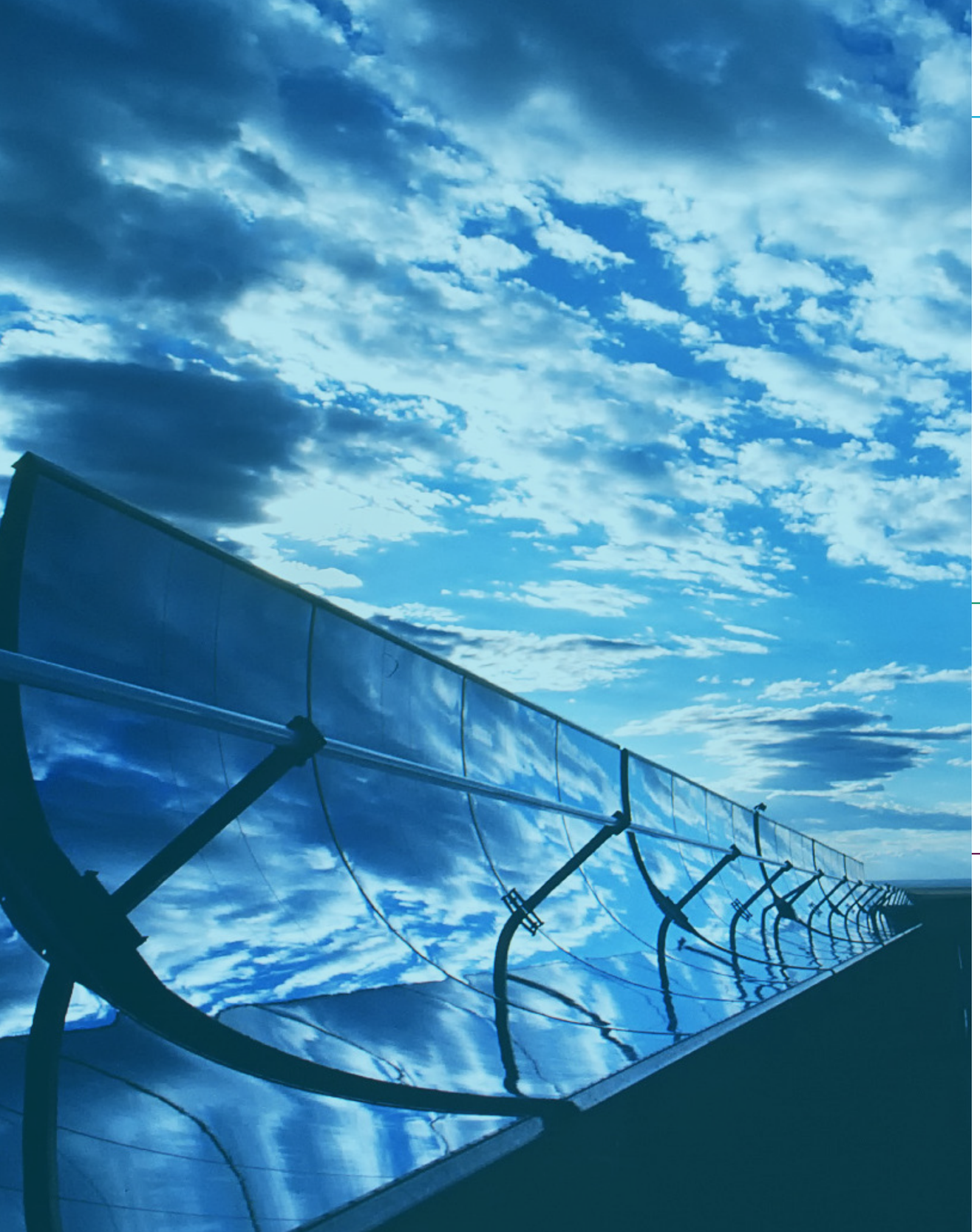
Sandia National Laboratories

TECH TRANSFER SUCCESS STORIES 2022

TECHNOLOGY Partnerships



FEATURED SUCCESSES

COVID-19 TECHNICAL ASSISTANCE PROGRAM (CTAP) SUCCESSES

LONG-TERM SUCCESSES

Sandia technologies can have an impact on everyday needs. Researchers have developed a mirror alignment measurement device, which may soon make one of the most popular solar collector systems, parabolic troughs, more affordable and energy efficient.

FEATURED
SUCCESSES

Sandia's projects span more than just national security. The Labs' strong foundation in broad science and technology research allows for innovations in a wide variety of industries, ranging from clean energy to biosecurity. The following successes highlight notable technologies and their impact in a range of fields.

Hydrogen Hubs

BayoTech builds hydrogen-generating hubs in the U.S.

PROBLEM

Hydrogen is seen by many as a critical enabler of the global transition to sustainable energy and is currently enjoying unprecedented momentum with a growing number of hydrogen-focused policies and projects graining traction worldwide. Although hydrogen is predominantly produced at large, centralized facilities before being delivered to end users, advances in fuel cell technology are driving demand for hydrogen in emerging applications, including in the materials handling, mobility and power sectors, where demand tends to be more distributed. However, for hydrogen to make a significant contribution to clean energy transitions, further action is needed to further overcome barriers and reduce production, transportation, and storage costs. New Mexico company BayoTech envisions local production of hydrogen as an avenue toward reducing these costs and helping the U.S. transition to hydrogen fuels.

INNOVATIVE EDGE

Sandia has a long history of investment in hydrogen—from materials interactions and hydrogen safety to emerging energy technologies and geosciences. The Labs' experts are working with industry partners to accelerate the deployment of zero-carbon hydrogen systems in transportation, industrial and other applications. In 2020, Sandia received an Excellence in Technology Transfer Award due to the success of licensing its bayonet chemical reactor technology to BayoTech, which the company is using in a steam methane reforming process to make hydrogen from natural gas on a small scale. Since the issuance of the license, the company has supplemented the technology with its own patented and patent-pending intellectual property and expertise. Robert Moore, a co-inventor of this technology, left Sandia to join BayoTech and continues to further build on its commercial applications as Director of Research and Development.

BayoTech develops modular, scalable and rapidly deployable generators that produce hydrogen at or near the point of use. The company's concept of multiple small distributed systems instead of a single large hydrogen production system is fundamental in reducing many barriers to the acceptance of hydrogen as an energy source, such as the cost and dangers of liquefying, transporting, and storing it. By producing hydrogen close to the application, the company is also able to serve a diverse set of end users, including traditional consumers in the industrial gas and chemicals industries, as well as those using hydrogen to power the fast-growing fuel cell segment.

IMPACT

Since its launch in 2015, BayoTech has invested in several efforts focused on providing accessible, scalable, and sustainable hydrogen and has attracted global attention from investors and industry partners, culminating in nearly $200 million in new equity from private investors as of February 2021. In July 2021, the company announced the acquisition of IGX Group, a manufacturer of high-pressure gas transport and storage equipment. This expanded the company's role in the hydrogen value chain beyond production to include distribution, storage, and dispensing of hydrogen. BayoTech is building hydrogen-generating hubs in the U.S. to provide hydrogen for a wide variety of applications in their surrounding regions—from retail hydrogen refueling stations and operators of fuel cell fleet vehicles to backup power systems. Construction is currently underway at the first BayoGaaS™ Hydrogen Hub site in St. Louis, Missouri, with another five sites in development. A unique feature of BayoTech's model for BayoGaaS™ Hydrogen Hubs is rapid scalability, in which the modular design, compact footprint and flexibility of its technology enable hydrogen production to grow quickly to meet market demand. Factory-built hydrogen production plants are transported to the site and quickly assembled—ranging from a one ton per day hydrogen generator to several tons per day.

By providing a consistent, cost-effective supply of low-carbon hydrogen, the company is helping to position the U.S. for its part in the transition toward a clean, secure, and affordable energy future while offering a real opportunity for New Mexico to establish a foothold as a center of excellence in the emerging hydrogen ecosystem. For Sandia, transferring the technology to industry helps the Labs fulfill one of its missions: to increase energy security and resiliency for the nation.

BayoTech's pilot plant in Albuquerque. Photo courtesy of BayoTech.

"Hydrogen will be a key enabler for the global energy transition. BayoTech's high-efficiency hydrogen generation technology provides a consistent, cost-effective supply of low-carbon hydrogen that can power zero-emission transportation, decarbonize industry and accelerate the transition to a clean energy future."

– Robert Moore,
Director of R&D, BayoTech

Attention Hackers: Welcome to HADES

Alternate reality misleads hackers and protects electrical grid

PROBLEM

Cybersecurity threats and attacks have made energy infrastructure an increasingly important aspect of national security. The Public Service Company of New Mexico (PNM) reports an average of 4,000 attempted cyberattacks each day, potentially crippling or damaging the energy grid. Highly secured substations, generating facilities, data centers, and other operational facilities are potential targets for hackers and malicious agents. The rise of sophisticated threats and attacks has prompted PNM to boost security measures.

To meet those needs, Sandia developed a novel cybersecurity technology to combat cyberattacks and has partnered with Z Division LLC, a local startup company, to evaluate the technology. The technology, called HADES, an acronym for High-fidelity Adaptive Deception & Emulation System, was previously tested within the U.S. government and involves long-term testing within New Mexico's electrical utility infrastructure. The technology has benefited from Laboratory Directed Research and Development funding Technology Readiness Gross Receipts Initiative funding. It was awarded an R&D 100 award in 2017.

INNOVATIVE EDGE

Years in the making, HADES lures a hacker into unwittingly falling into an alternate reality. The platform emulates an environment that can look like thousands of machines and provides mechanisms to directly interact with the adversary—something current deception products do not facilitate.

HADES is ground-breaking in that it creates a realistic, dynamic virtual deception platform that enables the user to detect, deceive, monitor, and neutralize potential cyber adversaries. HADES relies on software-defined networks, cloud computing, dynamic deception, and agentless virtual machine introspection as the basis for the platform. Once an attacker is detected, they are quarantined from the authentic network and moved to the deception network—a copy-pasted network indiscernible from the original, complete with seemingly active users and data transfers. After hackers are inside the system, HADES allows cybersecurity curators to watch, interact with, and learn from attackers to allow for future implementation of network defenses and prevent future attacks. The technology is a product of a new cybersecurity paradigm focusing on deception and false information rather than the traditional attempts of blocking network access.

COMMERCIALIZATION AND INDUSTRY IMPACT

HADES has the potential to develop actionable threat intelligence to better protect and defend critical energy and utilities infrastructure and sensitive data. Z Division is set to take the technology to market where it can apply the cybersecurity capabilities toward a wide range of industries and other institutions. PNM and Z Division will advance electric power system resiliency and safety capabilities that are critical to national security.

Sandia cyber researcher Vince Urias helped develop the Sandia-originated HADES program that employs alternative realities to confuse hackers.

HADES

Say Goodbye to Pathogens, Meet Breezy One

Autonomous disinfecting robot fleet sanitizes public spaces

PROBLEM

In the wake of the global COVID-19 pandemic, many public spaces and businesses were closed or restricted to admitting only a small percentage of their normal capacity. A critical component to reopening the economy was the ability to quickly and consistently disinfect these spaces, especially large, heavily used areas such as schools, transportation hubs, and arenas. Traditionally, disinfection is time- and labor-intensive work that requires a space to be closed for long periods of time and could expose cleaning crews to harsh chemicals. To quickly kill the SARS-CoV-2 virus in large areas, New Mexico company Build with Robots created the Breezy One™ disinfecting autonomous mobile robot which incorporated decontamination chemistry developed by Sandia. The Sunport, the largest commercial airport in New Mexico, uses Breezy One to conduct nightly disinfection to ensure the airport is as safe as possible for passengers and employees. Airports, arenas, and schools across the country are adopting Breezy One to provide a science-based approach to keeping spaces open.

INNOVATIVE EDGE

Most disinfecting robots either do not sufficiently eliminate harmful pathogens or require up to 24 hours before a disinfected space is safe to enter. In developing Breezy One, the company sought a disinfectant strong enough to kill viruses and bacteria at scale, but that also allows for the space to be used again quickly. The company licensed a disinfectant originally developed by Sandia for mitigation and decontamination of chemical and biological agents. This EPA-registered disinfectant, which is one of the strongest disinfectant agents commercially available, effectively decontaminates surfaces and air without leaving a harmful residue, allowing impacted spaces to be reentered as soon as two hours after disinfection. The disinfectant has been tested by nine government agencies and more than ten independent laboratories and was found to be effective against viruses, bacteria, and spores. It also meets nationwide hospital requirements for pathogen disinfection.

Using this disinfectant, Breezy One is able to decontaminate spaces over 100,000 square feet in under 1.5 hours, allowing a fast return to normal, safe operation. The quick turnaround means that businesses do not have to sacrifice more time than necessary to ensure their facilities are safe from harmful pathogens. The robot also allows cleaning staff to focus on providing services across the facility rather than spending time on extra sanitization procedures.

COMMERCIALIZATION AND INDUSTRY IMPACT

The partners were able to move from product conception to deployment in only three months, meeting the urgent need for large area decontamination due to COVID-19. Following its successful pilot at the Albuquerque Sunport, Breezy One was immediately made available to other facilities seeking to safely resume operations during the pandemic, including schools and warehouses. Using Sandia-developed disinfectant, Breezy One helps organizations safely operate during the COVID-19 pandemic greatly reduces transmissions of all other infectious diseases, and thereby reduces absenteeism in the places where people need to be.

A Sandia-produced disinfectant is used in the Breezy One robot, shown at the George Bush Intercontinental Airport in Houston, Texas. Image courtesy of Build with Robotics.

DragonSCALES: Solar Cells in Space

Energy technology developed by Sandia emerges as a versatile future solar cell power option, including for modular space stations

PROBLEM

Current solar technologies are considered inflexible, costly, and require substantial installation time. These barriers slow down the large-scale adoption of solar technology by a myriad of industries, including applications in space. New, creative solutions are simplifying—and substantially reducing the overall cost of—solar technologies as well as expanding application areas available to industry. Sandia contributed to overcoming these critical limitations in existing solar cell technologies by developing Microsystems-Enabled Photovoltaics (MEPV) cells: small, portable, and flexible solar panels that were often referred to as "solar glitter," now commercialized as DragonSCALES™.

INNOVATIVE EDGE

Sandia researchers used existing technologies to address current challenges in the solar industry, which resulted in the creation of MEPV cells. These cells are constructed using established microfabrication technology and tools used in microelectromechanical systems; liquid crystal device; light-emitting diode; and photovoltaics industries, thus eliminating the need for new, costly manufacturing tools. MEPV cells are also a lightweight, highly efficient energy source that can be folded for easy transport. This flexibility and size allow them to conform to a variety of shapes and make it ideal for aerospace, satellite, remote sensors, and embedded power applications. Over the course of development, Sandia has collaborated with multiple partners, including EMCORE Corp., the National Renewable Energy Laboratory (NREL), and the University of South Florida. These partnerships have advanced the technology by exploring manufacturing techniques and designs to make MEPV smaller in thickness than a human hair yet able to withstand harsh conditions such as those in space.

IMPACT

This R&D 100 award-winning technology was licensed by a Sandia scientist-turned-entrepreneur in 2017 through Sandia's Entrepreneurial Separation to Technology Transfer program, which permits Sandia employees to leave the labs to start up or expand technology companies. As such, the New Mexico company, mPower Technology, now markets the MEPV technology as DragonSCALES™ (Semiconductor Active Layer Embedded Solar) and is working with several customers on product iterations and embedded capability options. mPower has received inquiries from across industries, including aerospace, satellites, large surface area unmanned aerial vehicles, PV, remote sensing, and embedded power options for portable electronics. In late 2019, mPower was awarded a $1.1 million Small Business Innovation Research contract by the U.S. Army Combat Capabilities Development Command Soldier Center. The award has enabled mPower Technology to develop and test solar modules for soldier-portable and shelter-power applications.

Recently, Sandia provided technical assistance to mPower under the New Mexico Small Business Assistance and the Technology Readiness Gross Receipts program, and in 2021, mPower and Sandia won a national Excellence in Technology Transfer Award from the Federal Laboratory Consortium for transforming space power and other commercial markets. Accordingly, mPower was selected by Gravitics as the solar-cell supplier for its forthcoming "StarMax" habitats—one of the latest contracts that mPower has achieved with space-related companies. Its solar cells are currently aboard three satellites that were launched into low-Earth orbit by Lynk Global Inc., a company which is building a constellation of commercial cell towers in space. DragonSCALES are being evaluated as a potential solar power solution for the Lynk Global constellation fleet. London-based OneWeb, which already operates a constellation of about 600 satellites in space to provide high-speed Internet across the globe, also elected to test DragonSCALES' performance on new satellites. For astronauts on the moon, Honeybee Robotics and mPower are working to build a lunar charging station. These achievements seem to be just beginning as Kevin Hell, mPower Technology president and CEO said, "With the rapidly increasing interest in our technology for a wide range of new space power missions, we expect many more launches in the near future."

Formerly known as solar glitter, the flexible solar panels now commercialized as DragonSCALES were initially developed at Sandia. Image coutesy of mPower.

"The key limitation to silicon is that if you bend and flex it, it will crack and shatter… Our technology makes it extremely resilient while keeping all the benefits of high-efficiency, high-reliability silicon PV. It allows us to integrate PV in ways that weren't possible before, such as in flexible materials, and deploy it faster in lighter-weight, larger-area modules."

– Dr. Murat Okandan,
Founder and Chief Technology Officer , mPower Technology

Detecting Differences and Anomalies

PSA: a powerful tool in protecting microelectronic devices

PROBLEM

Today, most electronic devices include multiple microelectronic components. Defense systems and other high-reliability industries like medical and automotive rely on legacy components, which tend to be obsolete and difficult to source directly through traditional supply chains. This results in them inadvertently obtaining counterfeit, defective, or malicious parts. To discover if microelectronic components are authentic, a small number of representative samples are normally used for destructive analysis to provide authentication; this destructive method can be costly and cannot ensure a complete authentication of an entire batch of components. Therefore, there is a need for a cost-effective technique that provides timely analysis of all samples instead of solely representative samples.

INNOVATIVE EDGE

Sandia researchers developed a non-intrusive and non-destructive technique to help authenticate various microelectronic devices, ranging from discrete components to integrated circuits. The power spectrum analysis (PSA) technology is based on an unconventional biasing scheme to power microelectronic devices and to generate frequency-domain signatures of microelectronic devices, creating a distinct "fingerprint." This enables detection of subtle differences in devices. In many cases, these differences are not detected with conventional electrical testing.

PSA is very versatile and can be used to characterize a wide range of microelectronic devices, ranging from discrete components (e.g., diodes and transistors) to complex integrated-circuit chips with billions of transistors. PSA can be used for various applications. For example, it can differentiate parts that are manufactured by different manufacturers and foundries. The technique can also be applied to aging detection and process monitoring. PSA has applications in device screening for counterfeit identification, reliability assurance, and trust authentication.

COMMERCIALIZATION AND INDUSTRY IMPACT

Finding new methods of proving the authenticity of microelectronic components has been difficult because it requires industry to change the way it analyzes the parts; in addition, it requires investing in new, expensive equipment. Sandia signed a commercial license with Chiplytics, a new company that was founded in 2021, with the goal of providing a user-friendly, cost-effective inspection technology that uses PSA to commercial independent distributors and third-party inspection labs. Since its inception, the company has developed and shipped its first scalable PSA system to a customer in the defense and national security space for pilot testing. The team also engineered a PSA + machine vision system that was validated against the lab bench system at Sandia in April of 2022. The company plans to expand their product offering to capture the electrical testing market and help increase the throughput of legitimate independent distributors through data-driven processes. The company raised $300K through an incubation round from Scout Ventures and is raising a larger seed round to grow the team and build off the validation of their early pilots. With the commercialization of PSA technology, Chiplytics has the potential to save the electronics industry billions of dollars by verifying the authenticity and reliability of microelectronic components.

PSA generates distinct frequency-domain signatures (amplitude versus frequency) that can be used for counterfeit identification, reliability assurance, and trust authentication. Commercialization of this technology can provide a non-invasive tool for device screening in a timely and cost-effective manner.

Generating Resilient Power

Building upon Sandia's expertise in microgrids to shape the future of energy

PROBLEM

Unlike power plants, microgrids can help relieve stressed power grids during wildfires and other extreme weather events because they can supply primary power or backup power in case of emergencies. Microgrids are small-scale versions of interconnected electric grids that locally manage energy storage and resources—such as solar, wind, and thermal systems. Able to operate autonomously, they also can connect to a larger host grid, and connect or disconnect from a traditional grid. Essential services such as hospitals could greatly benefit from this resilient technology. Despite the numerous benefits, designing effective microgrids is challenging.

In 2018, Sandia signed a Cooperative Research and Development Agreement with Emera Technologies, Inc. to share tools and research focused on the future of energy, specifically in accelerating clean, community-scale direct current (DC) microgrids.

INNOVATIVE EDGE

Sandia has more than a decade of expertise in self-sustaining microgrid research and development for military applications, as well as in advanced microgrid controls, security and integration. Emera Technologies, an energy and services company headquartered in Canada, extends the Labs' microgrid research beyond the military, and builds upon Sandia's existing capabilities and toolkits.

The partnership leverages four of Sandia's facilities and toolsets:

- The Secure Scalable Microgrid Testbed (SSM) is a research facility that houses three interconnected DC microgrids.
- The Distributed Energy Technologies Laboratory (DETL) is a multipurpose research facility designed to integrate emerging energy technologies into new and existing electricity infrastructure.
- The Virtual Power Plant is a software package that anticipates the performance of energy sources and storage while determining the optimal level of operations and power balance.
- The Microgrid Design Toolkit, which is free through the Department of Energy (DOE), helps users understand and design systems that best match their needs. Previously used to optimize microgrid design on Army bases, the software evaluates the optimal layout of a microgrid, including topology, performance, reliability, and resilience.

Scientists are validating models as well as developing novel technologies aimed at solving complex electrical energy challenges at the SSM and DETL facilities. Such challenges could include the power system's ability to withstand natural disasters and unpredictable changes in renewable energy sources.

COMMERCIALIZATION AND INDUSTRY IMPACT

Emera conducted pilot testing of BlockEnergy at Kirtland Air Force Base in Albuquerque, New Mexico, and is now implementing the system in the nation's first neighborhood-level, solar- and battery-powered microgrid in Tampa, Florida. BlockEnergy is a self-contained system that automatically monitors and manages electric generation and distribution throughout the microgrid, ensuring a constant flow of energy where and when it's needed. The system provides neighborhoods with resiliency against any service interruptions on a utility's broader grid through an optimized design for a clean, cost-effective, independent, and resilient electricity supply.

Although alternating current (AC) microgrids are increasing in popularity and use, there is a growing amount of DC generation, storage, and electricity use in homes, requiring a conversion from AC to DC. Sandia and Emera are working to better position DC microgrids for meeting the nation's energy needs by bypassing this conversion. Sandia's tools and facilities, combined with Emera's experience in electricity, gas, and low-carbon energy utilities, will also provide clean, independent and resilient power generation and storage to rural communities, such as Native American households.

"There are demonstrated vulnerabilities with the grid in the United States and elsewhere. Large-scale outages that have recently impacted the electricity supply for entire islands are very good examples of the type of problems we need to prevent or mitigate for the safety and security of our country. With this CRADA we're trying to address what the future of energy is going to look like."

-Amy Halloran, *Sandia National Laboratories*

Sandia manager Abraham Ellis and technologist Roy Lopez discuss future work plans in Sandia's DETL, which is used for energy technologies research.

Simulating Energy Storage

QuESt helps industry, others achieve 100% carbon-free electricity

PROBLEM

Renewable energy sources, such as solar panels and wind turbines, produce electricity at an inconsistent rate, which presents challenges for the integration of renewables with existing energy infrastructure operations. Energy storage is at the center of these integration challenges, with storage system options ranging from lithium-ion battery-based designs to pumped-storage hydropower. Utilities and related industry partners need to evaluate potential storage options to determine the most impactful integration and storage opportunities. QuESt, developed by Sandia, is a free, open-source software for energy storage simulation and analysis that meets this need.

INNOVATIVE EDGE

QuESt investigates different use cases for energy storage systems, including grid and customer services. For example, QuESt considers the amount of energy used in a facility and evaluates energy storage system solutions, visualizing data in an interface that categorizes and charts comparisons for customers. The software was originally created as a graphical user interface for the optimization modeling capabilities of Sandia's energy storage analytics group. Originally released in 2018, QuESt consists of three interconnected applications: a data manager, a valuation tool (to maximize revenue from participating in energy arbitrage or providing ancillary services), and a cost savings tool (to estimate cost savings from behind-the-meter energy storage).

Development of the software was funded by the Energy Storage Program in DOE's Office of Electricity. Sandia has also been collaborating with other academic and industrial partners to expand the capabilities of QuESt. For example, integrated resource planning tool development has been conducted in conjunction with Quanta Technology. Sandia's QuESt team is also working to develop software capabilities to help the Public Service of New Mexico (PNM) and other utility companies assess paths for achieving 100% carbon-free electricity. Within the partnership with PNM, Sandia's QuESt team is investigating the costs and benefits of adding energy storage to the New Mexico grid; this analysis includes comparisons for transmission infrastructure expansion to better transport power from renewable energy power plants to cities.

IMPACT

Apart from industry, current QuESt users range from homeowners to utilities, such as PNM. Additionally, cities and states have benefited from the software. For example, New York State's Value of Distributed Energy Resources (VDER) program has utilized it for analyses of regional markets in an ongoing process to change compensation for distributed energy. QuESt simplifies transition and deployment of energy storage devices to reduce commercial costs, and continued application of the software in industry will aid in making energy storage system projects commercially viable.

Quest

Representative image of transmission infrastructure. QuESt is a free, open-source, Python-based application suite for energy storage simulation and analysis.

Detect, Track, Capture

MARCUS counters national security threats from small unmanned aircraft systems

The MARCUS team is working to further develop the technology with detection, threat identification, tracking assessment, and neutralization capabilities.

PROBLEM

Small unmanned aircraft systems (UAS), more commonly known as drones, are becoming increasingly popular for both entertainment and commercial purposes. Although users are expected to follow height restrictions to avoid potential interference with aircraft, their widespread use raises questions of how to detect, track, and police vehicles that pose a threat. Ground-based defense systems against these vehicles, such as radar, have limitations when attempting to identify a low-altitude UAS threat through obstacles such as buildings and trees. Organizations working within the government and defense industry have been exploring efficient ways to intercept UAS threats midflight, with some success in deploying nets from single drones. In 2017, Sandia robotics experts successfully demonstrated the intercept of a target vehicle, trapping it in the air and safely lowering it to the ground. Since then, Sandia has extended research and testing for a Mobile Adaptive/Reactive Counter UAS System (MARCUS), partnering with various organizations to more robustly address the future of UAS technologies.

INNOVATIVE EDGE

Sandia's 2017 demonstration, which used a swarm of four drones controlled by a ground-based computer system, was part of a two-year Laboratory Directed Research and Development project called Aerial Suppression of Airborne Platforms (ASAP). During this project, Sandia developed algorithms for airborne mobile defense systems in which a computer system would track each aircraft and send commands to the system as a whole, optimally positioning a team of drones to intercept their target. Airborne systems with sensors could dramatically enhance the ability to mitigate threats, even as the technology continues to evolve. Facing the challenge of developing a novel system with both ground- and aerial-based capabilities, the MARCUS project builds on the understanding that an airborne system, equipped with sensors, would have the ability to intercept small threats and keep them at a safe distance from the public and secure facilities. MARCUS encompasses three phases to address the UAS threat of the future: detect, track, and capture. In the detection phase, computers use information from airborne sensors and ground-based systems to identify possible threats. Additional systems can then be deployed to track the vehicle, gathering information to predict its future movements and to capture it midflight, if necessary.

IMPACT

Sandia is partnering with the North Atlantic Treaty Organization (NATO), the Department of Homeland Security (DHS), the Swiss Federal Department, and a group from the University of New Mexico (UNM) to continue research and testing for the MARCUS project. Collaborating through a Strategic Partnership Project (SPP), the team is working to further develop MARCUS with detection, threat identification, tracking assessment, and neutralization capabilities through the integration of small onboard sensors, software, modeling and simulation capabilities and ground platforms. The resulting technology could benefit multiple agencies, including the military, law enforcement entities, event organizers and agencies such as DHS. Improving the overall detection capabilities and effectiveness of counter unmanned aircraft systems (C-UAS) will enable successful responses to UAS threats while enhancing the security of restricted facilities.

Sandia leads the MARCUS project in collaboration with UNM and is supported by the science and technology procurement arm of the Swiss Federal Department of Defence, Civil Protection and Sport. Funding is provided by the NATO Science for Peace and Security Programme and incorporates advanced algorithms funded by the DHS Security Science and Technology Directorate. The project was expected to conclude in December 2022.

National Data Predicts COVID Waves and Spikes

Sandia researchers adapt an existing model to forecast new COVID-19 cases

PROBLEM

Accurate forecasts of new COVID-19 cases help decision makers anticipate the spread of the disease, estimate the impact of interventions, and allocate resources effectively. However, disease forecasting remains a challenge. During previous health crises such as plague epidemics, the lack of easily accessible, up-to-date information made it difficult to accurately predict the spread of disease. Without knowing which regions will experience either an influx or drop in COVID-19 cases, it is challenging for decision makers to properly allocate health care resources and response teams. To address this challenge, two Sandia researchers, Jaideep Ray and Cosmin Safta, repurposed a technology previously used to track plague and influenza-like illnesses to forecast COVID-19 outbreaks.

INNOVATIVE EDGE

More than a decade ago, Sandia researchers pioneered a model for tracking plague epidemics, then adapted it to track influenza-like illnesses in 2010. To augment the software to leverage global data networks and address the current COVID-19 pandemic, Ray and Safta sought the advice of colleagues with expertise in modeling, mathematics, and software engineering. The resulting model, named PRIME, draws from publicly available data distributed by the Centers for Disease Control and Prevention, the New York Times Data Repository, Johns Hopkins University, and various state departments of health. This widespread availability of data is a key difference between forecasting COVID-19 cases today and forecasting other outbreaks in the past, including the Ebola outbreak in 2015. It is now possible to get timely, accurate counts of COVID-19 cases and quickly communicate these numbers to the public. Within minutes, and without the need for high-performance computing resources, Sandia researchers leverage this data to forecast new regional or national cases in the short term. Although only useful for short-term forecasts (within a 10-day timeframe), this method is both easier to use and cheaper than other methods that require more robust computers and manpower. The data revealed by the forecasts can inform public health decisions and gauge the impact of interventions over time.

IMPACT

Since April 2020, the trends predicted by Ray and Safta have roughly followed the actual number of new COVID-19 cases and, with the help of another Sandia researcher named Patrick Blonigan, the framework was extended to handle multiple epidemic waves and help identify different disease dynamics at the regional, state, and country levels. Early in 2021, the team released the software as open-source, available from Sandia's GitHub repository (github.com/sandialabs/PRIME). The model has provided national results to the National Virtual Biotechnology Laboratory for publication on a DOE-run dashboard for federal decision makers. With the support of DOE's CTAP, the team also provided results to the New Mexico Department of Health to help guide regional responses throughout the state. As a result, DOE has awarded $5 million to create tools to increase the nation's level of preparedness for biological threats. The Sandia team will partner with Argonne National Laboratory to refine the models which might one day help the nation avoid the debilitating and deadly impacts of the next pandemic.

Representative image of forecasting COVID-19 cases.

"This method is a relatively easy and inexpensive way to get short-term forecasts about new coronavirus cases that decision-makers can use to allocate health care resources and response. This method is much easier and cheaper to do than methods that require more robust computers and manpower."

– **Cosmin Safta,** ***Sandia National Laboratories***

COVID-19 TECHNICAL ASSISTANCE PROGRAM (CTAP)

SUCCESSES

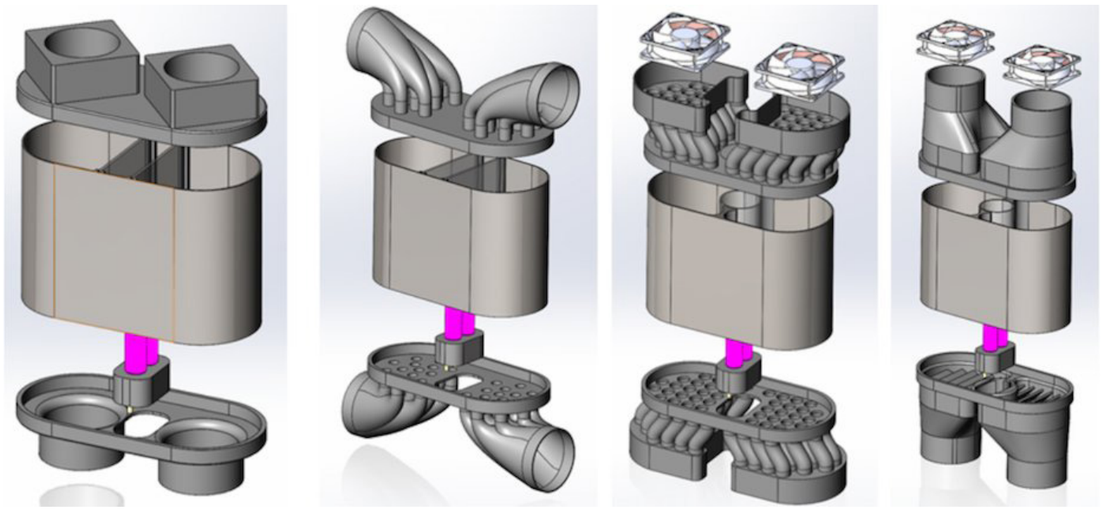
The following successes highlight just a few of the projects made possible by CTAP, which provided funding for DOE's national labs to partner with U.S. external entities on coronavirus-related projects.

Using UV Light to Sterilize PPE

Sandia evaluates a reusable mask prototype

When Sandia researchers developed a Pathogen Management Kit to equip ventilators of all types with the ability to disinfect exhaled air from COVID-19 patients, hospitals readily implemented them to help keep health care workers safe. Other organizations, such as Helpful Engineering, a nonprofit focused on solving social impact problems with open-source technology solutions, took notice of Sandia's capabilities in disinfection, most notably ultraviolet (UV) sterilization. At the time, Helpful was in the process of developing a prototype design for a reusable, filterless personal protective equipment (PPE) product that used UV light to sterilize the surrounding air and prevent viral particles from entering the eyes, nose, and mouth.

Helpful approached Sandia and discovered that the Labs' aerosol characterization facility, along with staff technical expertise and experience from recent projects, could help answer pressing questions regarding their product's design and performance. Sandia evaluated the UV chamber and headgear design within Helpful's reusable mask prototype, helping to bring it closer to a final product. The work provided insights to inform the final design, called UVisor, which is available as an open-source solution.



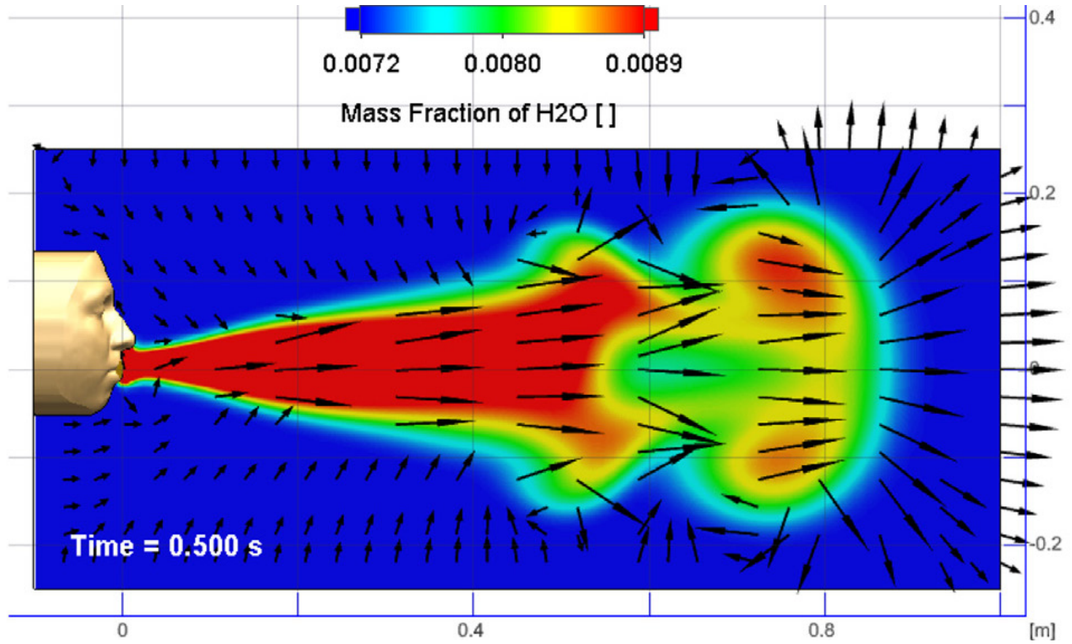
Sandia experts assessed prototypes of Helpful Engineering's headgear prototype (right) and UV chamber designs (above). Images courtesy of Helpful Engineering.

Real-time Results: Molecular Detector

Sandia assesses a molecular detector for potential SARS-CoV-2 applications

The COVID-19 pandemic required rapid development of new technologies. Sandia shared its unique expertise with companies such as RingIR to enable accelerated deployment of technologies to fight COVID-19. Sandia completed testing and evaluation of RingIR's molecular detector for potential SARS-CoV-2 applications. RingIR is a startup company that specializes in portable devices that identify gases on location and in real-time, measuring the infrared spectrum of various molecules to get a "fingerprint" of gases in the environment. The company is headquartered in Albuquerque, New Mexico with locations in Melbourne and Sydney, Australia.

The company approached Sandia with an interest in testing and evaluating their molecular detector's ability to identify SARS-CoV-2 in near real-time. Researchers at Sandia's Aerosol Complex have extensive experience generating aerosols of interest and conducting biological aerosol testing using MS2 bacteriophage as a surrogate for SARS-CoV-2. With funding from CTAP, Sandia's team used microbiology and analytical aerosol techniques to evaluate the penetration of an aerosol through the RingIR system. They also reviewed the effectiveness of external exhaust filter designs to expel and mitigate the aerosol. The team delivered valuable technical insights for RingIR to consider in the development of their product for urgent new applications.



Sandia researchers have extensive experience generating aerosols of interest and conducting biological aerosol testing.

"Our biological aerosol testbed, cross-disciplinary research team, and capabilities in aerosol generation and microbiology were uniquely valuable for understanding the RingIR detector's performance in a new application area."

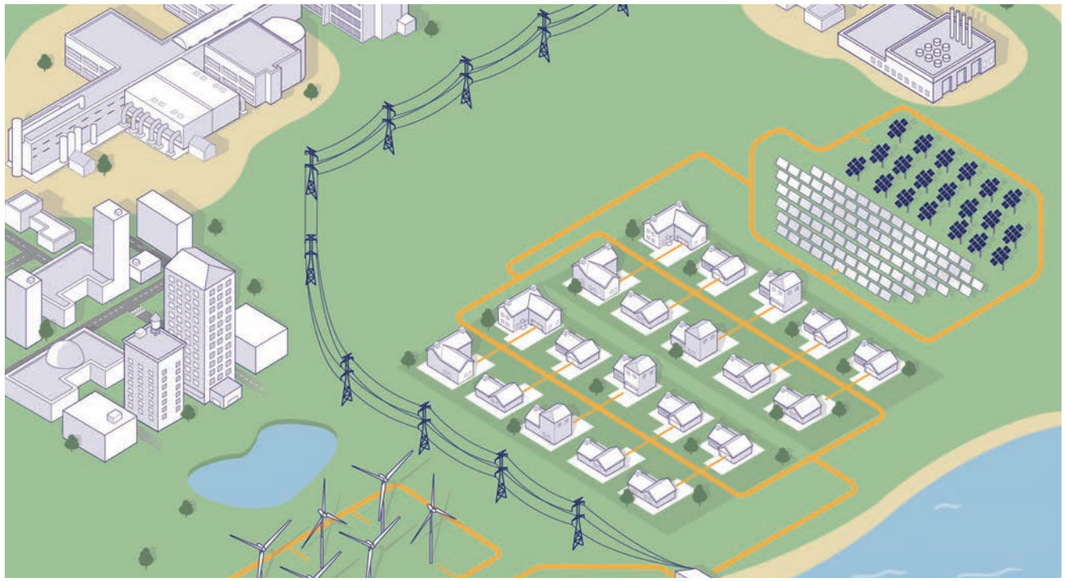
- **Andrew Glen,** ***Sandia National Laboratories***

Resilient El Rito

Sandia assesses the technical merits of a proposed community resilience microgrid project

In the second round of CTAP funding, DOE expanded the program's area of focus to spur recovery from the pandemic. This opened the door for entities to receive technical assistance from the national labs in broad areas of interest, including strengthening the nation's infrastructure and supply chains. Sandia provided assistance to Kit Carson Electric Cooperative (KCEC) in assessing the technical merits of a proposed community resilience microgrid project in the Village of El Rito, New Mexico, around the campus of Northern New Mexico College (NNMC). KCEC is the second largest electric distribution cooperative in New Mexico, serving Taos, Colfax and Rio Arriba counties and providing electricity to over 29,000 members. NNMC is an accredited two- and four-year degree granting institution of higher learning and primarily serves rural communities near its main campus in Espanola, New Mexico and its branch location in El Rito that is roughly 30 miles north of its main campus.

Through CTAP, KCEC and Sandia performed an analysis on a conceptual microgrid plan, considering a campus- and community-wide approach. The results provided suggestions for potential microgrid configurations, optimized according to the performance metrics defined. Sandia's experts provided several conceptual microgrid solutions that met the campus microgrid goals. For example, acknowledging that the existing 1.5 MW photovoltaic system on campus far exceeds the simulated campus load peak and energy demand, a small battery installation was suggested as a sufficient storage option to meet performance requirements. The core Resilient El Rito team has applied to the New Mexico Energy, Minerals and Natural Resources Department for a Grid Modernization Pilot Project grant to cover engineering requirements and is expected to commence work in 2023.



▲ *Sandia's Microgrid Design Toolkit (MDT) supports decision analysis for new "greenfield" microgrid designs as well as microgrids with existing infrastructure.*

Agriculture-Water-Energy in the Village of Questa

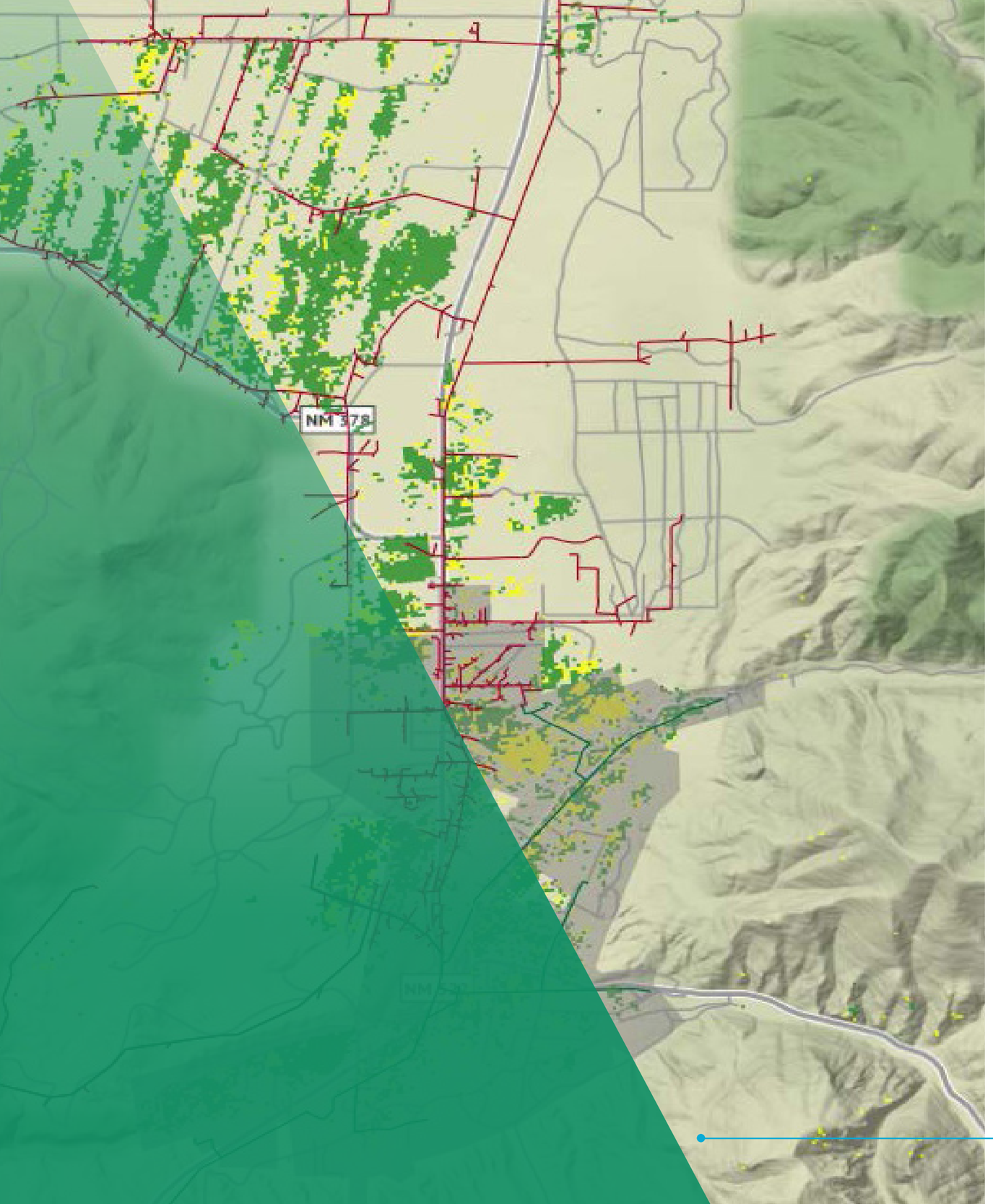
Sandia identifies pathways for increased solar power generation and economic development

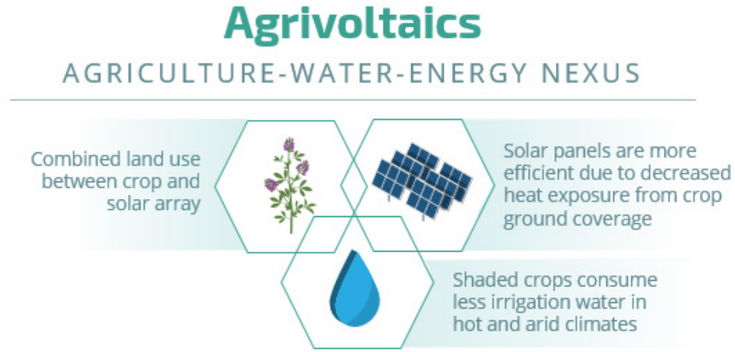
Sandia provided technical assistance in evaluating opportunities for renewable energy optimization in the region of Questa, New Mexico, a small, rural town that wanted to attract more businesses and residents to promote economic development. The goal of this study was to conduct an analysis of the present status of energy infrastructure in Questa and identify potential broad-ranging opportunities for renewable energy infrastructure or production capabilities.

Preliminary research efforts by Sandia technical staff broadly identified early opportunities for further research, development, and demonstration in the emerging renewable energy segment of agrivoltaics. Agrivoltaics is an emerging concept in which the land for photovoltaic (PV) installations is used for both agriculture and solar PV power generation. In recent years, agrivoltaic systems have been the subject of numerous studies due to their potential in the food-energy (and water) nexus. This concept would give landowners in Questa the opportunity to grow crops while also gaining income from power production.

Crop profiles showed that the majority of the land used for agriculture produced alfalfa and non-alfalfa hay. Furthermore, the Village of Questa is served by two electric power distribution systems. With this data, the team conducted an economic study to determine alfalfa crop yield and upfront investment costs as well as the recurring revenue potential from a PV system. The preliminary analysis found that power generated on farmland could serve the immediate area, loads to the south of the village on the same distribution system, and distant locations through transmission lines. A distributed energy network of PV systems with battery storage would provide more energy resilience for the area and, at the same time, the elevated PV structures would provide partial shade for crops and help save water resources for growing other fresh produce for the village and surrounding area.

As a direct result of CTAP engagement, a feasibility study is underway in Questa funded through a DOE Communities Local Energy Action Program (LEAP) grant. This work—executed in partnership with NREL, Sandia, LANL, Chevron, and the KCEC—will help the village determine whether it is a suitable location to build a green hydrogen production facility.





Map shows where alfalfa (green) and hay (yellow) are grown in the Questa area during 2020. The gray shaded area defines the boundaries of the village while the red and green lines depict the two-distribution electric power system lines.

LONG-TERM SUCCESSES

LONG-TERM
SUCCESSES

Several Sandia-developed technologies are making considerable headway in their respective industries or have established notable success and growth in recent years. Many of these technologies were created long ago to meet other needs at the Labs and continue to have an impact today. The following successes highlight a few examples of the lasting impact Sandia's technologies have in the world beyond the Labs' door.

TECH TRANSFER SUCCESS STORIES

Sandia Cooler

Air-cooled heat exchangers are used to reject excess heat from a concentrated source to the surrounding atmosphere for a variety of mechanical and electrical systems. Advancements in heat exchanger design have been very limited in recent years for most product applications.

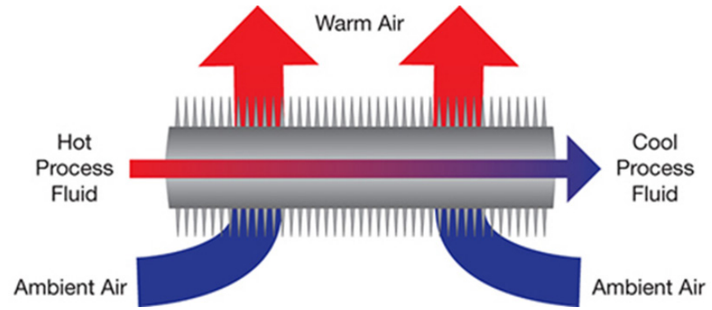
In support of heat exchanger advancement, Sandia developed the Sandia Cooler.

BACKGROUND

Heat exchangers may be used in HVAC systems, power plants, and mechanical devices and systems that require heat transfer.

Examples include various electromechanical systems, and electronics applications such as conventional computing systems. In a typical computing system that includes a central processing unit (CPU), one or more memory devices, and other circuitry, cooling of the CPU in particular is an important design consideration.[1] Air-cooled heat exchangers are used in a wide variety of applications, particularly where water is unavailable. They provide a simpler solution than water-cooled systems consisting of pumps, piping, and a central chiller or cooling towers—all of which increase the operating cost and maintenance of the system.[2]

The operating principle of an air-cooled heat exchanger is straightforward. Waste heat is transmitted to finned surfaces (typically aluminum or copper), and as ambient air passes over the fins, the waste heat is rejected to the atmosphere. While this is a fundamentally simple concept, maintaining optimum air-cooled heat exchanger performance takes diligence as the exchanger surface will deteriorate over time due to accumulation of particulate matter and other airborne contaminates.[3]



Air-cooled heat exchanger basics

The sizes of these units vary widely, from the very small (e.g., a car or truck radiator) to the very large (e.g., an A-frame vacuum steam condenser). Due to variety of sizes, researchers can take several approaches to the optimization of existing air-cooled heat exchangers, one of which led to the development of the Sandia Cooler.

RETURN ON INVESTMENT

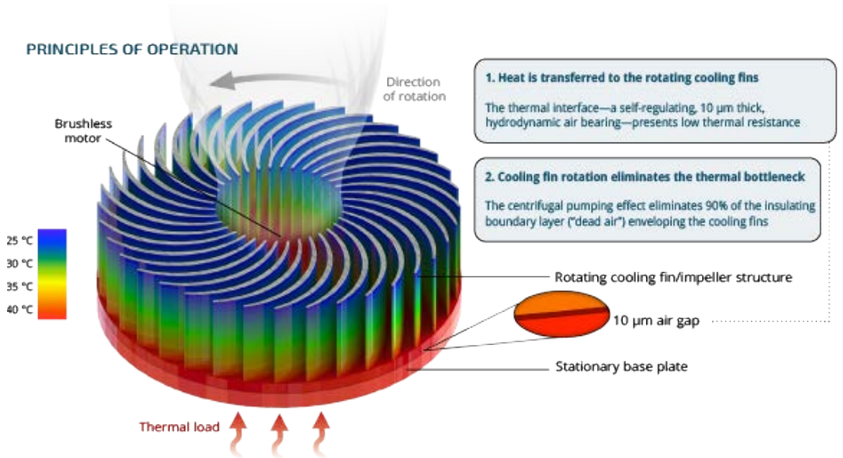
Sandia has successfully established several Strategic Partnership Project (SPP) agreements which utilize the Sandia Cooler. SPP agreements facilitate the availability of Sandia's unique resources to private industry and individuals, state and local governments, colleges and universities, non-profit organizations, international organizations, foreign governments, and foreign companies to validate or improve technologies.

Over the past 20 years, a number of Laboratory Directed Research and Development (LDRD) projects were conducted utilizing the Sandia Cooler. The LDRD program invests in high-risk, potentially high-payoff activities that enable national security missions and advance the frontiers of science and engineering. The LDRD program provides the flexibility to anticipate and respond quickly to future mission needs and to explore potentially revolutionary advances in science and technology.

TECHNOLOGY DEVELOPMENT

In 2008, researchers at Sandia developed the Sandia Cooler, a new technology for air-cooled heat exchangers, addressing major obstacles that exist in traditional CPU coolers.

In traditional CPU coolers, there is a heat transfer bottleneck, a layer of motionless air that adheres to and envelops all surfaces of the heat exchanger fins. This bottleneck largely determines the thermal resistance of the heat exchanger and is the primary physical limitation to the heat exchanger's performance. Another obstacle is posed by the inevitable deterioration of the heat exchanger surface over time by particulate matter and other airborne contaminates. This deterioration is especially important in applications where little or no preventative maintenance is typically practiced. The third major obstacle concerns inadequate airflow to the heat exchanger resulting from restrictions on fan noise. Small and medium-sized fans have relatively poor mechanical efficiency as unproductive expenditure of mechanical work on the surrounding air results in high noise levels.[5]



Sandia Cooler principles of operation

The Sandia Cooler is able to overcome the bottleneck of dead air, therefore offering a device which is smaller, quieter, and immune to clogging by dust. The new design allows heat to be efficiently transferred from a stationary base plate to a rotating structure that combines the functionality of cooling fins with a centrifugal impeller. The dead air that would traditionally lead to a bottleneck is subjected to a powerful centrifugal pumping effect, reducing the boundary layer thickness.[6] Additionally, high-speed rotation completely eliminates the problem of heat exchanger deterioration due to particulate fouling. Generating relative motion between the cooling fins and ambient air by moving the fins through the air also provides a drastic improvement in aerodynamic efficiency over traditional "fan-on-finned-heatsink" architectures, translating to an extremely quiet operation.[7]

PUBLIC IMPACT

The Sandia Cooler offers possible applications across a variety of industries and technologies including laptops, high-performance gaming personal computers (PCs), home video game boxes, light-emitting diode (LED) lighting, large appliances, and more generally, any device compromising one or more forced-air exchangers.

Since the creation of the Sandia Cooler, the Sandia team has worked with Wakefield-Vette Inc. to convert this technology to a market-ready, cost-competitive, electronics thermal management product, which was fulfilled in 2019 at Technology Readiness Level (TRL)-8. The team also worked to target an energy sector application with high-visibility that could effectively serve as an advertisement for the Sandia Cooler technology.

At the beginning of the partnership, the team determined that high-powered LED luminaires for use in factories, warehouses, big-box stores, high bays, etc. would be the best application space, as 50% of the electrical power provided to LEDs is immediately converted to heat. LED luminaries were also chosen because the technology will be more visible as opposed to being hidden in a PC or similar technology. Because the light emitting element of LEDs must be kept at a temperature of 80°C or below, these thermal management challenges decrease wall-plug efficiency and drastically lower the LED service lifetime. Wall-plug efficiency is important because high-bay luminaires have very high-power consumption, while long operating lifetime is important from the standpoint of bulb replacement costs including labor; an operating lifetime of 100,000 hours results in significant cost savings because servicing luminaires 30 to 60 feet off the ground is both expensive and inconvenient.[8]

To address these challenges, the team used what they refer to as "Type-II Sandia Cooler technology". The distinction between Type-I and Type-II Sandia Cooler technology is important to understand for this application. In a Type-I Sandia Cooler, the thermal load is attached to a heat spreading plate that resides in the stationary frame.

In a Type-II Sandia Cooler, the heat load is mounted directly to the rotating heat-sink-impeller. This has two advantages compared to a Type-I Sandia Cooler—it eliminates the thermal resistance of the air-gap region (hydrodynamic air bearing) and its tight mechanical/manufacturing tolerances.[9]

During the implementation of this technology, the objective of transmitting 1000 watts of electrical power from the stationary to the rotating frame with very high efficiency (99%) and at low cost was achieved. With the success of this project, the team is looking to deploy the LED luminaire at TRL-9. In order to reach this level, the team has proposed changes for implementation in the first mass-produced version of the high-bay luminaire. Proposed changes include consolidating power electronics, optimizing the rotary transformer, and eliminating mechanical fasteners and heatsink paste.[10]

A photo-realistic CAD rendering of the Sandia Cooler LED Luminaire product demo unit.

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Smart Microgrids

The nation's electrical power depends on one bulk power grid to support security and economic prosperity. According to the Department of Homeland Security's Homeland Threat Assessment of 2020, the largest cyber threat to homeland security is potential disruption to critical infrastructure, including power grids.[1] Critical infrastructure includes the physical and cyber systems which generate, transmit, and distribute electricity with an impact on economic security, public health, or safety. The surety of the nation's power grid is vital for providing essential services and would put the population at risk if disrupted. Power outages can have catastrophic consequences for critical organizations such as hospitals and military installations. Additionally, the current fossil-fuel dependent power grid is extremely fragile and vulnerable to overloads, storms that destroy power lines, and cyberattacks.[2]

In support of grid security, Sandia developed SPIDERS and the Microgrid Design Toolkit.

BACKGROUND

The solution to power grid and infrastructure vulnerabilities is to create fully independent and secure microgrids that operate separately from the bulk power grid. An independent microgrid would be more resilient to power disruption, protected against cyber-attacks, and utilize a more sustainable form of energy.

TECHNOLOGY DEVELOPMENT

To address these security challenges, the DOE and the Department of Defense (DoD) entered into a memorandum of understanding (MOU) in 2011 to accelerate joint innovations in clean energy and national energy security. As part of this MOU, Sandia was selected to lead the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) project. SPIDERS worked to address the risks faced by the grid by building smarter, more secure, and robust microgrids that incorporate renewable energy sources such as solar and wind. This effort combined commercially available technologies with Sandia's novel system integration techniques.[2]

The ultimate goal of the SPIDERS microgrid technology was to provide secure control of on-base generation occurring at military installations. Traditionally, when power was disrupted at a military base, individual buildings would switch to backup diesel generators, but that approach had several limitations. Generators might fail to start, and if a building's backup power system doesn't start, there is no way to use power from another building's generator. Additionally, on-base safety requirements state that all renewable energy sources on base must disconnect when off-site power is lost. The SPIDERS smart, cybersecure microgrid addressed these issues by allowing renewable energy sources to stay connected and run in coordination with diesel generators, which can all be brought online as needed. These advantages promote increased power reliability at military installations, while reducing their need for diesel fuel, thus reducing their carbon footprint.[2] SPIDERS microgrids are currently installed on Joint Base Pearl Harbor-Hickam and Camp Smith in Hawaii and Fort Carson in Colorado.

In 2014, Sandia received subsequent funding from DOE's Office of Energy to combine SPIDERS' capabilities with those of other national laboratories into a holistic Microgrid Design Toolkit (MDT). MDT is a visual design and trade-space optimization capability for microgrids. This method allows users to effectively search through very large design spaces for efficient alternatives; investigate the simultaneous impacts of several design decisions; have defensible, quantitative evidence to support decisions; and more.

The MDT offers a range of capabilities not available elsewhere including: performing mid-level topology optimization; accounting for both grid-connected and islanded performance, power and component reliability in islanded mode, and dozens of metrics when performing the trade space search; and presenting a user with a range of information from which to draw conclusions.

The first version of this toolkit was released in 2016. That same year, the United States Marine Corps (USMC) Systems Command provided additional funding to Sandia to assess microgrid power systems and Mobile Electric Hybrid Power Sources (MEHPS) for expeditionary units and brigades. Since 2016, this capability has been utilized by the Grid Modernization Lab Consortium and it was awarded a R&D 100 Award in 2017.

RETURN ON INVESTMENT

The SPIDERS and MDT efforts are both funded by DOE. MDT can be downloaded for free from the DOE website.[10]

PUBLIC IMPACT

The return on investment for technologies such as SPIDERS and MDT cannot be accurately communicated without highlighting the impact the toolkit has had on communities around the U.S. Initially, the SPIDERS template was intended for a broader cross-section of the U.S. economy and to help both the public and private sectors become more resilient to interruptions of the critical supply of electricity. However, with the emergence of MDT, the

capability has grown to impact communities across the U.S.[3] The City of Hoboken, New Jersey used an MDT predecessor to develop a preliminary microgrid design for backup power in response to Hurricane Sandy. In Alaska, the extremely cold winters make access to resilient energy sources a critical safety and health issue. Traditionally diesel fuel is used to generate electricity for remote villages, but the introduction of MDT has reduced fuel requirements and the use of local energy resources to improve community resilience. Additionally, in Louisville, Kentucky, the toolkit was used in a backup power system assessment and Microgrid Design of the UPS Worldport facility. Finally, a backup power system assessment and microgrid design was also conducted for the city of New Orleans, Louisiana.

After hurricanes Irma and Maria devastated Puerto Rico in 2017, the storms caused nearly complete devastation, including the catastrophic failure of the Island's power grid, water and wastewater infrastructure, and communications networks.

USMC

- The U.S. Marine Corps' Expeditionary Energy Office (E20) used the MDT to assess microgrid power systems and Mobile Electric Hybrid Power Sources (MEHPS) for expeditionary units and brigades.
- Over 50 microgrid models were developed in the MDT and used to provide design support for these islanded power systems.

SPIDERS

- Used a predecessor to the MDT to develop the preliminary microgrid designs for 3 military bases: Joint Base Pearl Harbor-Hickam, Fort Carson, and Camp Smith.

New Jersey

- The city of Hoboken used a predecessor to the MDT to develop the preliminary microgrid design for backup power in response to Hurricane Sandy.
- The primary goals of this design effort were to mitigate the impacts of extreme flooding on the distribution systems and electricity service throughout the city.

Other Uses

- Remote community power system assessments for villages in Alaska (Shungnak, Cordova).
- A backup power system assessment and microgrid design of the UPS Worldport facility in Louisville, KY and of the city of New Orleans, LA.

Sandia and Oak Ridge National Laboratory have partnered with the Puerto Rico Industrial Development Company (PRIDCO) to investigate the potential of industrial-scale microgrids in strategic locations on the island to bolster the resiliency of these and (potentially) surrounding locations. MDT is being considered as an option for this effort.

Looking forward, as the global security environment continues to evolve, the cyber threat to critical infrastructure, including power grids, will continue to grow and evolve. The important role that resilient grid technologies such as SPIDERS and MDT will continue to play in this area cannot be overstated.

> "The cyber threat to critical infrastructure, including power grids, will continue to grow and evolve."

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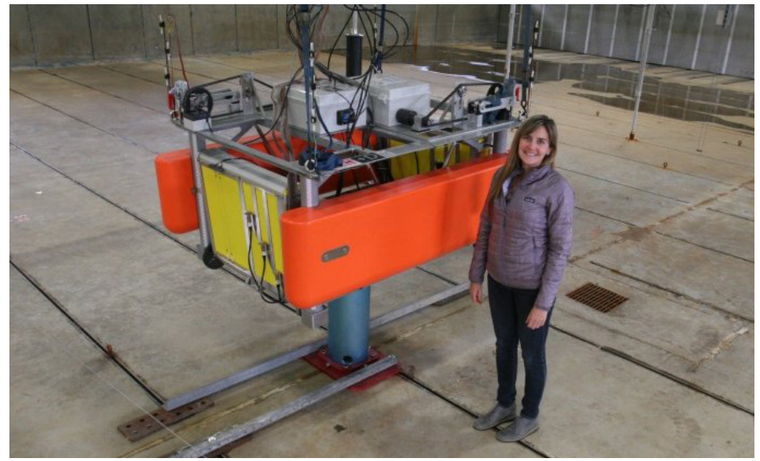
Wave Energy

As the earth's climate continues to warm, severe weather and natural disasters such as hurricanes, wildfires, flooding, and other events are becoming the norm—devastating communities and neighborhoods. Several countries, including the United States, are exploring new ways to curb greenhouse gases, which contribute to an increasing average temperature. To meet the call of reaching net-zero carbon emissions by 2050 in the U.S., scientists and researchers are pursuing innovations to advance clean energy, such as ocean wave energy technologies, which harness the energy of ocean waves to generate electricity.

Sandia supports clean energy and emissions goals through its Wave Energy Converter SIMulator (WEC-Sim), an open-source software.

BACKGROUND

Ocean waves have the potential to produce large amounts of renewable energy. To capture this energy and convert it to carbon-free electricity, researchers can use wave energy converters (WEC). A WEC harnesses the waves' motion, which then generates electricity. WECs can be used on a large scale—as in generating utility-scale power, power for desalination, remote communities, ocean instrumentation, and more.



Kelley Ruehl, an Energy Water Systems Integration mechanical engineer at Sandia, next to a WEC. Photo credit: Bret Bosma, Oregon State University

Wave energy is a vast energetic resource, but designing a WEC that operates efficiently and cost-effectively in this harsh environment continues to be a challenge. Unlike other renewable energy options such as solar and wind, wave energy is in the early stages of development. Advancing wave energy is related to the Powering the Blue Economy initiative, which is described by the World Bank as "the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystems."[1] WECs must be tested in realistic conditions at sea, which is more difficult to do than land-based testing. Numerous factors make the testing challenging, from the high cost of offshore testing to permitting challenges[2] to the corrosive nature of saltwater to biofouling.

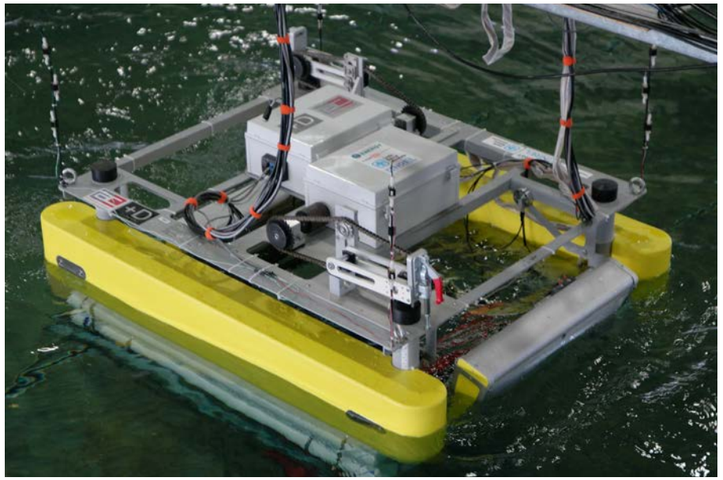
Energy generated from waves is difficult to capture because of the complexity of harnessing wave power. While some WECs generate electricity and transmit it through undersea cables to shore, others pass the mechanical energy of the wave onto land before it's turned into electrical energy. Researchers are continually looking for ways to generate energy from waves that are cost-effective so that the technology can eventually be leveraged to help the U.S. reach its goal of 100% clean energy.

Researchers at Sandia, in collaboration with partners at the National Renewable Energy Laboratory (NREL), developed the Wave Energy Converter SIMulator (WEC-Sim)—an open-source software for modeling the performance of WECs in operational and extreme environments. The open-source software is used by universities, industry, and others to better understand how WECs might fare in the open sea as they work to convert the motion of waves into usable energy. The WEC-Sim software is used prior to physical testing to model WEC dynamics and performance. Physical testing data can be used for validating WEC-Sim models. This allows wave energy developers to assess how their device will respond to different wave conditions, and whether it will operate as anticipated. It's also used after testing to determine how WECs will perform at different sites. The experimental testing is often to validate the numerical model so that it can be used to estimate power in conditions that can't be easily tested, such as at deployment sites.[3]

TECHNOLOGY DEVELOPMENT

The WEC-Sim software is funded by DOE's Water Power Technologies Office (WPTO). Around 2008, WPTO selected Sandia to lead a team in the Reference Model Project, which focused on developing open-access marine hydrokinetic technology point designs as reference models to include criteria such as cost, performance, design, and analysis. This award led to the beginnings of Sandia's Water Power Technologies group, which built on the Labs' previous work with water- and land-based wind technologies.[3]

About the same time, Kelley Ruehl, then a student, gave a presentation on wave energy conversion at a conference Sandia researchers were attending. Following the presentation, Ruehl was offered a position at Sandia as an intern. By 2011, Ruehl became a staff member, and in 2013, the WEC-Sim project was underway. Ruehl, now a mechanical engineer at Sandia, continues to lead WEC-Sim development. The software was initially copyrighted and released as open-source in 2014, with the latest version, 5.0, being released in 2022.



WEC-Sim Phase 1 testing at the Oregon State University Hinsdale Directional Wave Basin. Photo credit: NREL

The WEC-Sim software is developed in MATLAB/SIMULINK (programming platforms) using the multi-body dynamics solver Simscape Multibody, a simulation environment commonly used for 3D mechanical systems. WEC-Sim can model devices with rigid and flexible bodies, joints, power take-off systems, and mooring systems. Simulations are performed in the time-domain by solving the governing equations of motion in 6-degrees-of-freedom. The computer simulation models the forces on floating objects and calculates their dynamic behavior. Numerical simulations using WEC-Sim can reduce development time and lower costs, allowing developers to refine and optimize their floating concepts before deploying the device in the water for physical trials.

WEC-Sim is publicly available on GitHub, and Sandia's WEC-Sim team works with developers from around the world on different concepts in wave energy conversion. Through the software, developers can use WEC-Sim to anticipate how their WECs will operate in different conditions in the ocean. Many users work with the software extensively and have contributed to enhancements.

The WPTO's Testing Expertise and Access for Marine Energy Research program (TEAMER) connects WEC developers with facilities and WEC-Sim expertise at both Sandia and NREL.[4] TEAMER also supports marine renewable energy testing and development projects by funding developers wanting to collaborate with top expertise and facilities.[5]

Through the program, companies can approach TEAMER and apply for funding for numerical support using the WEC-Sim software. After an application is awarded, the WEC-Sim team provides support through formalized partnerships on development of device simulations, online trainings, and model validation. Numerous businesses and universities have used TEAMER to connect with WEC-Sim. For example, Ocean Motion Technologies used WEC-Sim to model and improve its engineering efforts.

RETURN ON INVESTMENT

As open-source software, WEC-Sim's return on investment is evident in the success it's had with TEAMER; its broad user base across academia, industry, and the national labs; and its potential to improve green/clean energy. In addition to its international recognition, WEC-Sim also is award-winning technology, having **won an R&D 100 award in 2021** within the Software/Services category for cutting-edge innovation in lowering costs and reducing research and development cycle time in the growing field of ocean energy.[6]

CRADAS

The TEAMER program has led to Cooperative Research and Development Agreements (CRADAs) between WEC developers and Sandia. Through October 2022, there have been 14 separate WEC-Sim projects associated with the TEAMER program.

Many continue to be active today, and it is anticipated that, while the TEAMER program remains active, similar partnerships will continue to develop. The CRADAs generally last six-to-nine months during which the WEC-Sim team trains the developer's team on using the software. Sandia and NREL own the open-source software copyright, and the WEC-Sim team manages it as well as conducts online trainings, forums, and webinars for new partners. Some companies have opted to modify the software to meet their needs.

Other partners include Pacific Northwest National Laboratory, Oak Ridge National Laboratory (ORNL), and numerous universities. Sandia also maintains active partnerships with wave energy converter companies.

OPEN-SOURCE

Three different metrics are used for tracking use of the software: GitHub productivity, publications, and website analytics. As of October 2022, WEC-Sim has a large international user-base and the number of users continues to increase annually. An indicator of its increasing use is the issue board on GitHub, which has received hundreds of inquiries. To date, the team has resolved more than **600 user questions regarding the software.**

The issue board provides valuable feedback to Sandia and NREL developers through addressing real-time user issues and challenges (i.e., input into needed software revisions and new functions). Jorge Leon Quiroga, a postdoctoral appointee in the Water Power Technologies department at Sandia, says that the team is continuously improving the software. The more user-friendly the software is, the more people will use it, which is one step to making positive impacts in renewable energy.

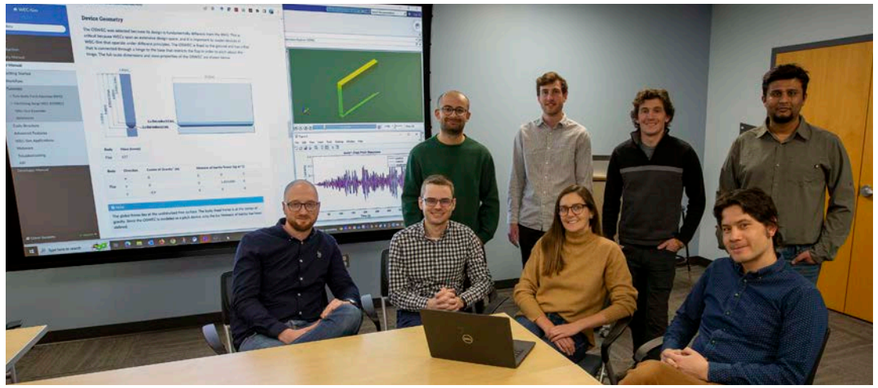
Quiroga further explains that WEC-Sim is the main research tool numerous businesses and researchers are using in the early phases of WEC development. For example, the tool has been mentioned in scientific publications about WECs that rely on WEC-Sim for finding resolutions to problems. WEC-Sim has been referenced in publications 125 times since 2013, and more than half of those mentions took place from 2019 to 2021.[9] In addition, the WEC-Sim website has seen a **111% increase in worldwide traffic since FY18.**

WEC-Sim has a large domestic and international user base, including companies Ocean Motion Technologies[10] and CalWave.[11]

PUBLIC GOOD

Wave energy devices could one day power millions of U.S. homes, businesses, remote communities, and even military bases. Harnessing the motion produced by ocean waves to generate clean energy could eventually be applied for use in utility-scale power generation, powering energy-intensive desalination plants, and mechanical and electrical power applications. Using wave energy could also be part of the solution in easing severe weather caused by climate change by reducing greenhouse gases.

However, before new water-power technologies can successfully compete in the commercial clean-energy arena, developers must create dependable technology in wave energy conversion, which will in turn decrease the cost of powering communities. WEC-Sim is instrumental in advancing wave energy conversion technology so that it can potentially have a broad impact in the realm of affordable renewable energy alternatives. Sandia is committed to pursuing clean energy innovations in ocean wave energy technologies to advance the mission of reaching net-zero carbon emissions.



The WEC-Sim team. Left to right standing: Jorge Leon (Sandia), Jeffrey Grasberger (Sandia), Dominic Forbush (Sandia), Salman Husain (NREL); Left to right sitting: David Ogden (Velocity Global), Adam Keester (Sandia), Kelley Ruehl (Sandia), Nathan Tom (NREL). Photo by Taylor Mankle (NREL).

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> Harnessing the unrelenting power of the ocean is a clean, innovative, and sustainable way to curtail carbon pollution — benefitting American businesses and families, especially coastal communities hit hardest by the impacts of climate change. Diversifying and expanding our clean energy sources will usher in a new era of energy independence that makes the grid more resilient, curbs the climate crisis, and saves Americans money on their energy bills.[12]
>
> **- Jennifer M. Granholm, *U.S. Secretary of Energy***
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> ”

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