aircraft's structural condition in real time and signal the need for maintenance. The team worked to provide the installation procedures for these new sensors to technicians and now oversees monitoring of the in-flight tests. Delta Air Lines and a foreign aircraft manufacturer have partnered with Sandia researchers in two separate programs to install about 100 sensors on their commercial aircraft. These sensors are now part of an FAA certification process that will make the sensors widely available to US airlines.

COMMERCIALIZATION AND INDUSTRY IMPACT

Once the sensors have passed through the FAA's certification process, structural health monitoring in aircraft will help commercial airlines be more cost effective by basing maintenance on the actual condition of aircraft, rather than fixed schedules and inspection routines. Constant monitoring for structural health will also assist airlines by increasing oversight and decreasing aircraft downtime, particularly if sensors are mounted in hard-to-reach areas. Improved practices will reduce preventable aircraft failures as well as the accompanying safety issues. Benefits will be passed on to passengers, further ensuring safety and on-time flights.

◀ *Sandia National Laboratories senior scientist Dennis Roach, center, works inside the cabin of a B737 test bed, installing and acquiring data from Structural Health Monitoring sensors with Sandia mechanical engineers Stephen Neidigk and Tom Rice.*



Like nerve endings in a human body, in situ sensors offer levels of vigilance and sensitivity to problems that periodic checkups cannot.

- Dennis Roach, *Senior Scientist,*
Sandia National Laboratories



Entrepreneurial Success in Safe and Reliable Batteries

Designing reliable, quality power sources for mission success.

PROBLEM

Reliable, quality power sources are integral to national security missions. Both private consumers and government entities need efficient power sources that are capable of being continuously monitored. Sandia spinoff company Advanced Manufactured Power Solutions (AMPS) provides custom, high-quality, and high-reliability battery packs for the defense and space industries. Its battery packs power high consequence, demanding applications with missions in extreme environments.

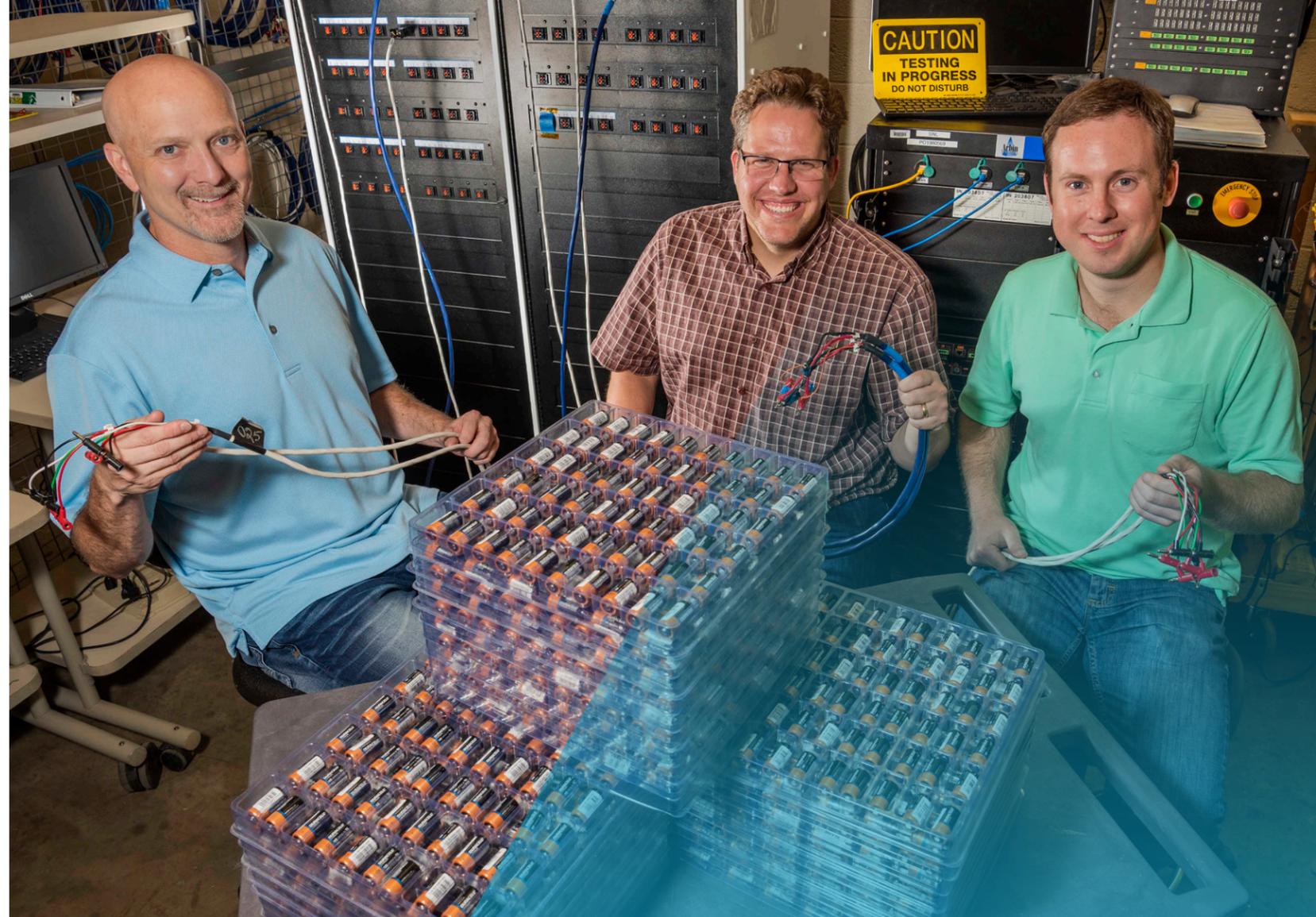
INNOVATIVE EDGE

Former Sandia employees Joe Beck and Eric Branson left the labs utilizing Sandia's Entrepreneurial Separation to Transfer Technology (ESTT) program to launch AMPS. The partners utilized the skills, expertise, and experience that they acquired during their time at Sandia to start their company, which builds battery packs, cables, and other small components of larger machines. Since the company's primary customers are government organizations and defense contractors, AMPS designs, develops, and produces high-reliability, custom power sources supporting national defense and other high-value applications. Understanding that quality, reliability, and traceability are all critical to mission success, the company employs a rigorous quality management system throughout the development and production process. AMPS delivers a rigorous documentation package with hardware to demonstrate compliance to all requirements, ensuring that its products function as designed and provide unique power source solutions.

COMMERCIALIZATION AND INDUSTRY IMPACT

AMPS focuses on rapid product realization of high-reliability power sources and teaming with the customer for accelerated cycles of learning to deliver better value (higher quality, shorter development cycles, lower cost, etc.). AMPS, which supports several defense contractors, is also a Sandia supplier and creates high-paying jobs that help stimulate the local economy. The three-year-old company reached a significant growth milestone recently with its first out-of-state contract, a project for NASA's Jet Propulsion Laboratory in Pasadena, California.

Sandia National Laboratories engineer Brian Perdue, center, collaborates with Advanced Manufactured Power Solutions co-founders Eric Branson, left, and Joe Beck, right, to build custom battery packs.



Many successful companies have their origins at Sandia, and each one exemplifies the entrepreneurial spirit found here. We're proud to see our former colleagues continuing to better society from the private sector. And in the case of AMPS, they continue to support Sandia's national security mission.

- Jackie Kerby Moore, *Manager of Technology and Economic Development, Sandia National Laboratories*



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