LOS ALAMOS NATIONAL LABORATORY ◇ SUMMER 2022

NATIONAL ★ SECURITY SCIENCE

THE CLIMATE ISSUE

- **Collaborative climate modeling:** New tools help predict the impacts of climate change.
- **Mapping the sting of climate change:** Shifting environments increase the spread of dangerous viruses.
- **The energy beneath us:** The Hot Dry Rock Program proved the Earth's heat can be used for power.

+PLUS:

New software to transform the bioplastics industry	Forecasting the future of water	Do look up! Hollywood and Los Alamos tackle climate change

"No nation can find lasting security without addressing the climate crisis."

—U.S. Secretary of Defense Lloyd Austin III, April 2021

"The scientific community has made clear that the scale and speed of necessary action is greater than previously believed. There is little time left to avoid setting the world on a dangerous, potentially catastrophic, climate trajectory."

—Executive Order on Tackling the Climate Crisis at Home and Abroad, January 2021

"Increasing temperatures; changing precipitation patterns; and more frequent, intense, and unpredictable extreme weather conditions caused by climate change are exacerbating existing risks and creating new security challenges for U.S. interests."

—Department of Defense Climate Risk Analysis, October 2021

"Climate change is a geopolitical issue every bit as much as an environmental one."

—Boris Johnson, prime minister of the United Kingdom, February 2022

"Not adapting to climate change will be even more consequential with failure measured in terms of lost military capability, weakened alliances, enfeebled international stature, degraded infrastructure, and missed opportunities for technical innovation and economic growth."

—U.S. Department of Defense Climate Adaptation Plan, September 2021

"For today's soldiers operating in extreme temperature environments, fighting wildfires, and supporting hurricane recovery, climate change isn't a distant future, it is a reality."

—Secretary of the Army Christine Wormuth, February 2022

"Adversaries and other malign actors may seize dwindling resources while seeking new opportunities to threaten U.S. national interests."

—United States Army Climate Strategy, February 2022

"The combination of environmental degradation, rising temperatures, changing precipitation patterns, and other climate effects is likely to lead to an array of human challenges such as food and water insecurity and threats to human health."

—Annual Threat Assessment of the U.S. Intelligence Community, February 2022

"Climate change will increasingly exacerbate risks to U.S. national security interests as the physical impacts increase and geopolitical tensions mount about how to respond to the challenge."

—National Security Council's "Climate Change and International Responses Increasing Challenges to U.S. National Security Through 2040," October 2021

"Every fraction of a degree matters. Every voice can make a difference. And every second counts."

—António Guterres, United Nations Secretary General, February 2022

"Scientific forecasts indicate that intensifying physical effects of climate change out to 2040 and beyond will be most acutely felt in developing countries, which we assess are also the least able to adapt to such changes. These physical effects will increase the potential for instability and possibly internal conflict in these countries, in some cases creating additional demands on U.S. diplomatic, economic, humanitarian, and military resources."

—National Security Council's "Climate Change and International Responses Increasing Challenges to U.S. National Security Through 2040," October 2021

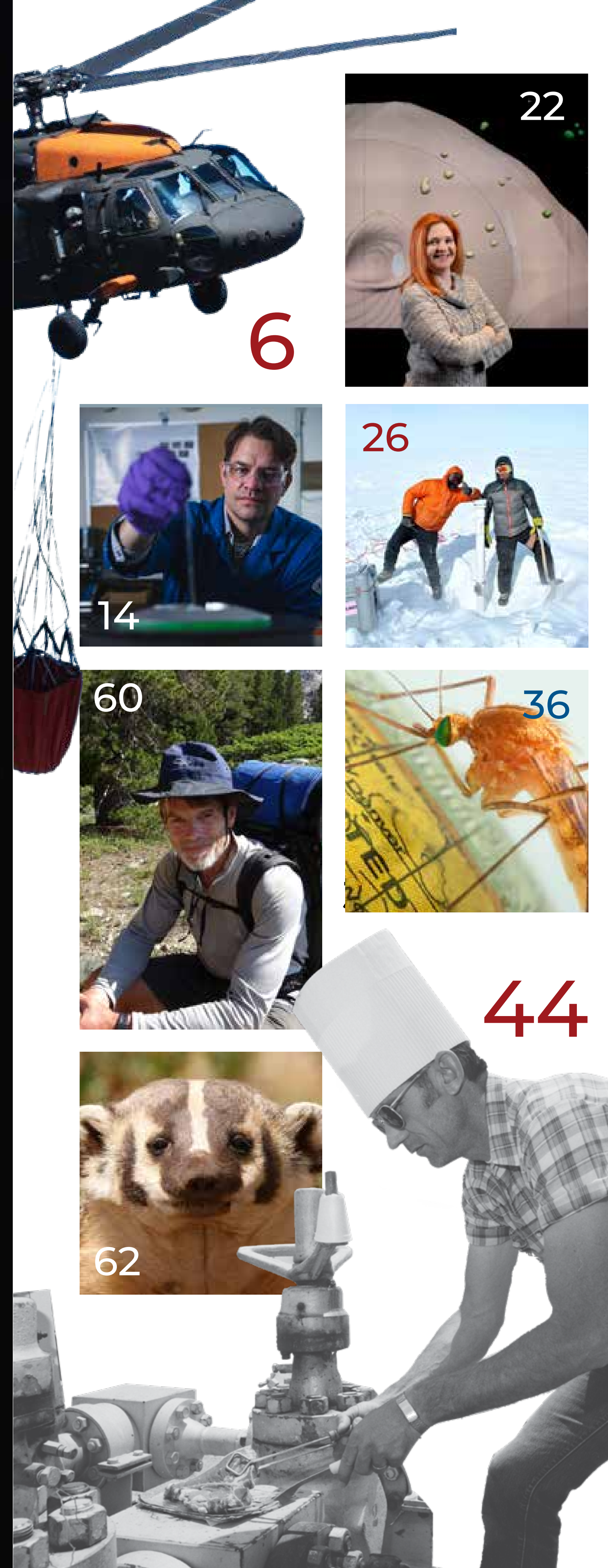
NATIONAL ★ SECURITY SCIENCE

PHOTOBOMB

▼

Los Alamos National Laboratory develops and manufactures detonators—small devices that trigger explosives. Since the 1940s, most detonators have been electrically initiated. But those days are numbered now that Los Alamos is developing safer and more efficient optical detonators—detonators that initiate when a laser provides the correct signal.

During a 2021 series of experiments called Odin's Tesseract ("Odin" as in the Norse god and the Marvel comic character, and "tesseract" as in the geometric analog of the cube popularly pictured as an infinity stone in the Marvel cinematic universe), electrical and optical detonators were attached to and detonated on different sides of a translucent, illuminated plastic cube (pictured). The results showed that the explosive wave breakout was equal on all sides—confirming optical detonators can perform as well as electrical detonators. ★



IN THIS ISSUE

FEATURES

About the cover: The Cerro Pelado fire started on April 22 just southwest of Los Alamos National Laboratory. On May 4, photographer David Woodfin snapped this image of Frijoles Canyon, just a few miles from Lab property. "I took it through the window of the SUV that we were being escorted in," Woodfin says. "We stopped at this spot for less than a minute, and this is one of 30 photos I took in about 45 seconds." Turn to the back cover to learn more about firefighting efforts in Los Alamos County. ★

THE CLIMATE ISSUE

At home and beyond, Los Alamos National Laboratory strives for sustainability and a greener, healthier future.

BY MONICA WITT
Deputy Facility Operations Director

This issue of *National Security Science* magazine explores the scientific and operational contributions Los Alamos National Laboratory is making to address climate change.

As I write this, the topic seems especially timely. I can look out my window and see the smoke from the nearby Cerro Pelado fire and the Hermits Peak/Calf Canyon fire, which is the largest wildfire in New Mexico history. Across the globe, India's heat wave is the hottest on record in over 122 years. The ever-present and growing threat of climate change is not a problem any of us can ignore.

At the Lab, we are taking steps to achieve net-zero emissions by 2045. The commitment and follow-through required to meet this target will take a tremendous amount of dedication, focus, and adoption of new technology. Luckily, we have decades of experience in carbon capture and clean-energy technologies. We will change the energy we use, cars we drive, buildings we work in, gases used in programmatic work, and the vast web of our supply chain.

The energy we use comes from many sources, including coal, gas, hydroelectric, wind, and solar. Transitioning our energy profile away from fossil fuels to cleaner sources is key to reaching net-zero. Los Alamos is planning a 50-acre solar array as one of the first steps to change our energy profile. We are also working to integrate carbon capture technologies and a hydrogen fuel blend in our on-site gas turbine generator, and investing in efficient lighting systems and building controls to improve facility operations. Carbon neutrality can be achieved by transitioning our fleet, facilities, and operations away from fossil fuels and incorporating science-based technologies. This is where operations meets science, and where we truly shine.

In 2021, after more than 20 years at Los Alamos, I received the Department of Energy's Sustainability Champion award. This was a rewarding moment, and I told my then-17-year-old daughter about our efforts that resulted in a reduction of energy use by more than 7 percent since 2015 and water consumption by more than 20 percent since 2007. She seemed unimpressed. Good thing I'm not ready to retire.

In this magazine, you will read about the research and initiatives Los Alamos is taking—from developing a global climate model of the Earth's climatic future (see p. 26), to exploring geothermal energy (see p. 44), to studying how climate change affects the spread of disease (see p. 36). You will see how climate change threatens our national security and some of the many ways Los Alamos National Laboratory is protecting our nation and our planet. I hope you will join me in supporting and contributing to this essential and consequential endeavor. ★

MASTHEAD

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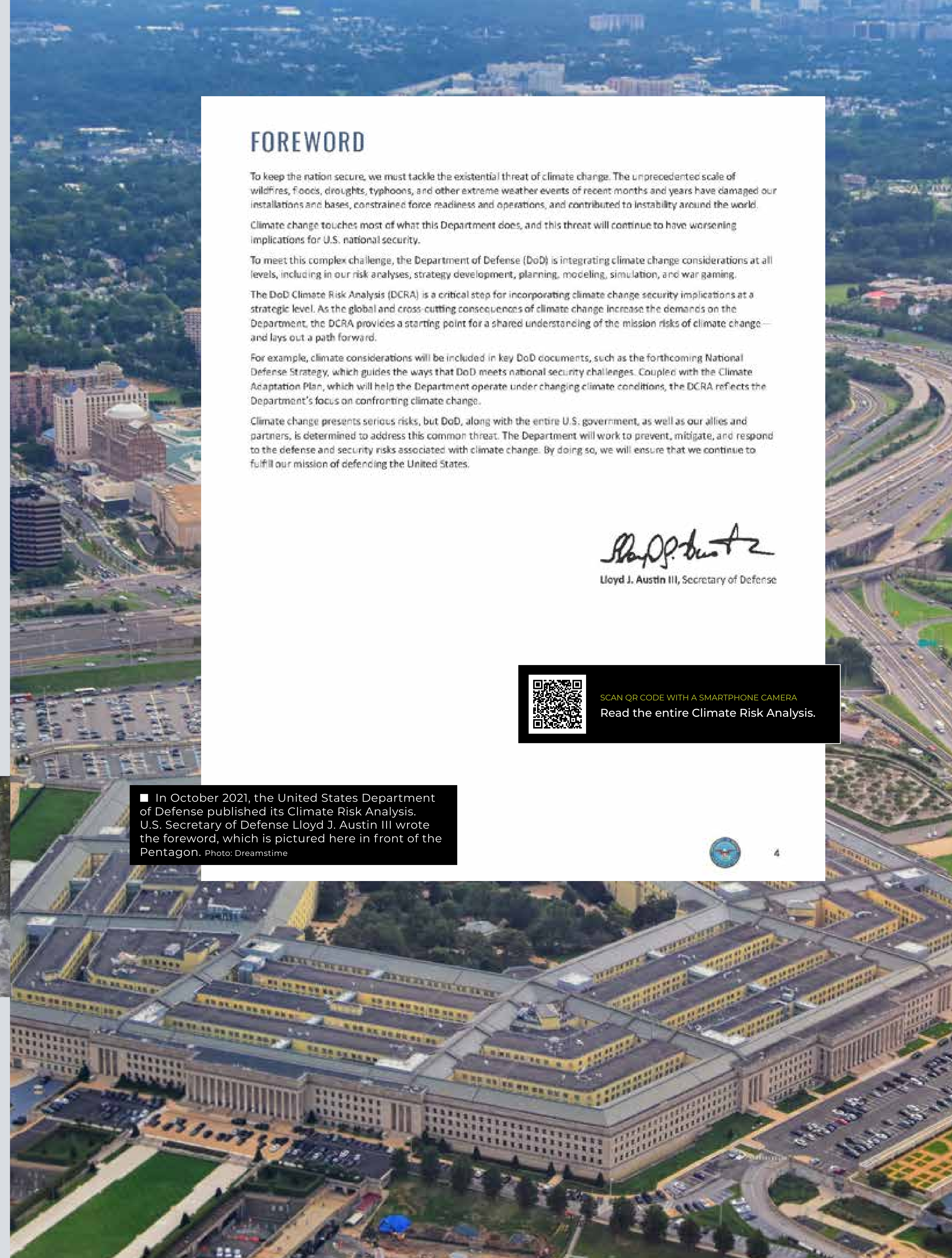
NSS STAFF SPOTLIGHT

Photographer David Woodfin is always up for an adventure. For this issue, he joined Art Director Brenda Fleming and Editor Whitney Spivey on an early morning photoshoot in northern New Mexico's Jemez Mountains. He's pictured here at Sulfur Springs, a geothermal area in the Valles Caldera National Preserve. To see images from this outing, turn to "The energy beneath us" on p. 44. ★



FOREWORD

To keep the nation secure, we must tackle the existential threat of climate change. The unprecedented scale of wildfires, floods, droughts, typhoons, and other extreme weather events of recent months and years have damaged our installations and bases, constrained force readiness and operations, and contributed to instability around the world.

Climate change touches most of what this Department does, and this threat will continue to have worsening implications for U.S. national security.

To meet this complex challenge, the Department of Defense (DoD) is integrating climate change considerations at all levels, including in our risk analyses, strategy development, planning, modeling, simulation, and war gaming.

The DoD Climate Risk Analysis (DCRA) is a critical step for incorporating climate change security implications at a strategic level. As the global and cross-cutting consequences of climate change increase the demands on the Department, the DCRA provides a starting point for a shared understanding of the mission risks of climate change—and lays out a path forward.

For example, climate considerations will be included in key DoD documents, such as the forthcoming National Defense Strategy, which guides the ways that DoD meets national security challenges. Coupled with the Climate Adaptation Plan, which will help the Department operate under changing climate conditions, the DCRA reflects the Department's focus on confronting climate change.

Climate change presents serious risks, but DoD, along with the entire U.S. government, as well as our allies and partners, is determined to address this common threat. The Department will work to prevent, mitigate, and respond to the defense and security risks associated with climate change. By doing so, we will ensure that we continue to fulfill our mission of defending the United States.

Lloyd J. Austin III, Secretary of Defense

4

SCAN QR CODE WITH A SMARTPHONE CAMERA
Read the entire Climate Risk Analysis.

■ In October 2021, the United States Department of Defense published its Climate Risk Analysis. U.S. Secretary of Defense Lloyd J. Austin III wrote the foreword, which is pictured here in front of the Pentagon. Photo: Dreamstime

INFOGRAPHIC

THE INTERSECTION

Science and culture converge in northern New Mexico—and beyond.

SCIENCE

CULTURE

For most of March 2022, downtown Los Alamos looked a lot like it did in 1945—right down to the streetlights and automobiles. J. Robert Oppenheimer and Leslie Groves were even spotted around town—in the form of actors Cillian Murphy and Matt Damon, respectively, who will portray the famous scientist and general in the forthcoming film *Oppenheimer*.

Three Black Hawk helicopters were part of a firefighter training exercise at Los Alamos National Laboratory in late April. The exercise, in which the helicopters transported and dropped water, was a collaboration among the Laboratory, the National Guard, the U.S. Forest Service, and the National Park Service.

During Women's History Month, the American Association for the Advancement of Science's If/Then STEM program partnered with the Smithsonian to display 120 life-size, 3D-printed statues of women—the largest collection of statues of women ever assembled—in Washington, D.C. Among them was Harshini Mukundan, who leads the Physical Chemistry & Applied Spectroscopy group at Los Alamos National Laboratory. Photo: If/Then

Los Alamos was named the best town to live in New Mexico and No. 7 of the top 50 places to live in America according to Niche's 2021 rankings. Niche ranks cities using government data and millions of resident reviews. Photo: Los Alamos County

Located near Amarillo, Texas, the Pantex plant's five-turbine wind farm is the largest government-owned wind farm in the country. The farm generates approximately 40 million kilowatt-hours of electricity, which equals approximately 60 percent of the electricity used for Pantex operations. Pantex, a Department of Energy–operated plant, works closely with Los Alamos to support stockpile stewardship and other national security–related work. Photo: Pantex

What fuels firefighters? Girl Scout cookies, of course! Thanks to Los Alamos troop #10762 for providing dozens of boxes of cookies for the people fighting the Cerro Pelado fire. Here, Brownie Jocelyn Valdez hands off the delivery to Rich Nieto, the Laboratory's wildland fire management officer. Photo: *Los Alamos Daily Post*

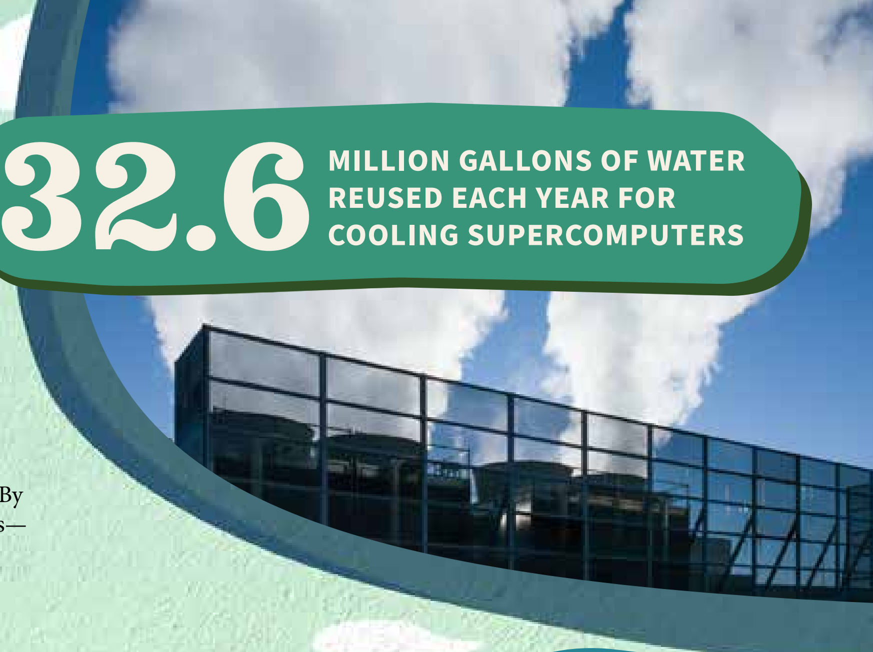
BY THE NUMBERS

SUSTAINABILITY AT LOS ALAMOS

The Laboratory works to reduce its carbon footprint.

In 2011, Los Alamos National Laboratory established its Sustainability Program with the goal of reducing its overall carbon emissions and increasing environmental sustainability. By 2045, the Lab—which contains 8 million square feet of facilities—aims to become a net zero carbon emissions campus.

So far, progress toward achieving this goal includes:



32.6 MILLION GALLONS OF WATER REUSED EACH YEAR FOR COOLING SUPERCOMPUTERS

95 BUILDINGS OUTFITTED WITH AUTOMATION SYSTEMS

13 BUILDINGS CERTIFIED AS SUSTAINABLE

31 BUILDINGS RECEIVED EFFICIENT LIGHTING UPGRADES

24 ELECTRIC VEHICLE CHARGING PORTS INSTALLED

7.4 PERCENT REDUCTION IN LAB ENERGY USE SINCE 2015

ABSTRACTS

SNAP, CRACKLE, STOP

Los Alamos scientists work to end climate change–fueled fires.

BY JILL GIBSON

Flames crackling, smoke billowing, evacuation bags packed, and nerves on end. In recent months, wildfires have swept through the western United States, including one just a few miles from Los Alamos National Laboratory.

Experts warn that the prevalence of fires is increasing. According to a February 2022 report from the Department of Homeland Security, "Wildfires across the U.S. and around the world are becoming more frequent, costly, and dangerous. Risk factors include urban sprawl into previously undeveloped lands prone to wildfires and climate change hazards."

The threat fires pose to national security is rising as well. "As a national security concern, wildfire has several facets," says Los Alamos scientist Rod Linn, who creates computer models that predict how wildfires will behave in different situations. "Wildfires are threatening everything from energy security to water security."

Los Alamos scientist Jon Reisner notes that in addition to wildfires that start naturally or by accident (from an unextinguished cigarette, for example), "wildfires or urban fires can be intentionally induced by foreign governments via detonation of nuclear weapons or by ignition of numerous small fires that can upscale into large fires under the right conditions."

Whatever the cause, Reisner explains, "Fires can lead to fear, panic, and possibly a large number of fatalities; impact critical infrastructure such as power, gas, and water lines; disable military equipment and personnel; and hide an adversary's troop movement. Longer term, fires could significantly impact food, crops, and water supplies."

When it comes to water, "wildfires are a catalyst for large-scale ecosystem change," Linn says. "They have the ability to destroy or change the quality of water in large regions." He adds that even if the fires are far away, the trickle-down effects can be far reaching. "If we have a growing number of fires in Colorado, where the Colorado River watershed is, they pose a huge risk to significant water resources downstream—as far away as California." Water scarcity can affect agricultural production, food availability, and prices. A disrupted water supply could lead to national instability and economic unrest.

Smoke generated by wildfires is also a concern because a variety of critical national security operations are also susceptible to smoke. "When significant smoke is generated over large areas it can impact both health and visibility, which can impact flight operations, with this concern becoming more common in a warming world," Reisner says.

Why has the number of fires increased recently, and will it continue rising? Linn says the answer is complicated. "Some people will say that's climate change and others will say that it's fire exclusion, which translates to too much fuel on the ground. We've been putting fires out as fast as we could for the past 100 years. The environment systems are really out of balance. I think it's probably a combination of the two. Unfortunately, when they come together, it creates a bad scenario."

■ In May 2022, the Cerro Pelado fire burned 45,000 acres just a few miles from Los Alamos National Laboratory, but with no threat to the Lab's radioactive material, which has many layers of protection, including defensible space, secure facilities, and fire-resistant containers.

Adding to this bad scenario is the fact that wildfires are not only increasing due to climate change, but they are also contributing to climate change. "Climate change is producing a growing number of large fires and burning fuel that in the past was not expected to burn," Reisner says. "For example, in 2021 a significant heat wave in the Pacific Northwest desiccated trees found in the temperate rainforest of British Columbia, leading to a fire that induced the highest ever injection of aerosol into the stratosphere. Further, this fire produced clouds that produced as much lightning in one day as what typically occurs in one year, and the lightning then ignited numerous fires downstream of the initial fire."

Reisner says similar heat waves could occur in other regions, such as the northeast United States, leading to fires that not only consume large tracts of forest, but also affect cities. Additionally, the number of fires burning in the sub-surface arctic peat moss has increased. The burning peat moss releases a lot of carbon dioxide and methane, leading to further global warming.

Linn agrees that wildfires are both a result of and contributor to climate change. "Wildfires are a source of aerosols and carbon release, so they have the ability to influence local and regional climate."

By developing high-fidelity modeling tools that predict fire behavior and provide data for mitigation, Los Alamos scientists are developing new ways to address growing and changing fire threats throughout the world and even locally, at the Laboratory. "The first step is to reduce fuel loading near facilities, including both surface and vertical fuels such as trees or shrubs," Reisner says. "Next, buildings should be spaced and engineered to withstand fires and include several layers of filters to mitigate smoke impacts on personnel and property." At the Laboratory, crews remain vigilant about removing underbrush, downed limbs, and other fire fuels from the property and establishing a defensible wildfire perimeter to ensure all hazardous materials on-site stay safe.

Prescribed burns—intentionally lit and carefully controlled fires—are another way to help prevent big wildfires. Experts plan these fires to reduce excessive vegetation that could provide fuel for bigger wildfires. Los Alamos researchers work closely with partners, including the U.S. Forest Service and the U.S. Geological Survey, to create models that predict the behavior of prescribed burns and wildfires nationwide. Linn says he is in favor of prescribed burns, but adds, "We need to do our homework so that we're doing them safely. The more homework we can do, and the more we understand how to make them safe, and we understand the conditions on which they can be done safely, the better success we're going to have." ★

Marcos Hernandez, of the Lab's Chemical Diagnostics and Engineering group, holds a cement block made with algae—an example of a construction good made from biomaterials.

RESEARCH & DEVELOPMENT

MODELING AND ENGINEERING CLIMATE RESILIENCE

A new geospatial modeling platform and laboratory experiments help determine how carbon-based waste sources can best be turned into energy and usable products.

BY WHITNEY SPIVEY

Renewable energy resource availability varies from region to region. Some places might be better suited to solar, for example, while others are better for wind. And even then, Earth's climate is changing so rapidly that it's unclear if a solar area will always be a solar area and a wind area will always be a wind area. So, how do we prepare for such a varied and unpredictable future?

One thing that's certain is that most places around the globe produce waste—things like crop and forest residues, algae, landfill refuse, wastewater, and animal manure—that contains carbon. Carbon, it turns out, is a potential clean and renewable energy resource.

To determine how carbon might be best turned into energy, a team of seven multidisciplinary researchers at Los Alamos National Laboratory is developing a modeling tool, called the Waste-carbon Economic and Climate Action Tool (WECAT). WECAT will be used to identify the availability of carbon from various waste sources and then determine the feasibility of converting these sources to a reliable energy supply.

"By identifying the potential for development of carbon-based energy resources that were previously underutilized, we expect that this technology will be transformational in its ability to spur innovation in and development of new, low-cost clean energy resources in the coming decades," says Kurt Solander, of the Lab's Computational Earth Sciences group.

The researchers are using military bases as their initial test cases. "The military is in a unique position to develop and apply tools and technologies that would assist them in preparing for and preventing impacts of climate change on their facilities and operations," explains bioscientist Babetta Marrone of the Bioenergy and Biome Sciences group at Los Alamos. "Of course, our tools could also be applied to civilian municipalities or organizations that are concerned with the availability of energy resources to provide electricity to local populations."

WECAT is part of a larger initiative, funded by Los Alamos' Laboratory Directed Research and Development program, called Biotechnology for Regional Climate Resilience, which also includes biomanufacturing efforts. "This year we are focused on developing construction materials and fuel pellets using microalgae grown on carbon dioxide captured directly from the air," Marrone explains. The hope is that eventually WECAT will be able to model options for local biomanufacturing opportunities, which would get users one step closer to energy independence.

"Giving communities the ability to produce their own energy and bioproducts would create new jobs and revenue streams, and at the same time reduce greenhouse gases, mitigate climate change, and reduce dependence on foreign countries for energy supplies," Marrone continues. "Energy security *is* national security." ★

From left: Julian Dann, Adam Collins, Sajjan Heerah, and Emma Lathrop adjust a drone that can be used to deploy autonomous methane detection technology to identify and reduce greenhouse gas emissions.

RESEARCH & DEVELOPMENT

PLUGGING THE LEAKS

Los Alamos scientists use machine learning to reduce greenhouse gases.

BY JILL GIBSON

Decreasing greenhouse gases, helping oil and gas companies cut costs, and ensuring nuclear safety—it's all in a day's work for one team of scientists from Los Alamos National Laboratory.

With funding from the U.S. Department of Energy's Advanced Research Projects Agency, scientists have created software that uses machine learning codes to analyze wind speed, wind direction, and how methane is dispersed into the atmosphere. When paired with special infrared laser sensors that can be mounted just about anywhere—on drones, outside a natural gas plant, or inside a facility—the technology can work autonomously to trace the source of methane leaks.

"Methane is a greenhouse gas about 25 times more potent than carbon dioxide," says Manvendra Dubey, the lead scientist on the project. "If we can reduce methane leaks, we will reap benefits immediately, as methane's lifetime is short. This offers a bridge to carbon neutrality, because, if you reduce methane, you will immediately see lower carbon dioxide, the major long-term greenhouse gas."

Dubey says methane leaks are common in the oil and gas industry, but leak detection has always been done manually, which is time consuming. Wind blows methane away from the location of the leak, so pinpointing the leak can be difficult. "Often there's a delay, and the thing has been leaking for months," he explains. "There's a need to automate the process and add 24/7 monitoring."

So, working with the Los Alamos team, a California company called Aeris developed an extremely sensitive methane sensor that uses a mid-infrared laser. Los Alamos researchers then developed software that uses machine learning code to translate the information from the sensor. Because the system uses artificial intelligence and machine learning, it can run continuously in the background to detect problems early on. Dubey points out that stopping leaks saves companies money while also helping the environment. "It's a win-win."

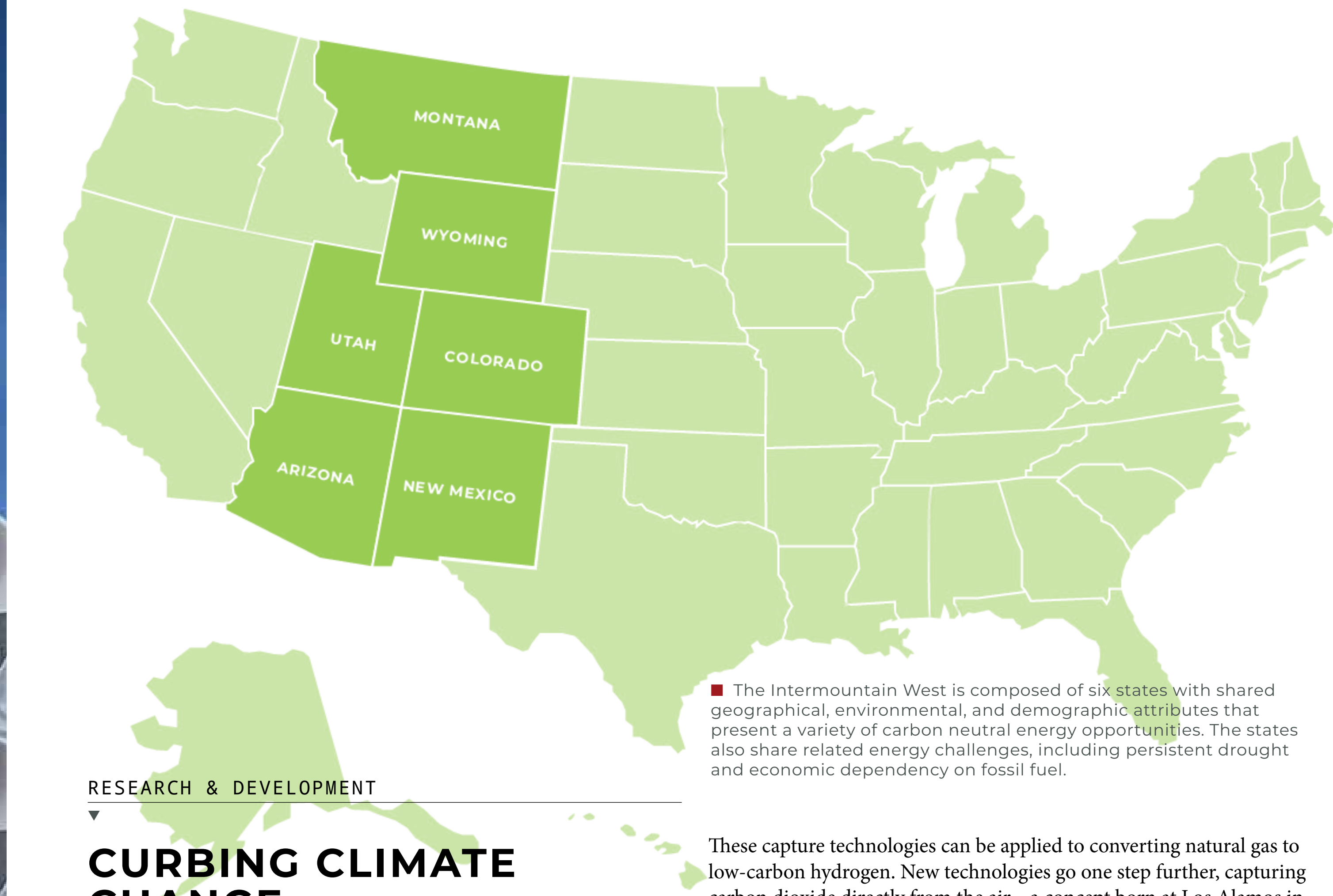
Aaron Greenlaw Meyer, a researcher on Dubey's team, says he believes the technology, which is called the Autonomous, Low-Cost, Fast Leak Detection System, has the potential to make a significant difference. "It's a nice way to reduce our carbon footprint," he says, "because all of this oil and gas infrastructure inevitably has leaks associated with it, but just by finding those leaks, we can really put a stop to a lot of fugitive emissions that we didn't know were there before."

Meyer describes this approach as far more practical than trying to completely overhaul the energy sector to reduce carbon emissions. "This is kind of low hanging fruit, as it were, to be able to mitigate the climate impacts of oil and gas extraction," he says.

Recently, Lab scientists have begun applying the software to detect a different kind of leak—those in nuclear waste storage drums kept underground at sites such as the Waste Isolation Pilot Plant in Carlsbad, New Mexico. "If methane and other gases are produced by reactions in the waste and then vented to avoid accumulation and pressure buildup, we can measure them in the storage facility with our ultra sensitive instruments prior to any risk of explosion or exposure," Dubey explains.

"You can't fix leaks you don't know about, whether what's leaking is radioactive material or methane," he continues. "You can't approach a problem if you don't know it's there." ★

Carbon capture plants, such as the one pictured here, are essential to meeting net-zero emissions targets and addressing the global climate crisis.
Photo: DOE



The Intermountain West is composed of six states with shared geographical, environmental, and demographic attributes that present a variety of carbon neutral energy opportunities. The states also share related energy challenges, including persistent drought and economic dependency on fossil fuel.

RESEARCH & DEVELOPMENT

CURBING CLIMATE CHANGE

Capturing and storing carbon dioxide will be good for the atmosphere.

BY CHARLES POLING

As the urgency increases to head off the worst effects of climate change, the airwaves and internet are buzzing with talk about how carbon capture and carbon storage support various strategies to keep excess carbon dioxide out of the atmosphere.

"The fact is, carbon capture and storage underpin just about every path to reining in climate change and limiting global temperature increases to 1.5 degrees Celsius," says George Guthrie, a program manager for carbon capture at Los Alamos National Laboratory.

Carbon capture and storage involves two key components, both technically achievable today: capture of carbon dioxide from complex gas mixtures and permanent carbon dioxide storage in underground reservoirs.

"Capture of carbon dioxide at some large industrial sources has been done commercially for decades," Guthrie says. The technology centers on separating carbon dioxide from other gases as they leave the smokestack. "The Department of Energy [DOE] has invested in research—including at Los Alamos—to extend carbon dioxide capture technologies to a wider range of operations, such as natural gas power plants and other industrial processes. Commercially available solutions exist today to reduce carbon dioxide emissions from some sources by 90 to 95 percent."

These capture technologies can be applied to converting natural gas to low-carbon hydrogen. New technologies go one step further, capturing carbon dioxide directly from the air—a concept born at Los Alamos in the 1990s. Systems are already being tested and deployed commercially today, and the costs are coming down.

The second key component of carbon capture and storage is permanent geologic storage of carbon dioxide. "We know from nature that carbon dioxide can be stored underground for geologic periods," Guthrie says. One example is McElmo Dome, a geologic reservoir in southwest Colorado that has naturally accumulated more than 1 billion tons of carbon dioxide.

Research by Los Alamos, Sandia National Laboratories, New Mexico Tech, and others has found reservoirs across the nation that could sequester hundreds of billions of tons or more. For comparison, annual emissions in the United States are around 6 billion to 7 billion tons.

Moving from research on carbon capture and storage to deployment has gained momentum under the Intermountain West Energy Sustainability & Transitions (I-WEST) initiative. With sponsorship by the DOE, Los Alamos is leading this initiative, which brings together regional universities and colleges, research institutions, local communities, and Native American nations across six western states (Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming) to create a sustainable-energy economy.

Through a place-based approach using workshops and other outreach that puts people first, I-WEST is learning about stakeholders' unique concerns and needs regarding jobs, energy use, and environmental stewardship. From that input, I-WEST will develop a roadmap to a carbon-neutral economy in the region—and it's already clear that carbon capture and storage will be a key piece of the puzzle. ★

Photo: Dreamstime

THE FUTURE OF PLASTICS

New software could help transform the budding bioplastics industry.

BY BRITTANY DOWD

More than 380 million tons of plastic waste is generated worldwide each year. Approximately half of this waste is single-use plastics, which are typically made with chemicals sourced from fossil fuels, such as petroleum. Single-use plastics are generally used once and then discarded. Few are recycled, an often-tedious process that uses tremendous resources. Most end up in landfills and are discarded into the environment, where they are a significant source of pollution, taking decades to degrade.

"As a society, we generate a staggering amount of plastic waste, with severe consequences on the environment and human health," says Joseph H. Dumont, an engineer at Los Alamos National Laboratory. "We could mitigate the overwhelming problem of petroleum-derived plastic pollution with the development of bioplastics that safely, completely biodegrade."

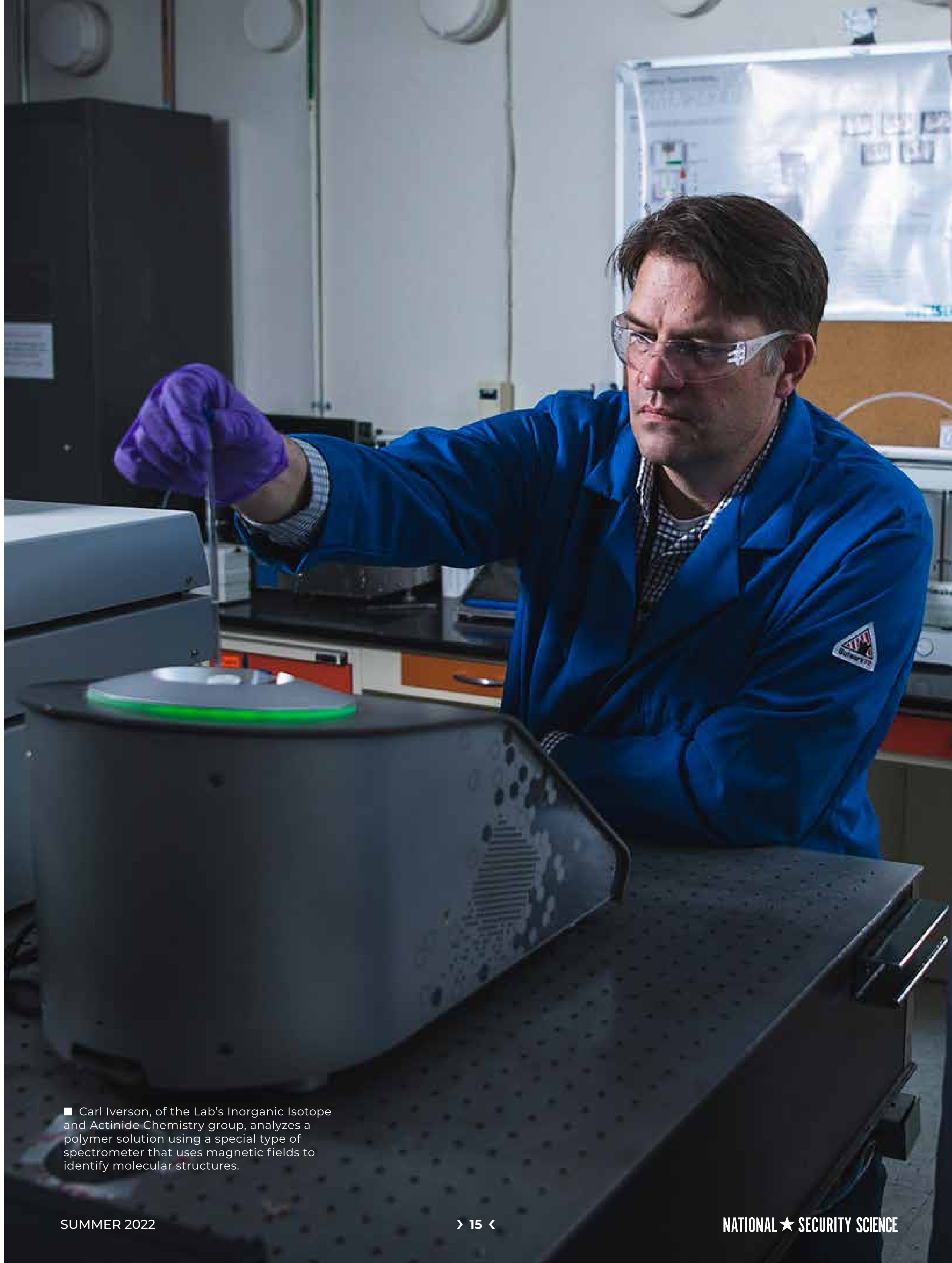
Bioplastics are made from renewable resources and can more easily be broken down to recycle or degrade. However, currently available biopolymers—essentially the building blocks of bioplastics—need significant research and development (R&D) to have the functionality to compete with and replace petroleum-derived plastics. R&D is an exhaustive, expensive process that cycles continuously as researchers work toward polymer optimization, without any guarantee of success.

"We are still decades away from developing large-scale, competitive bioplastic options," Dumont says.

That's why Dumont and a team of researchers at Los Alamos have created BioManIAC (Bioplastics Manufacturing with Intelligent Adaptive Control), a software platform that integrates machine-learning and big-data approaches to rapidly discover new biopolymers and enable plastic producers to more quickly transition to sustainable bioplastics.

BioManIAC fills the gaps in polymer data to gain insight into polymer properties and predict new polymer structures. BioManIAC guides researchers to the most promising polymers and limits real-world experiments to those few necessary to validate the machine-learning platform's predictions. In this way, BioManIAC reduces development costs up to 75 percent and accelerates the discovery of new bioplastics, at a rate about ten times faster than traditional R&D.

"BioManIAC accelerates the development of new bioplastics, using a machine learning–based approach to predict biopolymer structures with the desired features necessary to replace conventional plastics," Dumont explains. "These new bioplastics will help us reduce our impact on the environment now and for generations to come." ★



■ Carl Iverson, of the Lab's Inorganic Isotope and Actinide Chemistry group, analyzes a polymer solution using a special type of spectrometer that uses magnetic fields to identify molecular structures.

■ The on-chip neuromorphic backpropagation algorithm was tested on this neuromorphic research processor, codenamed Loihi, from Intel.

MACHINE LEARNING GOES GREEN

Los Alamos develops an algorithm to reduce power use in autonomous systems.

BY CRISTINA OLDS

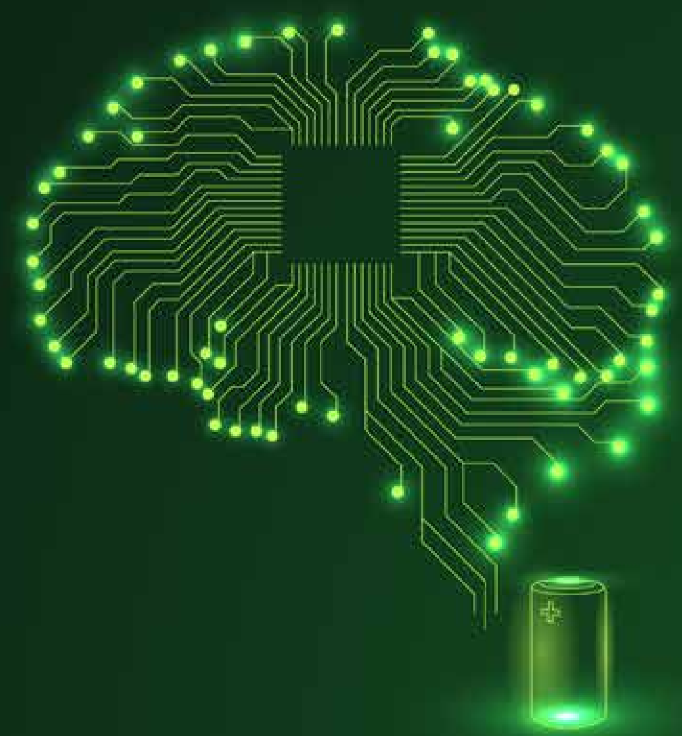
Machine learning—a type of artificial intelligence in which software uses complex algorithms to become increasingly better at predicting outcomes—is everywhere these days. Technologies such as drones, satellites, and robots all use machine learning to (for the most part) make our lives easier. But traditional machine learning software also uses a lot of power, which means it has a big carbon footprint. For example, the carbon produced while training an autonomous car to drive equals that of five regular cars over their entire lifetimes.

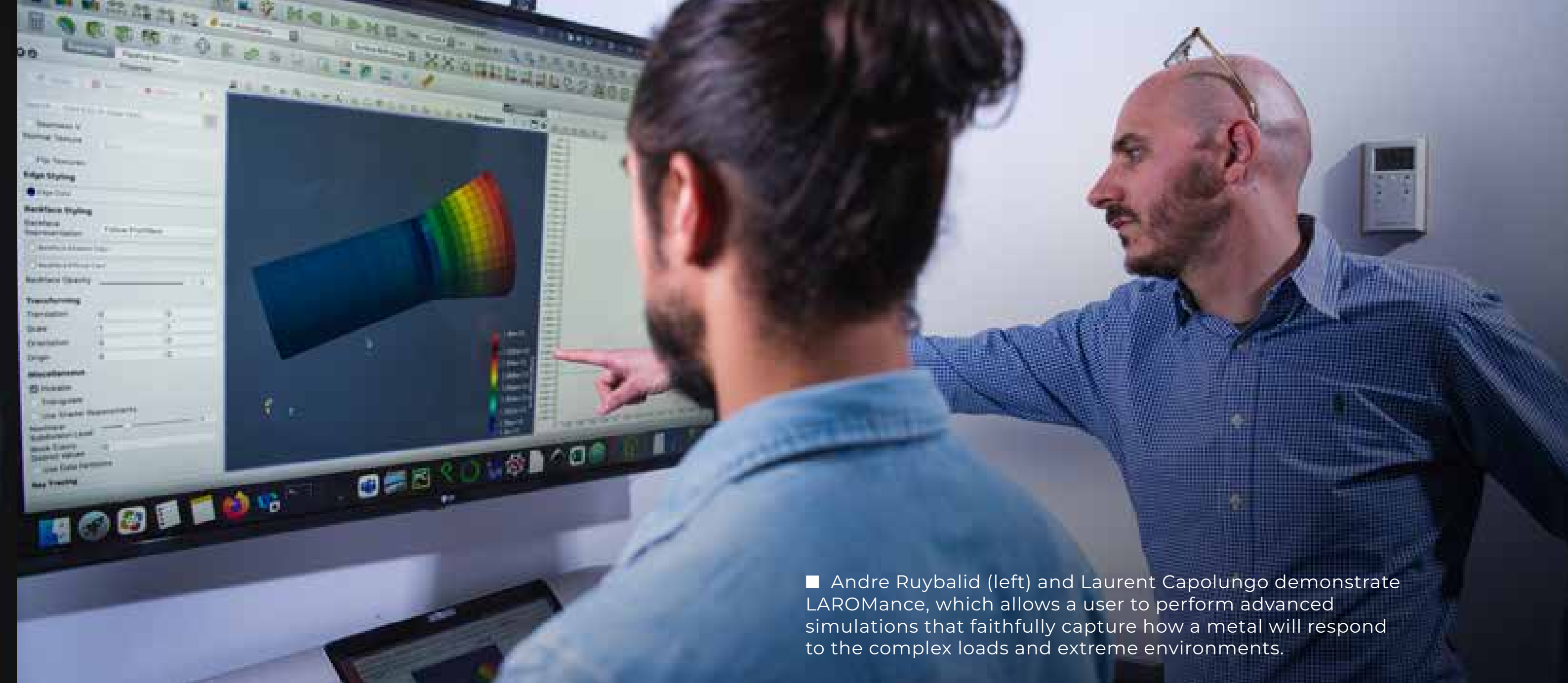
To lessen the environmental impact of artificial intelligence technologies, researchers from Los Alamos National Laboratory developed a new type of machine learning algorithm that runs on a neuromorphic processor.

Neuromorphic processors are inspired by the human brain, which uses synapses to send signals from neuron to neuron. Computations on a neuromorphic processor are similar; the computing elements mimic neurons and synapses. Thus, like in the human brain, many subprocesses can occur simultaneously.

While operating on neuromorphic processors, the algorithm developed by Los Alamos uses backpropagation that can determine precisely which "synapses" need to be modified within a "neural network" to improve the network's predictions as new information is processed. Unlike previous machine learning algorithms, the Los Alamos algorithm implements backpropagation on a self-contained neuromorphic processor without offloading any tasks to a traditional graphics processing unit (GPU) or central processing unit (CPU). This enables the algorithm to use 100 times less power than the equivalent algorithm on a conventional GPU.

Because of these important features, the algorithm is called the on-chip neuromorphic backpropagation algorithm, or ONBA for short. The algorithm, which was submitted for a 2022 R&D 100 Award—the Oscars of innovation—is being used as a module in more sophisticated machine learning frameworks and will help curb the environmental impact of the machine learning technology that we've all come to rely on. ★





■ Andre Ruybalid (left) and Laurent Capolungo demonstrate LAROMance, which allows a user to perform advanced simulations that faithfully capture how a metal will respond to the complex loads and extreme environments.

PERFORMING UNDER STRESS

Data-driven models predict the response of metals in extreme environments.

BY LISA KISNER

Discoveries and advances in metallurgy—the science and technology of metals—have enabled the development of our modern society from the Bronze Age to the present. Today, in addition to their traditional roles, metals are important to worldwide clean energy efforts. That's because many proposed clean energy solutions hinge upon our ability to understand and predict how metallic structural components behave over time when subjected to extreme and complex environments, such as harsh temperature or irradiation. As a metal is subjected to evolving mechanical and thermal loads, ensuring subsequent deformation will not result in unfavorable—or even catastrophic—conditions is essential. Being able to predict the response of the material can help mitigate future problems without stifling deployment.

This requires relating how the state of internal stresses, microstructure, and key elements of the material's composition will affect the likely response of a structure. Risk can vary even within seemingly identical components; small changes in fabrication parameters can result in unseen changes in microstructure that can have large impacts on component reliability over decades. The challenge is to relate these micrometer-scale states to performance of large-scale structures.

Advanced mechanistic and microstructure sensitive models provide a pathway to simulate the expected performance of a structural metallic component. Given the pressing needs for rapid technology deployment, models that give designers, regulators, and the public confidence in clean-energy technologies are worth the investment.

Researchers at Los Alamos National Laboratory developed Los Alamos Reduced Order Model for advanced non-linear equations (LAROMance, pronounced *la romance*) to meet these challenges. The suite of data-driven models predicts the mechanical response of structural engineering metals subjected to extreme environments. These constitutive models are fully integrated into finite element solvers and allow simulations of the response of engineering structures as a function of the state of the microstructure of the base metal.

Usually, the expected lifetime of a material system is established by performing a series of tests on the structure to assess its performance and safety. LAROMance goes one step further by being able to extrapolate beyond the data available. LAROMance models are derived from mining a database of responses of the metals. This database stores the result of advanced simulations using complex scientific constitutive models that are sensitive to the state of the microstructure. It can be applied to any arbitrary quasi-static loading condition, such as stress relaxation, creep, tensile tests, and cyclic tests.

LAROMance captures the entire spectrum of behaviors of the metal in a unified fashion. This predictiveness stems from the fact that the LAROMance models are fit against a large database of expected mechanical response of microstructure changes generated via use of a high-fidelity mechanistic polycrystal model.

LAROMance opens new avenues to incorporate microstructural information into real-world decision making on engineering problems. In particular, the ability to analyze nuclear reactor or gas turbine components, which are expected to perform flawlessly while subjected to truly extreme conditions, provides a solid pathway to accelerate technology deployment. LAROMance introduces highly predictive materials tools as a turnkey solution to any user irrespective of their expertise in materials science. ★

Los Alamos researchers use a tethered balloon system to gather measurements such as temperature, humidity, wind speed and direction, turbulence, and aerosol properties.

FORECASTING THE FUTURE OF WATER

Los Alamos scientists study water availability in the Colorado Rockies.

BY JILL GIBSON

Researchers from Los Alamos National Laboratory are working to learn more about how climate change and extreme weather impact mountainous water sources.

Heath Powers, of the Lab's Earth Systems Observations group, leads a team that is working at the Department of Energy's Surface Atmosphere Integrated Field Laboratory (SAIL), which is in the Upper Colorado River Basin and collects data from the East River Watershed. The work began in September 2021 and will last through June 2023.

Powers says that SAIL is an atmospheric observatory with highly advanced measurement capabilities. "It's very much like a celestial observatory where you use fancy instruments to get a much better detailed view of what's happening. We use very sophisticated and complex instruments that most people don't have to get a really comprehensive picture of what's happening from the ground all the way up to the top of the atmosphere."

The study focuses on the Colorado River watershed, which provides 60 to 90 percent of the water in the mountainous western United States, but Powers says the results can also apply to mountainous regions across the world. "At the core of this study is understanding what processes lead to impacts on precipitation right now and what those impacts are in future climate scenarios. One of the fundamental parts of this study that we're hoping to gain information about is how we think the water resources will change in a changing climate."

Allison Aiken, a Los Alamos aerosol scientist who is part of the SAIL science team, says the information they are collecting will be crucial for forecasting the future. "We need to know and understand if there are going to be areas that we've relied on for water supplies that are going to be drying up in the future. That's a huge national security issue. We need water to survive."

Along with capturing detailed measurements of rain and snowfall and snowpack, SAIL tracks how dust and wildfires impact clouds and precipitation. "There are lots of variables, but we fortunately come equipped with lots of instruments to get at every one of those variables," Powers says.

Aiken looks forward to how the information they gather will predict the effect of climate change on water availability. "It's one of the reasons I went into environmental science," she says. "I care about the planet and the people that are on it. I'm very proud to be part of the data collections and measurements to try to answer these big questions."

Powers agrees, but he laughs, saying he hopes to avoid certain questions. "People often ask, 'So can you tell me what the weather's going to be? Are we going to get a lot of snow this year?' I tell them, 'I can't tell you about this year, but I'm hoping to be able to tell you what the weather will be in 50 years.'" ★

■ Air Force visitors witness an explosives experiment at one of Los Alamos' firing sites.

MILITARY

CULTIVATING PARTNERSHIPS

Nuclear experts exchange ideas and discuss deterrence.

BY WHITNEY SPIVEY

In March 2022, Los Alamos and Sandia national laboratories hosted 12 nuclear experts from the United States Air Force. The purpose of the two-day visit was, according to host Mike Port of Los Alamos' National Security and International Studies Office, "to facilitate critical topic discussions and to cultivate trusted partnerships by candidly discussing national security topics with respect to the future threat spectrum, future nuclear deterrence programs, advancing technology, and closing technology gaps to address emerging threats."

In addition to several integrated deterrence- and technology-focused briefings, both laboratories demonstrated capabilities not readily available within the Department of Defense. Because of its success, the visit will be recurring, with Los Alamos, Sandia, Lawrence Livermore National Laboratory, and the Air Force rotating hosting duties. ★

QUOTED

"The people of NNSA work every day to enhance international security and prepare for potential threats that could undermine nuclear safety, security, and deterrence. That preparation has served the world well."

—Jill Hruby, head of the National Nuclear Security Administration (NNSA), in a memo to employees at NNSA plants, sites, and laboratories, including Los Alamos. ★

■ Jason Lee, a research scientist in the Lab's High Performance Computing division, works on ABOF hardware.

RESEARCH & DEVELOPMENT

POWERFUL STORAGE FOR BIG DATA

A radically new approach to storage acceleration aids data manipulation for research and discovery.

BY BRIAN KEENAN

Data is a vital part of solving complicated scientific questions in fields such as climate, genomics, and nuclear physics. However, an abundance of data is often only as good as the ability to efficiently store, access, and manipulate that data. To facilitate discovery with big data problems, researchers at Los Alamos National Laboratory, in collaboration with industry partners, have developed the Accelerated Box of Flash, or ABOF, an open storage system acceleration architecture for scientific data analysis, which can deliver 10 to 30 times the performance of current systems.

"Scientific data and the data-driven scientific discovery techniques used to analyze that data are both growing rapidly," says Dominic Manno, a researcher with the Lab's High Performance Computing division. "Performing complex analysis to enable scientific discovery requires huge advances in the performance and efficiency of scientific data storage systems."

Scalable computing systems use data processing units (DPUs) to speed up intensive functions between central processing units (CPUs) and storage devices; however, scientists have struggled to use DPUs within production-quality storage systems for complex high-performance computing simulation and data-analysis systems. ABOF solves that problem using a unique hardware and software storage system co-design that is programmable and attached to the network. This makes it simpler to use DPUs to move intensive operations away from the storage server CPUs. No major storage system software modifications or application changes are required. The result is faster and more efficient data manipulation that decreases time, cost, and energy use.

An example of a project that might benefit from storage system acceleration is the Energy Exascale Earth System Model (E3SM, see p. 26), an Earth system modeling, simulation, and prediction project. Currently, the model runs, then is analyzed—a serial process. ABOF, however, could provide the architecture and the speeds to conduct analysis and modeling in parallel.

"For this kind of project, the value in a technology like ABOF would be in model analysis," says Luke Van Roekel, a scientist with the Lab's Theoretical division and co-lead of E3SM's Water Cycle science campaign. "The data could be shipped off to ABOF, which can do analysis while the model moves to its next tasks on the main nodes. Analysis on E3SM's large data volumes is where ABOF would potentially really shine." ★

Wendy Caldwell

PLANETARY DEFENSE

DO LOOK UP!

Hollywood tackles climate change with a little help from Los Alamos.

BY LISA KISNER

When *Don't Look Up* hit the small screen in December 2021, viewers couldn't resist the star-studded satire. In its first month on Netflix, the film garnered 359.8 million viewing hours, making it the second most watched original movie released by the streaming service to date.

The premise is that of many disaster movies: A potentially humanity-ending threat is headed our way, and the heroes try to save the day. With *Don't Look Up*, that threat is a 10-kilometer-wide comet, and the heroes are scientists from Michigan.

As a scientist in the Verification and Analysis group of the Computational Physics division at Los Alamos National Laboratory, Wendy Caldwell is always looking up. "A good chunk of my work right now is planetary defense," she says. "We look at ways that we might prevent a catastrophic event like an asteroid impact, something like what wiped out the dinosaurs."

One project Caldwell has contributed to is NASA's Double Asteroid Redirection Test (DART). Launched in November 2021, a mere month before *Don't Look Up*'s release, DART is the first full-scale mission to test a kinetic impactor on an asteroid. Caldwell describes a kinetic impactor as a "space cannonball" designed to crash into an object and change its trajectory. DART's target is Dimorphos, a small asteroid moonlet orbiting Didymos, a larger near-Earth asteroid.

When she isn't watching the skies, Caldwell turns her gaze a bit closer to home—and sometimes that means the television, especially when a particular film is on her radar. "One of the things I really appreciated about the movie was the science," she says of *Don't Look Up*. "I've heard the director Adam McKay talk about DART, and I can tell they talked to experts because a long period comet from the Oort cloud is the biggest threat, and six months is about the shortest time span we would have, so that is our worst-case scenario."

Although filmmakers put significant effort into getting the science right, including talking to DART team members, the story is considered a thinly veiled allegory for the impending climate crisis.

"The movie is farcical, but it still presents a big problem. If we act early enough, we might be able to do something. If we ignore it and hope it goes away, we're doomed," Caldwell explains. "In that regard, it's definitely similar to climate change."

She also believes addressing extinction-level events—whether climate or comet related—requires global collaboration. "You have to get people on the same page," she says. "You have to acknowledge there's a problem, and you have to listen to the experts who say there's a problem."

But that's easier said than done. "This movie really highlights that sometimes believing there's not a problem is easier to digest than admitting there's a problem because then it's a scary thing that you have to deal with. Maybe you don't know how to deal with it, and that's scary, too."

Caldwell also says some people see climate change as a long-term problem. "There's this idea of, well, I won't be here anymore, who cares, right? And we could take that approach with planetary events too. But that's not good enough because if everybody had that idea, then where would we be as a society? We have to do what we can."

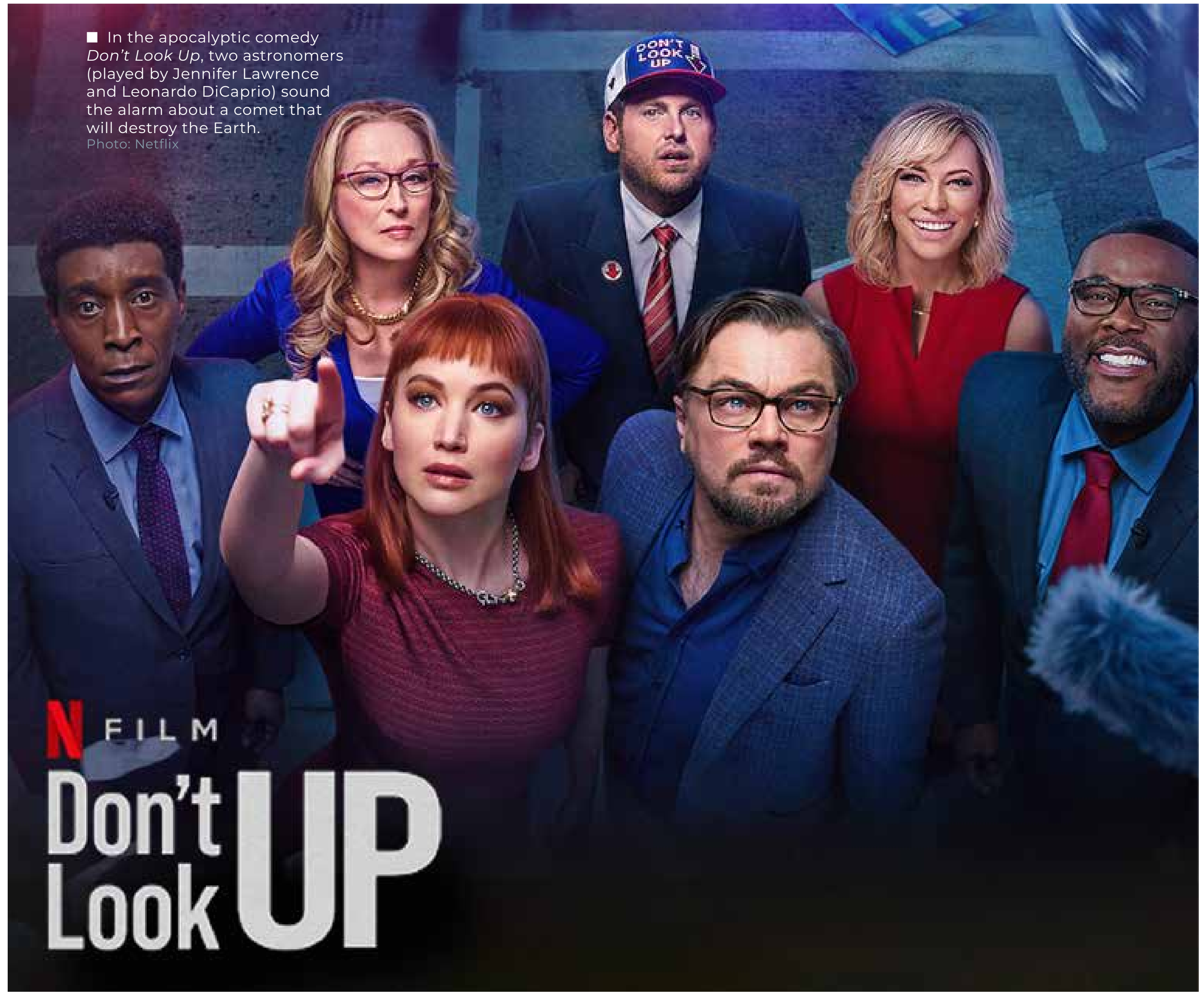
She worries that simply having data and evidence isn't enough, which is why *Don't Look Up* is so important. Director Adam McKay "is tackling a very poignant, difficult issue, but he's doing it in a way that is accessible to people," says Caldwell, who likes his movies because they start dialogue. "That's always a net benefit to society, when people start to have these conversations or start to wonder what it'd be like for an asteroid hit or when was the last big asteroid strike?"

The foundation for being human, according to Caldwell, is wanting to know and understand things. "It might annoy people, but it's good for humanity to ask 'Why?'" she says, adding that, "It's just as important to ask 'Why not?'"

Speaking of questions, a key one: Within our lifetime, how likely to occur is the worst-case scenario depicted in the movie? Her answer: "Almost zero." But the odds of it happening eventually are practically 100 percent, and that's why DART is so important.

DART is on track to strike Dimorphos this fall, and Caldwell can't wait to take her eyes off the sky and start analyzing the data. ★

SCAN QR CODE WITH A SMARTPHONE CAMERA
Listen to *Don't Look Up* director Adam McKay promote DART in a short clip from NASA.



In the apocalyptic comedy *Don't Look Up*, two astronomers (played by Jennifer Lawrence and Leonardo DiCaprio) sound the alarm about a comet that will destroy the Earth.
Photo: Netflix

■ Mark Boslough visits the New Mexico Museum of Natural History and Science, where an exhibit depicts asteroids careening toward Earth.

LOOKING TOWARD AN UNCERTAIN FUTURE

From planet-killing asteroids to climate-change consequences, a scientist warns of global catastrophe.

BY JILL GIBSON

The end of the world isn't an abstract concept for physicist Mark Boslough. In many ways, the end of the world is his life's work. Boslough researches global catastrophes, such as what would happen if an asteroid collides with Earth. He has also devoted decades to studying and raising awareness of another threat to the planet: climate change.

Retired from Sandia National Laboratories, Boslough now conducts research on comet and asteroid impacts for Los Alamos National Laboratory and the University of New Mexico. He is also a fellow of the Committee for Skeptical Inquiry.

Boslough and his research have been the subject of many documentaries, news features, and magazine articles—including this one. *National Security Science* sat down with Boslough to hear his thoughts on climate change, its connection to planetary defense, and what we can all do to protect the Earth.

What is the connection between asteroids or comets hitting the planet and climate change?

I've always made the connection, both from a risk perspective and from a physics perspective, between planetary impacts and climate change. When I was a grad student, I designed experiments to capture carbon dioxide and water released from minerals from high-velocity impacts. About the same time, the Alvarez hypothesis suggested that the dinosaurs had been wiped out by an asteroid. It was clear to me and to others that the impact alone didn't kill the dinosaurs—climate change and the change of the atmosphere associated with the impact also played a role.

So, I never made a strong distinction between the impact risk and the climate risk. In fact, the risk assessment uses the same methodology. In both cases, there's a nonzero probability that the outcome is globally catastrophic.

In your opinion, what is the public perception of climate change?

There's a perception, at least outside the scientific community, that uncertainty is an excuse to relax. People aren't sure that climate change is going to wipe us out, therefore, they don't have to worry about it. But being blind to what's happening does not work in our favor.

Since the early '90s, when we started working on the asteroid risk, the actual quantitative risk has gone down by an order of magnitude because we've discovered most of the big asteroids that we know are on Earth-crossing orbits but are not going to hit the Earth for at least 100 years.

But in the meantime, even though our climate models aren't perfect—which creates uncertainty—they are continually improving, and we do know the composition of the atmosphere is changing. The climate risk has continued to accelerate. We have a lot fewer years to arrest that increase and keep ourselves below the catastrophe threshold, whatever it turns out to be. We don't know how many bullets are in the gun, so to speak, and that's all the more reason to not be pointing that gun at anyone. Don't take the risk.

What do you believe is the solution to the climate change crisis?

We need policy changes. We need collective behavior. And we've got to make nonfossil-fuel energy cheaper than fossil energy because nonfossil energy does not damage the atmosphere, and fossil energy does.

What makes me the most upset is the insistence by many people that we should continue to subsidize fossil fuels. We're encouraging people to burn fossil fuels. We should be doing the opposite. The limited resource is not fossil fuel. It's the cooling capacity of the atmosphere. We're just squandering that right now because it's free for the taking.

And what happens if we don't take action?

As time goes on, we're pumping more and more combustion products into the atmosphere, and the cooling capacity of the atmosphere is going down. So, we're closer to whatever the margin is for catastrophe. The closer we get to that margin, other things are going to go wrong. There's a cost, even if we don't cross the catastrophe threshold. But at some point, we're going to cross it. ★

By J. Weston Phippen

COLLABORATIVE CLIMATE MODELING

Powerful new tools help predict climate change and its potential impacts on national security.

■ Greenland's Ilulissat glacier appears pristine and perpetual, but it is actually the fastest moving glacier in the world. Los Alamos scientists use sophisticated computer models to simulate how glaciers might appear years into the future.

HUMANS ARE NOW LIVING IN THE WARMEST climate in modern history. Wildfires, droughts, hurricanes, flooding, extreme heat, and coastal erosion are more intense and more frequent with each passing year.

What do these climate changes mean for national security?

In January 2021, the Biden administration issued the Executive Order on Tackling the Climate Crisis at Home and Abroad, which stated that the climate crisis is "at the forefront of this nation's foreign policy and national security planning" and declared that "the United States will … move quickly to build resilience, both at home and abroad, against the impacts of climate change that are already manifest and will continue to intensify according to current trajectories."

Soon after, the National Intelligence Council issued a National Intelligence Estimate on climate change, which concluded that "climate change will increasingly exacerbate risks to U.S. national security interests as the physical impacts increase and geopolitical tensions mount about how to respond to the challenge." Among the report's main concerns were global competition over clean-energy materials, societal strife in regions with chronic drought, strains on military readiness, and potential conflict over fossil fuel resources in the Arctic.

However, identifying concerns is different than addressing them. The overwhelming scope and complexity of climate change make it difficult to tackle or even know where to start. But climate modeling—using computer software to create virtual representations of past, present, or future climate scenarios anywhere on Earth—can help.

According to the National Oceanic and Atmospheric Administration's Climate.gov website, climate models "use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, and land." When developing climate models, researchers must identify and quantify Earth system processes and represent them with mathematical equations. Then, variables are set to represent conditions and changes. Supercomputers are used to solve the equations and simulate various scenarios.

"The evolution of climate models has been one of increasing complexity run on faster and larger computers," explains the National Intelligence Estimate. "The first climate models examined how the Earth's energy balance and atmosphere might vary over time, and only considered atmospheric physics and rudimentary representations of the oceans and land. In time, scientists added more detail, such as ocean and land chemistry and biology."

Today, the report continues, "climate models operate by solving a very large set of sophisticated equations for three-dimensional grids in the atmosphere and oceans."

Climate modeling is all about making choices, explains Luke Van Roekel, of the Fluid Dynamics and Solid Mechanics group at Los Alamos National Laboratory. "You have to say there are some things I'm going to explicitly resolve and some things I'm not going to pay attention to because they may make the model unnecessarily complex without adding value," he says. "Imagine the Gulf Stream, a big process that is hundreds of kilometers long. If you zoom in, there are little waves and eddies that break off from the waves, and if you zoom in more, there are even smaller eddies. So we have to understand what scale of these features is most important to model and what might have a smaller impact on our understanding of these systems."

THE ENERGY EXASCALE EARTH SYSTEM MODEL

As of 2021, more than 30 major climate-modeling centers around the world are able to make projections 10, 50, 100, or even 1,000 years into the future using sophisticated models that run on supercomputers.

Since 2013, Los Alamos National Laboratory, along with about a dozen universities and seven other national labs, has been working on the Energy Exascale Earth System Model (E3SM). E3SM, which is funded by the Department of Energy, aims to be the fastest, most accurate, and highest resolution Earth system model in the world.

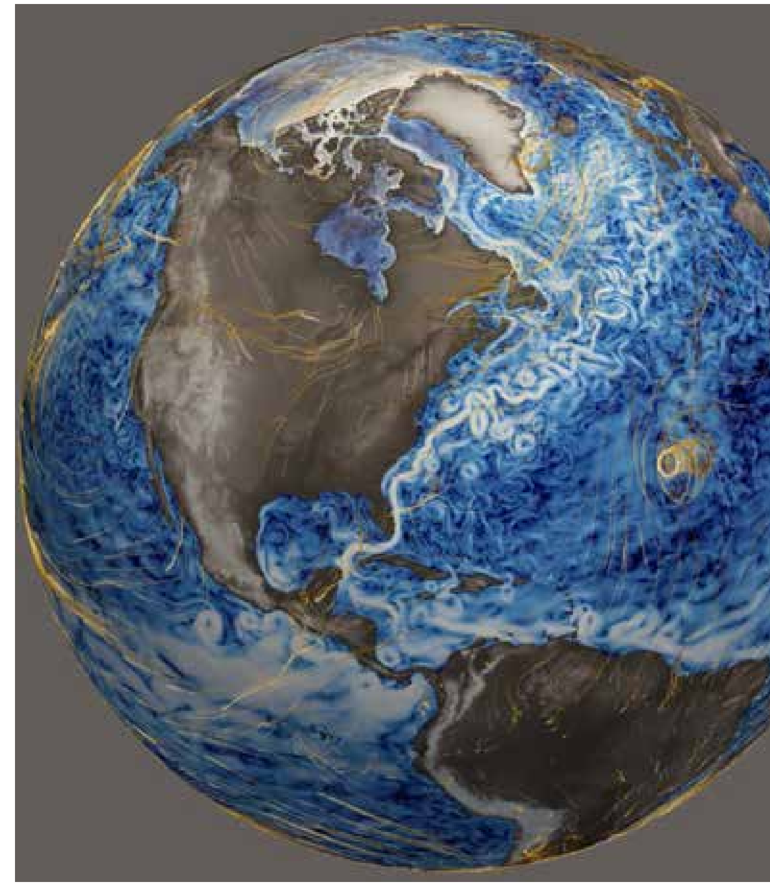
"Imagine being able to explore and quantify changes in the physical climate system at unprecedented resolution and for any imaginable future climate conditions," explains Stephen Price, a member of the Lab's Fluid Dynamics and Solid Mechanics group and the institutional lead for the Lab's E3SM efforts. "This is our goal for E3SM."

E3SM is essentially a suite of models that can operate independently or together. Individual models are used to simulate various natural and manufactured aspects of the Earth's land, oceans, and atmosphere, such as ice sheets, rivers, storm surge, soil saturation, vegetation, and even crop yields.

Some individual models account for the interactions of several Earth systems, such as E3SM's sea ice model, which can simulate sea ice melt in the north and south poles by taking into consideration the physics of how sea ice freezes and melts, how it moves across the ocean's surface, and how it is influenced by ocean currents, wind, and other systems.

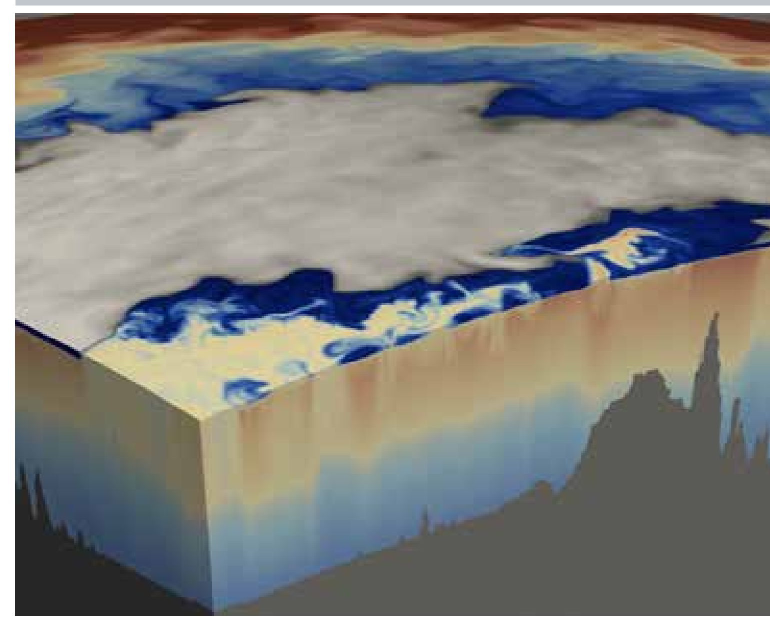
When coupled together by appropriate software, these individual models can simulate fluxes of heat, moisture, energy, and features all the way down to scales as small as the absorption of greenhouse gases by algae. "The coupling of the individual models in E3SM is becoming increasingly sophisticated," says Van Roekel, who co-leads the Lab's E3SM Water Cycle efforts, "such that we could look at hurricanes as they blow water onto the coast and quantify regions susceptible to sea water inundation and how this will change in different climate conditions. That would be pretty sophisticated for a climate model."

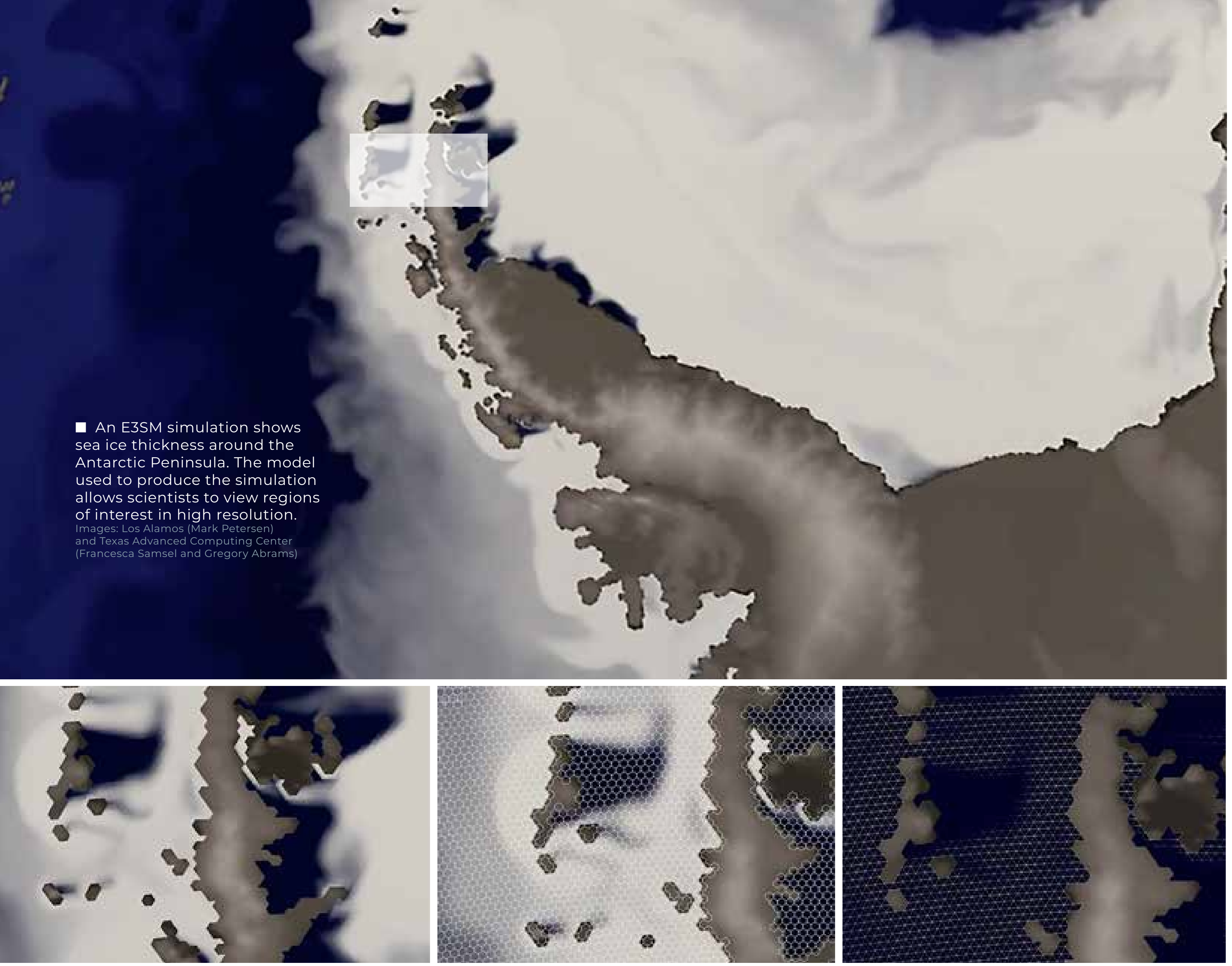
Early results for one model used in E3SM, the MPAS-Albany Land Ice (MALI) model, have already proven extremely useful. In August 2021, Los Alamos, along with 38 other international collaborators, studied nearly 900 simulations to understand how melting ice sheets (large masses of glacial ice) will impact global-mean sea-level rise by 2100. They found that under unabated emissions, sea-level rise could be as high as 30 inches. Alternatively, by limiting global warming to 1.5 degrees Celsius, sea-level rise by 2100 could be limited to five inches—thus confirming that human choices will indeed play a part in determining just how detrimental climate change will be.



Ocean, ice, and atmospheric dynamics interact in E3SM simulations. Above: Atmospheric streamlines (yellow) and ocean currents (white to blue) affect Arctic sea ice. Below: A cross-section of ocean temperature near Antarctica shows sea ice (gray) opening to expose warm, convecting waters to the cold atmosphere above.
Images: Los Alamos (Mark Petersen) and Texas Advanced Computing Center (Francesca Samsel and Gregory Abrams)

SCAN QR CODE WITH A SMARTPHONE CAMERA
Watch an E3SM polynya simulation.





An E3SM simulation shows sea ice thickness around the Antarctic Peninsula. The model used to produce the simulation allows scientists to view regions of interest in high resolution.
Images: Los Alamos (Mark Petersen) and Texas Advanced Computing Center (Francesca Samsel and Gregory Abrams)

A NEW ERA

In addition to global sea-level rise caused by melting ice sheets, scientists are using E3SM to focus on the more localized effects of melting ice sheets.

Price explains that recently, Lab scientists noticed an alarming result in their E3SM simulations of the Southern (Antarctic) Ocean and its possible interactions with the Antarctic ice sheet. In one simulation, cold freshwater circulating along the Antarctic coast in a counter-clockwise direction was arriving at the Filchner-Ronne ice shelf—the Earth's largest floating ice shelf by volume. This was of particular interest to researchers because the simulation showed that this influx of water contributed to a rapid increase, about 10 times the normal rate, of this ice shelf melting over only a few years.

The implications for ice loss and sea-level rise are significant as Antarctica's ice shelves are critical for limiting the movement of ice off of the continent and into the oceans.

This was just a simulation. But it had researchers worried and wondering if such an event could occur in the real world. If so, how?

Luckily, complex models such as E3SM are the perfect tool for exploring questions like "what if?" and "how?" Through a series of E3SM simulations, the team discovered that, due to ocean currents, changes in ice shelf melting in one region of Antarctica can have catastrophic implications (including ice shelf melting, which results in sea-level rise) in other regions of Antarctica.

This revelation would have been impossible to discern from research expeditions because of the size and complexity of the physical system involved. Researchers are now aware of this interconnectedness—and its implications—because of E3SM.

COMPUTING POWER

The supercomputers currently used to run E3SM models operate at between 10 and 100 petaflops. A single petaflop can make one quadrillion computational operations every second. The Department of Energy owns two of the top three petaflop computers, but to unlock the full potential of E3SM will require something faster.

Resolution is also limited by current supercomputers. The resolution of most E3SM simulations can be drilled down to 60-square-mile cubes. So, scientists may be able to answer a question like, "How high will the water rise along the Eastern Coast of the United States in 50 years?" But that resolution doesn't allow for more specific answers to questions such as, "In half a century, will a specific military base be under water?"

E3SM is being designed to run on exascale computers, which are in development. One exaflop (as processing power is called for exascale computers) is 1,000 times faster than a petaflop, which means that the resolution of most simulations will be improved to 6-square-mile cubes, and select regions may be even finer resolution. For climate modelers, that difference in resolution could mean differentiating between an entire city being flooded versus specific sections of a city being destroyed by floodwaters.

However, the transition to exascale computing will not be seamless. "Exascale computing presents an acute challenge in that the new computer architectures are quite different from those before," explains scientist Elizabeth Hunke of the Lab's Fluid Dynamics and Solid Mechanics group. "Using exascale computers will require recoding many of our older models, but these new computing systems will open grand new possibilities for climate science."

COLLECTING DATA

How can a model—a vast assemblage of mathematical calculations—simulate often incomprehensible acts of nature?

All modeling begins with data, and that data is provided by scientists such as Joel Rowland, of the Lab's Earth Systems Observations group. "I try to understand how we go about getting enough real-life observations to incorporate into the climate models, which then make up the mathematical architecture of the model," he explains.

In many cases, these real-life observations come in the form of historical data. In the United States, especially in the lower 48 states, extensive climate records are available through government organizations such as the National Oceanic and Atmospheric Administration, the United States Geological Survey, and the National Aeronautics and Space Administration. Then, "we do what's called a spinup," Rowland says. "We'll run the model, but we set it for conditions that existed 160 years ago. If the simulation reflects known historical observations—for example the precipitation over a specific region matches what we know to have occurred in the past—then we can make judgments on the accuracy of the model."

> "Imagine being able to explore and quantify changes in the physical climate system at unprecedented resolution and for any imaginable future climate conditions. This is our goal for E3SM."
>
> –STEPHEN PRICE

Unfortunately, other countries do not have such meticulous climate records, which is problematic for building a global model such as E3SM.

The climate of the Arctic, for example, is not well documented—especially when it comes to the region's floodplains and rivers, which are Rowland's focus area. Without historical data to plug into models, Rowland must collect current climate data himself. Recently, he's traveled to the Yukon and the Koyukuk rivers in western Alaska. There, he uses river gauges, takes water samples, and measures soil erosion where land interfaces with running water. He takes the data back to Los Alamos where he analyzes it and eventually enters the information into a model that feeds E3SM.

Rowland hopes to learn more about how water impacts permafrost—permanently frozen layers below the Earth's surface. As the ice in the ground melts, mounds form on the Earth's surface. These mounds alter the flow of water on the surface, which further accelerates ice

Glaciologists from The Ohio State University and Los Alamos install equipment for measuring the thinning rate of Greenland's Ilulissat glacier.

"Using exascale computers will require recoding many of our older models, but these new computing systems will open grand new possibilities for climate science."

–ELIZABETH HUNKE

melt in the ground and permafrost thawing. This thawing releases gases, including carbon dioxide and methane—both important drivers for global warming.

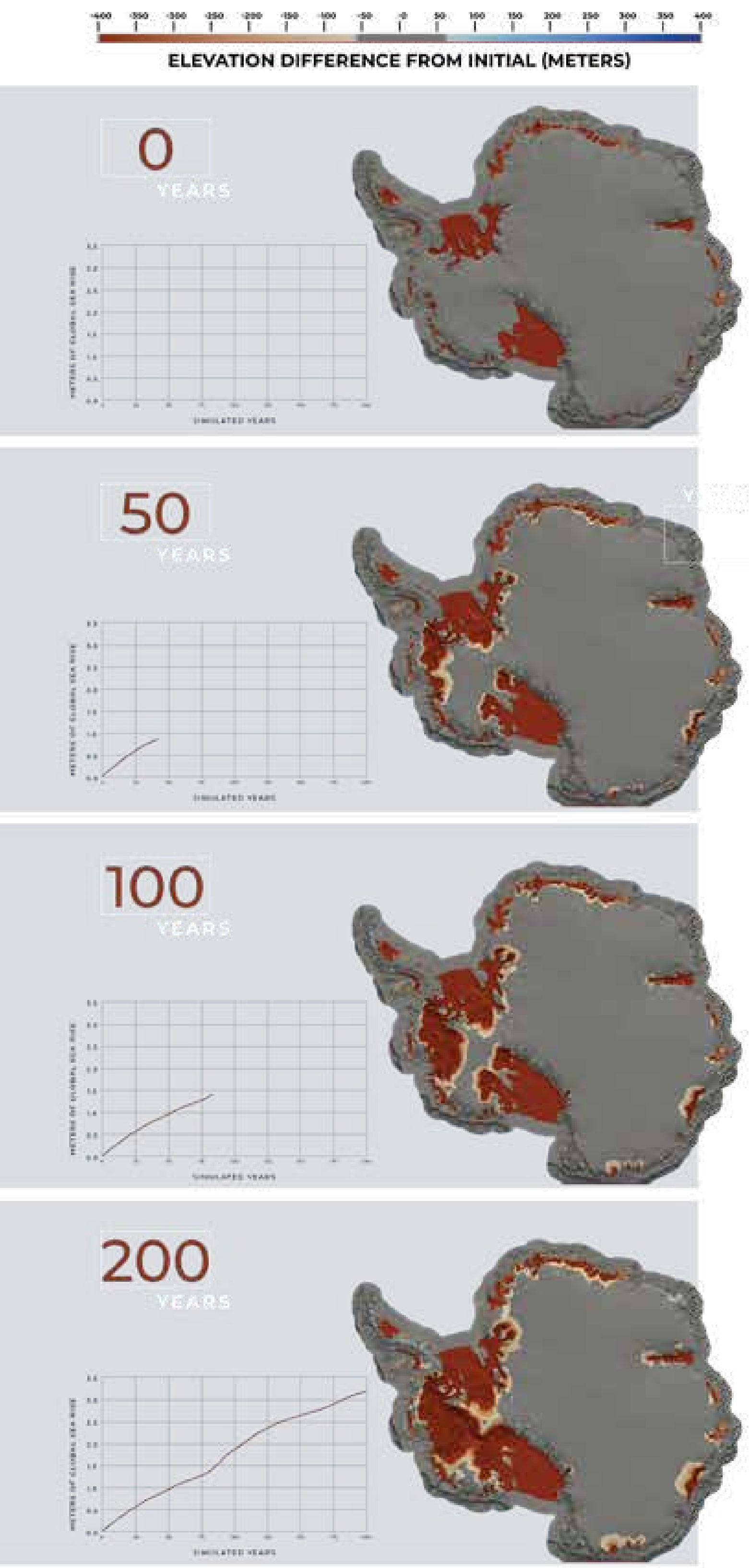
"We had to ask ourselves if we needed to enter this mounding interaction into the model," Rowland says. "Is it important? Well, in this case, that seemingly small dynamic becomes very important." Globally, permafrost holds nearly twice as much carbon as already exists in the atmosphere, so any interaction that speeds up the release of this carbon is vital to understanding the climate future.

NATIONAL SECURITY IMPLICATIONS

Before coming to Los Alamos in 2019 to work as part of the Information Systems and Modeling group, Travis Pitts worked in the U.S. Intelligence Community. "I was focused on the Middle East for a long time, then I turned my attention to security issues in the Arctic," Pitts says. "I started to realize really quickly that, in both of those areas, if I wanted to answer questions about the future of national security I had to involve scientists."

That's when Pitts decided to come to Los Alamos and join the Lab's Climate Impacts on National Security (CINS) team, originally led by Cathy Wilson of the Earth Systems Observations group and now co-led by Pitts and Price. In this role, Pitts has become heavily involved in figuring out how to apply E3SM to national security problems.

Researchers from The Ohio State University and Los Alamos walk across glacially sculpted bedrock near the town of Kangerlussuaq, Greenland, which is a major staging area for international research.



■ The MALI model, developed by Los Alamos, simulates extreme sea-level rise as Antarctic ice sheets melt.

> "Internal instability in one area of the world can lead to instability elsewhere. That's obviously important when we think of national security."
>
> –TRAVIS PITTS

"We've had a vision for a long time about what we want from E3SM," Pitts says. "We want it to focus in on future climate impacts in strategically important areas of the world and to be able to do that frequently and with ease." Doing that could mean simulating the impacts of climate change on important national security infrastructure domestically and internationally.

"It really comes down to looking more closely at strategically important locations and how climate impacts will affect everything from infrastructure to food yields," Pitts says.

Rising sea levels, for example, will likely wreak havoc on U.S. military bases across the world. To understand exactly how bad the danger could be, E3SM, using a model called New Science for Multisectors Adaptation, can simulate rising sea levels in a specific area combined with any number of other factors such as hurricane storm surge and coastal erosion. The simulations can help researchers and policymakers understand if military facilities will become more vulnerable in the future.

Climate change might also lead to conflicts that affect national and global security. In 2010, for example, food shortages caused by drought contributed to uprisings in the Middle East that killed more than 60,000 people.

Looking forward, in the Arctic, melting ice will alter how commercial and military vessels travel near the North Pole. Receding ice may also make currently inaccessible resources, such as oil, accessible. Who does that oil belong to? The answer is complicated because the Arctic falls under the jurisdiction of eight coastal countries. Will competition ensue? What will that competition do to the geopolitical situation?

"Internal instability in one area of the world can lead to instability elsewhere," Pitts says. "That's obviously important when we think of national security."

■ Situated no more than 10 feet above sea level, Norfolk, Virginia, is home to the world's largest naval base. By 2100, the sea level is projected to rise between 2.5 and 11.5 feet.
Photo: U.S. Navy/Christopher Stoltz

To address the interface between humans and the climate, Lab researchers on the CINS team are working with Earth system models to look at food security. For example, by taking historical crop yield data from staple foods (corn, soybeans, rice, and wheat) and cross-referencing those with historical climate data, they can understand how past shifts in precipitation or temperature affect the quantity of crops produced. Once they know that, E3SM can be used to predict future yields based on variations in the climate.

"In the United States, we'll be able to look at changes in crop yields over agricultural hotbeds like those in the Midwest and California, which we know will both experience a high degree of climate change," says Kurt Solander, a researcher with the Computational Earth Sciences group. "Globally, we know that areas like Asia and Africa will also be very susceptible to higher temperatures, and both of those regions grow a lot of food for the world. In a global supply chain, it doesn't matter if as a country you consume a lot of soy or not, because the ripples from the losses in one region of the Earth will touch far beyond."

GOING CLASSIFIED

As an "open source" model, E3SM is available for use by any interested climate researcher. But E3SM and its component models have also been transferred to the Lab's classified computing networks. It might seem odd, at first, to have models that simulate climate change running alongside models that are most often used to simulate nuclear explosions. But, just like the Lab's nuclear weapons work, the Lab's climate work has become essential for national security, and moving E3SM models to classified supercomputers allows researchers to conduct simulations and analysis in specific regions, under specific scenarios, that have national security implications.

"With the model being on the classified system now, we'll be able to answer a lot more questions for a wider variety of clients," Pitts says. "We've already had a lot of interest in E3SM recently."

Hunke agrees. "E3SM allows more detailed calculations to be focused in regions of interest, computed concurrently with the entire, global Earth system," she says. "Now that climate change implications for national security are becoming obvious, E3SM has a clear role in providing the Department of Energy and other agencies the climate prediction capabilities needed for decisive action." ★

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

As climate change becomes an increasingly greater concern for national security, Los Alamos scientists are developing the world's fastest, most extensive, and most accurate models to help the nation take action.

Photo: Dreamstime

Mapping the sting of CLIMATE CHANGE

Shifting environments increase the range of fungi and insects that spread dangerous viruses.

BY JILL GIBSON

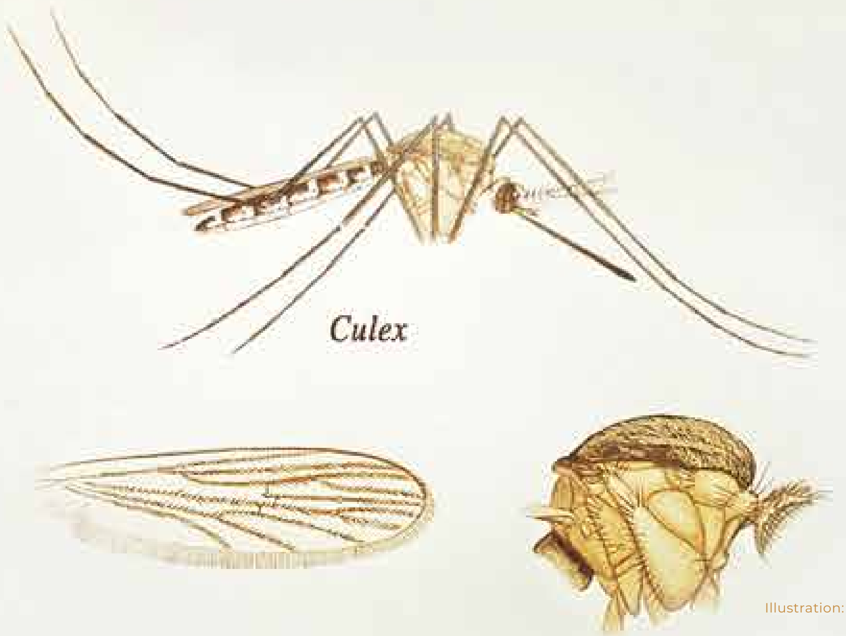


Illustration: CDC

When most people see a forecast for warm weather, they plan for outdoor activities. Los Alamos National Laboratory scientist Andrew Bartlow says warm temperatures remind him that climate change could boost the danger of disease.

"Climate change is a big thing," says Bartlow, who studies West Nile virus, Zika, dengue fever, chikungunya, brucellosis, Q fever, Rift Valley fever, and potential pandemic pathogens, such as coronavirus and influenza. "Places get hotter, drier, or wetter—that's going to shift where diseases are going to pop up."

Understanding how environmental conditions impact emerging disease and learning how to mitigate disease spread is a key part of Bartlow's work in biosecurity and biosurveillance. "We're making sure we can identify pathogens and threats early and quickly so we can have the best possible response," he says.

In 2021, the World Health Organization issued a report calling climate change "the single biggest health threat facing humanity." Los Alamos researcher Morgan Gorris, who is studying how weather and climate affect people, agrees with that assessment.

"The effects of climate change on human health are incredibly important because not only do they affect us directly, like exposing us to more extreme heat events or more flooding events, they also have these indirect effects like allowing more disease vectors to flourish or allowing new diseases to inhabit new locations, so people that weren't exposed to a disease before might become newly exposed to something," Gorris says. "Climate change is expected to increase the number of disease outbreaks and emerging or new diseases."

Even a slight increase in temperature can have a dramatic impact on the environment. Researchers have found that climate change is increasing the danger from diseases carried by insects, such as mosquitoes and ticks. Human population growth is also causing people to encroach into animal habitats leading to disease transmission.

"We really need to be aware of things like Chagas disease," Bartlow says. Chagas is an inflammatory infectious illness once found only in South America, Central America, and Mexico that has now made its way, due to warmer temperatures, to the United States. "The parasite that carries Chagas has already been found in kissing bugs in Texas," Bartlow says. "That's scary to me." Chagas can stay undiagnosed in a patient's bloodstream for more than a decade before causing heart failure and sudden cardiac arrest.

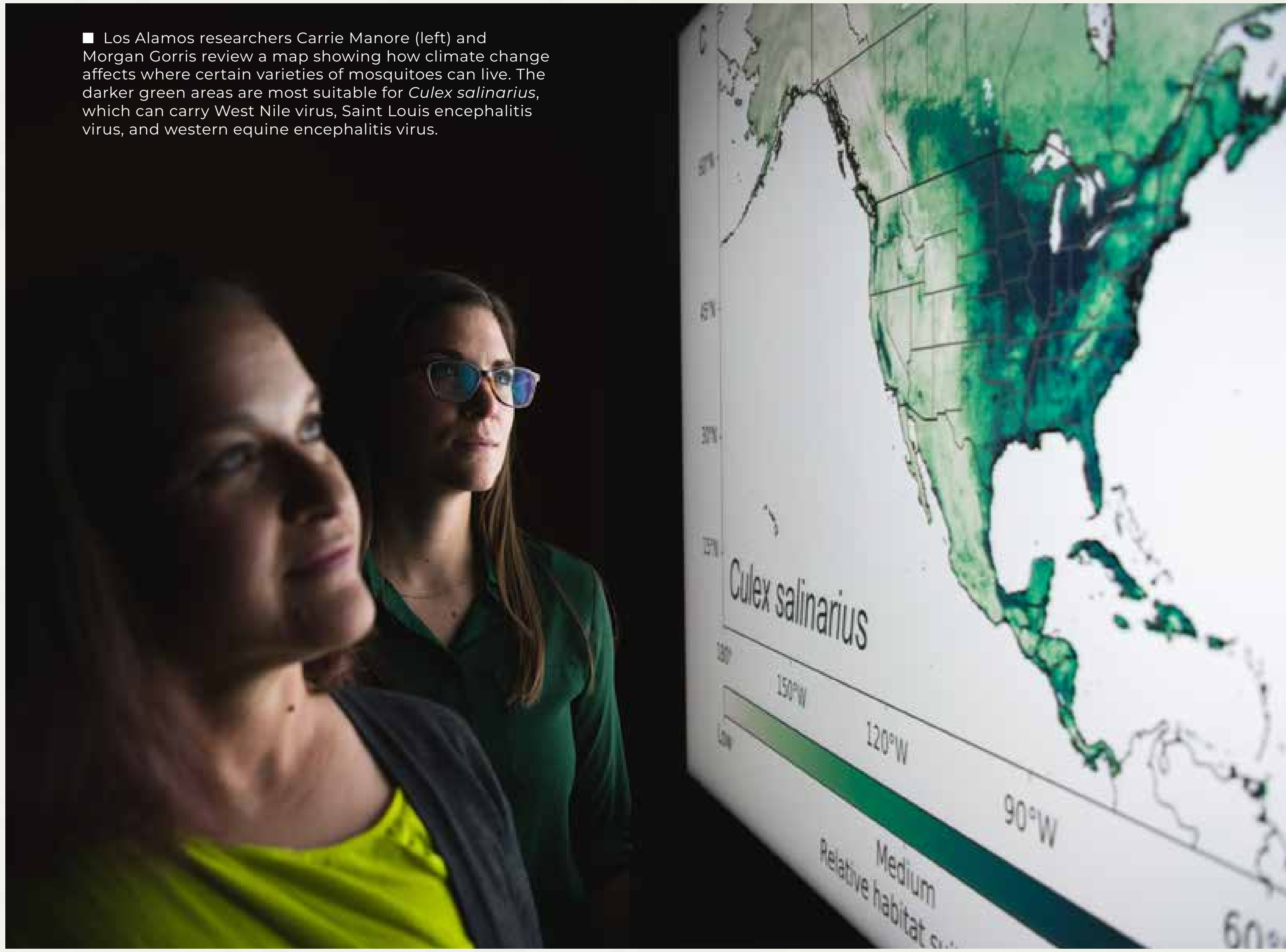
> "Climate change is a big thing. Places get hotter, drier, or wetter—that's going to shift where diseases are going to pop up."
>
> —ANDREW BARTLOW

Modeling a moving menace

Bartlow, Gorris, and their colleagues from the Lab's infectious disease and Earth systems teams focus on vector-borne diseases, such as West Nile and Zika, which are transmitted by blood-sucking arthropods. The scientists' goal is to develop projections for how and when insects will move into new geographical areas. "It's very significant," says Jeanne Fair, of the Lab's Biosecurity and Public Health group. "It's a huge problem for all of us in the temperate regions of the future."

Infected arthropods transmit pathogens when they bite and feed on people. Fair's research shows that mosquitoes and ticks are expanding their ranges and carrying numerous diseases into new environments. In recent years, Lyme disease and other pathogens once limited to certain geographical areas have spread across the country. In 2020, the World Health Organization reported that vector-borne diseases accounted for more than 17 percent of all infectious diseases, causing more than 700,000 deaths annually. A 2018 study by the Centers for Disease Control and Prevention showed vector-borne disease in the United States had increased by 300 percent from 2004 to 2016.

Fair's colleague, Carrie Manore, is an epidemiological mathematician who specializes in modeling mosquito-borne diseases. Manore's work involves compiling information on how temperature, precipitation, humidity, vegetation, human infrastructure, and other factors



■ Los Alamos researchers Carrie Manore (left) and Morgan Gorris review a map showing how climate change affects where certain varieties of mosquitoes can live. The darker green areas are most suitable for *Culex salinarius*, which can carry West Nile virus, Saint Louis encephalitis virus, and western equine encephalitis virus.

affect the way illnesses such as Zika and malaria spread. “Climate change is expected to shift the geographic boundaries of where diseases currently are,” she says. “As temperatures warm, there may be more disease vectors that can start living farther north in warmer habitats; diseases that were once limited to tropical and subtropical areas could now become temperate diseases.”

Manore stresses the importance of collecting data to build accurate mathematical forecasts of how and when these mosquitoes will reach new geographic areas. Preventing disease will only be possible with accurate data, Manore says. “In some cases, we can do a really good job with our forecasting and predicting. And that’s particularly true for diseases where we have good data, like dengue, influenza, and illnesses like COVID-19. There are others where we are limited by data availability. If we have a pathogen that’s kind of rare that we don’t have a lot of data on, the uncertainty around it increases. One of the things we’re working on is encouraging open sourcing of data and working with partners to help us get the data we need to have more certainty.”

Both Fair and Manore say collecting the data, building the models, and tracking the patterns represent essential steps toward disease prevention and protection. “With modeling, you can test mitigations,” Fair says. “Once you have the models coupled, you can look at different scenarios. What if we increased spraying [to kill insects] or irrigated [our crops] differently?”

The models could allow individuals and public entities to adjust accordingly. “You can quantify the risk of certain things,” says Manore. “I can say: Don’t go to this region because this is the hot zone right now, or stay in a house with screens, or wear mosquito repellent,” she notes. “It’s also useful for decision makers and public policy people to say, ‘We are expecting a bad year for Zika, or whatever, and these are the things we can do to impact that risk and hopefully reduce it.’”

“Climate change causes cascading impacts that we don’t even anticipate. We live in one giant ecosystem, and if it gets out of equilibrium, it’s going to impact everything.”

—CARRIE MANORE

D. andersoni

Illustration: CDC

Dodging deadly dust

While climate change has some scientists looking at winged sources of disease flying above them, other researchers are focused on the ground. Increasing temperatures and shifting precipitation patterns are predicted to cause a rise in cases of coccidioidomycosis, or Valley fever. The infectious fungal disease lives in the soil and flourishes in warm, dry climates that undergo periodic drenching rains.

The fungi grow during the wet periods, then break apart into tiny spores that travel in dust. When dust and dirt blow or are disturbed and people inhale the spores, the fungus invades their immune systems. The symptoms vary widely, often mimicking pneumonia or lung cancer. The fungus can also attack a person’s skin, bones, nervous system, and brain. People who aren’t killed by Valley fever often require antifungal treatments for the rest of their lives.

Once seen primarily in Arizona and central California, now, in response to environmental changes, Valley fever may spread across the western United States.

“Our projections show that the disease may extend all the way north to the United States–Canada border by the year 2100,” says Gorris, who notes that although the number of cases is rising dramatically, awareness of the fungal spore illness remains limited, and many cases go undiagnosed.

“One of my main hopes in studying this disease is to increase awareness,” she says. “A lot of folks haven’t heard about Valley fever, but by raising disease awareness among physicians and health care providers, we may be able to reduce the time to a diagnosis, and reduce the time to start treatment, and hopefully improve disease outcomes.”

In the meantime, Gorris hopes that a global effort to slow climate change will also slow the spread of Valley fever. “There is no feasible way to stop the spread of Valley fever by changing our physical environment because the disease is very interconnected with soils and rodents,” she says. “The only plausible way of reducing the spread is to reduce our greenhouse gas emissions and limit climate change.”

As Gorris works with fellow researchers to forecast the spread of Valley fever, she also collaborates with Los Alamos statisticians and epidemiological mathematicians to investigate other fungal diseases that live in the soil. Histoplasmosis and blastomycosis are two more infections that could spread because of climate change.

Coccidioidomycos

Illustration: CDC

“Fungal diseases are something that people don’t talk about much that are pretty terrifying,” Manore says. “Climate change causes cascading impacts that we don’t even anticipate. We live in one giant ecosystem, and if it gets out of equilibrium, it’s going to impact everything.”

Hijacking habitats

Drought, flooding, food insecurity, and unprecedented weather phenomena are displacing people across the globe, leading to widespread migration. According to Bartlow, as climate change drives people to relocate, they are increasingly taking over animal habitats. “Land use has changed from forest to agricultural land and more urbanized areas, and people are encroaching into wildlife habitats. People are going to come into contact with animals and be more exposed to potential pathogen threats.”

Bartlow recalls cases of Hendra virus in Australia. The disease spreads when infected fruit bats urinate and defecate on pastureland where horses graze. The horses become infected and spread the virus to people. Studying diseases that spread from animals to humans, called zoonotic diseases, is an important part of mapping the impact of climate change. “We still need to understand more, and that will help with the modeling and then ultimately mitigation,” Bartlow says. “So I think we’re at the point right now where we know a lot about these things, but we need to do more.”

Gorris echoes these concerns and emphasizes the urgency of this research. “The more humans interact with their natural environment, and the more we expand into undisturbed lands as we’re building out and creating more urban areas, the more we risk these chances of spillover and creating new diseases in the human population.”

But increasingly populated areas aren’t the only places that pose a threat. Thawing arctic permafrost poses yet another reason climate change could lead to disease outbreak. Bartlow says he fears that harmful bacteria and diseases once frozen in the earth are defrosting as temperatures rise. “We’re actually working on some proposals to do biosurveillance in Arctic regions where permafrost is thawing,” he says. “We want to be actively

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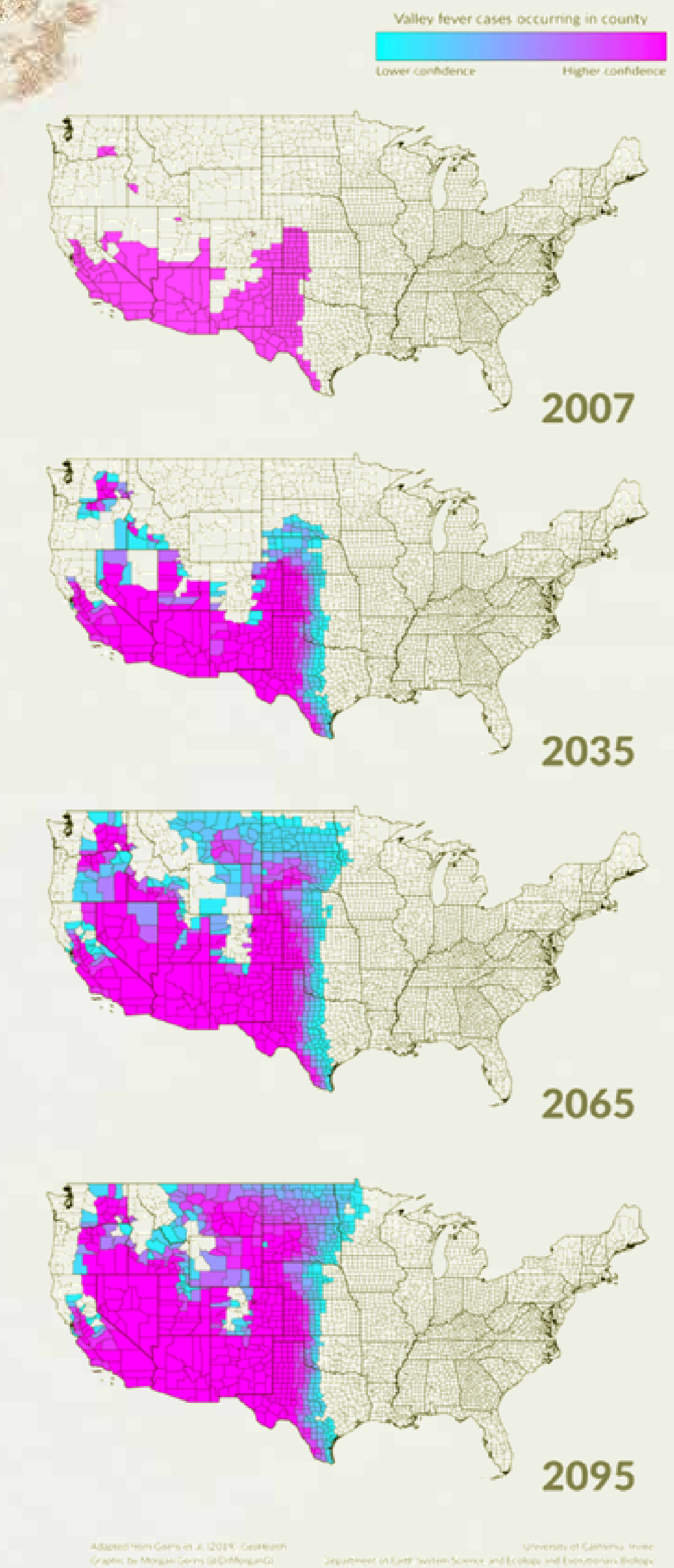
Watch an animation of the graphic below.



Jeanne Fair (right), a Los Alamos biosecurity and public health researcher, visits with Mumen Alrwashdeh, a Jordanian colleague, during an April 2022 research trip to the Azraq Wetlands in Jordan. The team hopes to learn about migratory birds that transmit diseases to humans.

surveilling these areas where things could come out such as anthrax, for example. There have been some outbreaks in Siberia recently that came from bacteria in thawing permafrost that got into reindeer populations and then in humans. It's a big worry."

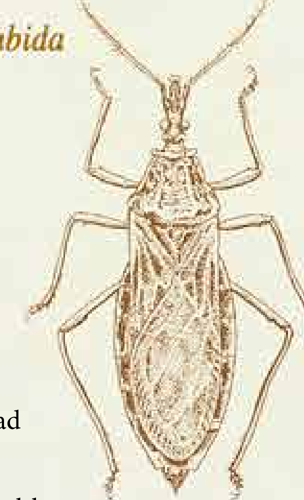
Another worry is diseases that haven't posed a threat to humans for a century or more. Frozen victims of smallpox and the 1918 flu virus may be buried in the thawing permafrost. "There will definitely be some of these pathogens that are now getting exposed, and potentially some of them may be ones that we haven't had around in a long time," Fair says.

> "It may seem funny to think of human health as a national security concern, but it is. If we can't protect the health of our own nation, we create instability and a vulnerable population."
>
> —MORGAN GORRIS

Although the threat lurking in thawing permafrost might not be as imminent as that posed by migrating mosquitoes, Bartlow and Fair believe it's worth investigating. "We don't really know what's out there," Bartlow points out. "Just think of things that could be in there in the permafrost, thawing and then being released. That's why we want to go up there and actually do active surveillance—so we can be prepared."

Preparing to prevent pandemics

The desire to prepare for environmental changes and their impacts on disease spread motivates many Los Alamos scientists to continue their research. "The opportunity to work with health officials and epidemiologists to inform folks where these diseases might be a risk makes me feel like I'm contributing to my community and helping," Gorris says.



Triatoma rubida
Illustration: CDC

Manore agrees, stressing the need for continued research. "Investing in strategic public health research that keeps people healthy by preventing and catching things early is how we reduce mortality and morbidity," she says. "Our data and models help quantify risk for people and really informs them."

Part of preparation involves collaborating with scientists around the world. "Diseases do not respect borders," says Manore, who cooperates with researchers in Ecuador, Brazil, and Mexico.

Bartlow and Fair are working with partners in Georgia, Jordan, Kenya, Tanzania, Rwanda, Uganda, and Ukraine to help researchers in those countries learn how to extract and sequence RNA and DNA to identify pathogens. "Having these systems set up in all parts of the world is super important," Bartlow says. "We give other researchers the tools, we train them, and we have a shared goal of preventing pandemics. If they identify something, they can do the necessary mitigation strategies in their own countries. But with globalization, things spread much more quickly. We are really trying to understand ecological health security," he concludes.

Fair says that the COVID-19 pandemic offers a lesson about global interconnection. "A threat anywhere is a threat everywhere," she notes. "As we have environmental change caused by climate change, then that's only going to potentially exacerbate the connectedness of threats."

At the International Livestock Research Institute in Nairobi, Kenya, scientists, including a team from Los Alamos, research the spread of infectious zoonotic diseases such as Rift Valley fever.

The scientists also agree that the importance of studying the connection between climate change and disease spread cannot be overstated.

"It may seem funny to think of human health as a national security concern, but it is," Gorris says. "If we can't protect the health of our own nation, we create instability and a vulnerable population."

Fortunately, according to Fair, Los Alamos National Laboratory has access to both the experts and technology to tackle this issue. "When we think of climate change and infectious diseases, a multitude of complex systems come together. Studying really complex systems requires a very collaborative, multidisciplinary effort. It can only be done at a lab like Los Alamos."

With this collaborative research, the scientists say they have the power to make a difference. Gorris notes that her work offers reassurance that positive change is possible.

"When we looked at the projections of Valley fever in response to climate change, we looked at a high greenhouse gas emission and high climate warming scenario, but we also looked at a moderate greenhouse gas emission and moderate warming scenario. What we found was limiting the amount of greenhouse gas emissions limited the spread of Valley fever. So, ultimately, reducing greenhouse gas emissions could reduce the number of Valley fever cases. And I think that's a very important point to take home. It's not all doom and gloom." ★

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

Researching the climate change–driven spread of infectious diseases will help identify ways to reduce threats and protect human health.

THE ENERGY BENEATH US

The Los Alamos Hot Dry Rock Program proved that heat could be extracted from deep inside the Earth and used for power.

BY WHITNEY SPIVEY

■ The geothermal features in the Sulfur Springs area of the Valles Caldera National Preserve are signs of a dormant (but not extinct) volcano in the mountains of northern New Mexico.

■ The Valles Caldera National Preserve is the only place in New Mexico with geothermal features such as mud pots—boiling pools of mud—and fumaroles.

BOILING MUDPOTS, STEAMING FUMAROLES, BALMY HOT SPRINGS. These hydrothermal features are reminders that heat lurks just below the Earth's surface in and around northern New Mexico's Valles Caldera—a 13-mile-wide depression in the otherwise rugged Jemez Mountains. The caldera was formed by several powerful volcanic eruptions, most recently at about 1.25 million years ago.

So perhaps it's no surprise that, back in the 1970s, when researchers at Los Alamos Scientific Laboratory were searching for a location to test out their Hot Dry Rock Program—their idea to extract heat from deep inside the Earth to create energy—they looked no farther than the western edge of the Valles Caldera.

"Without the means to explore far and wide, they went looking 'just over the hill' west of Los Alamos, in the Jemez Mountains," remembers Laboratory engineer Donald Brown in his 2012 book *Mining the Earth's Heat: Hot Dry Rock Geothermal Energy.* "The Los Alamos team reasoned that recent volcanic activity … would have produced a region of elevated temperature that would extend radially outward from the caldera at least several miles."

But the scientists weren't interested in the mud pots, fumaroles, hot springs, or any other hydrothermal phenomena that bubbled up from natural reservoirs just below the surface. Instead, they were interested in engineering a geothermal reservoir, much, much deeper underground.

Why? Because they believed that one of the world's greatest untapped energy sources was right beneath their feet.

Energy underfoot

Hot dry rock generally refers to a type of rock found almost everywhere below the Earth's surface. As the phrase implies, this rock is hot—hundreds of degrees Fahrenheit, due to its location deep underground—and dry, meaning that it is nearly impervious to fluids. Hot dry rock does not contain water nor does it absorb water that comes in contact with it.

Hot dry rock is found at different depths all over the world. In areas with high geothermal activity, such as parts of northern New Mexico, hot dry rock might be closer to the Earth's surface and therefore more easily reachable to humans, should they choose to access it.

"The natural heat in hot dry rock at accessible drilling depths is one of the largest supplies of usable energy that is available to man," Los Alamos scientist Morton Smith wrote in *The Furnace in the Basement: The Early Days of the Hot Dry Rock Geothermal Program, 1970–1973.* "It is potentially capable of satisfying the world's total energy needs for thousands of years."

The natural heat in hot dry rock at accessible drilling depths is one of the largest supplies of usable energy that is available to man."

—MORTON SMITH

Conceptually, extracting heat from hot dry rock is simple. A borehole is drilled a few thousand feet into the Earth. When the borehole is at a depth with sufficiently high temperature rock, water from the surface is injected into the borehole at a pressure high enough to fracture the rock at the bottom of the hole—a process called hydraulic fracturing. The resulting fracture system creates a fluid reservoir.

Although the location, shape, size, orientation, and growth of the reservoir are controlled by local geological conditions, they can be determined from monitoring the fracture process. As the rock fractures, microseismic waves (aka very small earthquakes) are generated. These microseismic waves can be detected and recorded by seismic instruments. Using the resulting seismic data, scientists can estimate the reservoir's location and approximate dimensions.

After this analysis, a second borehole is drilled to intersect the fluid reservoir. If the drilling is successful, the two boreholes and the reservoir create an interconnected fluid system underground.

The next step is to extract geothermal heat. A high-pressure injection pump circulates water down the injection borehole, into the fluid reservoir. There, the water heats up through contact with the surrounding high-temperature rock. The water then flows up the second borehole, which is called the production borehole. En route to the surface, the

■ Spence Hot Springs are located about 30 miles west of Los Alamos in the Jemez Mountains.

hot water must be kept at a pressure high enough to keep it from flashing to steam.

At the surface, the hot water flows through a heat-exchanger. The heat is used as energy, and the cooled water is recirculated. The process repeats.

Hot dry rock contains "a truly international energy supply that, if it could be brought to the surface at useful temperatures and reasonable cost, would be a major source of energy for every country in the world—including those that lack all other indigenous energy supplies," Smith summarized. "In an environmentally concerned world, this should make it a very desirable energy source."

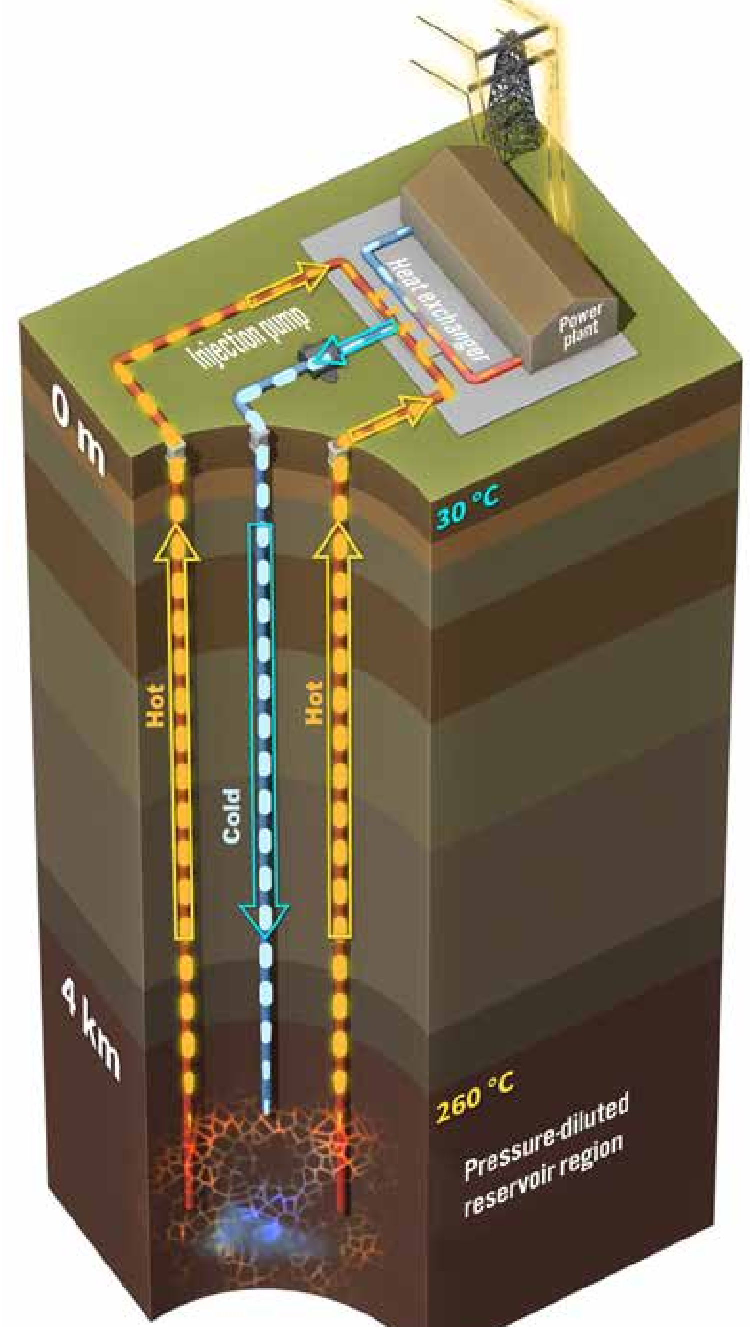
Hot Dry Rock at Los Alamos

The concept of mining heat from hot dry rock was devised by Smith and others from Los Alamos in the early 1970s. The initial Hot Dry Rock (HDR) Program was "informal in every respect, including financial support, and was carried on largely on a volunteer basis," Smith wrote. Those who contributed did so out of pure curiosity and in their own free time. No one had any direct experience with geothermal energy, but they became almost-experts in geology, geophysics, hydrology, drilling, rock mechanics, hydraulic fracturing, and related areas. Even legendary Los Alamos physicist Frank Harlow (the founder of computational fluid dynamics) got involved by modeling the efficiency of heat extraction from a hot dry rock reservoir.

Eventually, their findings were sufficient to garner support and funding from the Laboratory and later from the Atomic Energy Commission (AEC, the predecessor to the current Department of Energy, or DOE).

In December 1971, with permission from the U.S. Forest Service, the not-yet-official Los Alamos "geothermal group" began drilling shallow (approximately 600-foot-deep) boreholes on national forest land near the western rim of the Valles Caldera. After measuring geothermal gradients—the rate at which temperature changes with depth—in these holes, they concluded that, using modern drilling equipment, hot dry rock should indeed be accessible anywhere in that area.

So, the group members decided to drill a deeper hole, which would help them further their understanding of local geology, hydrology, and heat flow. They chose Barley Canyon, near present-day Fenton Lake State Park, for Geothermal Test Well No. 1 (GT-1). Drilling began on May 9, 1972. "Because no deep holes had ever been drilled in the area in which we were drilling

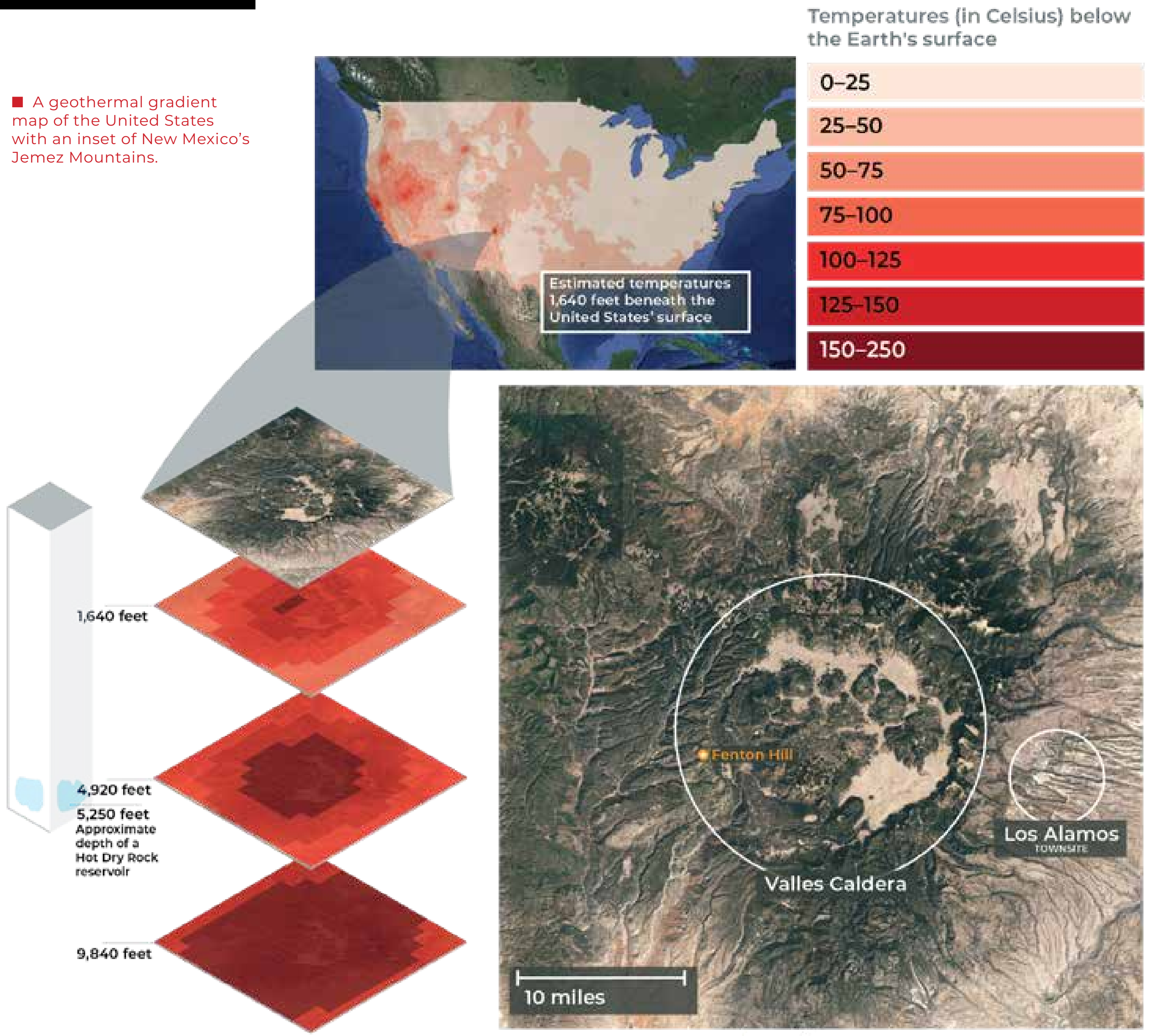


■ "Any time you have an underground chamber and you're trying to understand how fluids move around and get out of the reservoir, those are problems of a reservoir engineer," says Hugh Murphy, a reservoir engineer who led the entire HDR Program from November 1986 to December 1988.

GT-1, nobody knew exactly how far down it was to the top of the [hot dry rock]," Smith wrote.

Fifty-two days later, the group had an answer. The hole was 2,575 feet (nearly a half mile) deep, with the bottom 470 feet in hot dry granitic rock, which was at a temperature of about 210 degrees Fahrenheit.

GT-1 experiments, many of them having to do with hydraulic fracturing, began in February 1973. "We were handicapped by subfreezing temperatures,



■ A geothermal gradient map of the United States with an inset of New Mexico's Jemez Mountains.

several heavy snowfalls, and the fact that—in undertaking novel and difficult experiments—not everything worked the first time we tried it," Smith wrote. "However, we accomplished most of the things that we had set out to do, and our results were sufficiently encouraging to justify support for later and more elaborate experiments."

Among the most important findings from the GT-1 experiments was that hot dry granitic rock is not homogeneous. The group had expected to hit only hot dry granite, but it was rather a patchwork of granite, gneiss, and amphibolite.

The group also discovered that hot dry rock is not isotropic—identical in all directions. The rock has joints—cracks—that have been sealed over the years by mineral deposits or heat. Instead of breaking the hot dry rock apart, hydraulic fracturing actually causes the joints to open. Therefore, the resulting reservoir is not a single fracture but rather a network of joints intersecting other joints—a "dendritic [branched] pattern of interconnected joints," according to Brown.

Alternate energy needs

As the Los Alamos team was dipping its toes into hot dry rock, the United States was being subjected to an oil embargo by oil producers in the Middle East. "All of a sudden, there were lines at the gas station," remembers Leigh House, a now-retired Laboratory seismologist who worked on the HDR Program. "It was seen as a time of energy shortage, and so there was interest in finding alternatives to oil and gas."

In 1971, the United States Congress directed the AEC to assume responsibility for all research related to energy supply, conversion, distribution, and storage. "The U.S. was becoming aware of the limitations of its conventional energy supplies and the environmental problems that resulted from their exploitation; the AEC had been directed to do something about those limitations; and the AEC was now informed that one of its major laboratories was ready to undertake the development of a new, essentially inexhaustible, environmentally benign, domestic energy supply," Smith explained. "So far as we were concerned, the timing of all this couldn't have been better."

An October 1972 letter from the AEC to Los Alamos Director Harold Agnew authorized the Laboratory "to initiate work in general energy development areas" with the broad goal of "turning over to industry viable technologies, or as mutually agreed to, the final development of technologies." By fiscal year '73, money for the Los Alamos Hot Dry Rock Program began to roll in, which meant more experiments and more drilling (at millions of dollars per hole, drilling was by far the most expensive part of the Hot Dry Rock Program).

Because of limited space and muddy conditions in Barley Canyon, a new location was necessary. Fenton Hill, less than two miles southwest of Barley Canyon, was chosen. The Forest Service transferred management of the 20-acre property to the AEC, which then contracted Los Alamos to operate it. The mesa-top site, located off paved State Highway 126, was accessible to heavy equipment and close to existing power lines. And because a wildfire in 1971 had destroyed most of the trees, no vegetation had to be removed to set up shop.

Drilling begins

Reaching rock at a suitably high temperature at Fenton Hill involved first drilling through volcanic tuff near the surface and then through a layer of limestone before encountering granitic rock, which was the drilling target.

Drilling through any type of rock relies on pulverizing the rock below the drill bit. Getting the pulverized rock fragments out of the way of the drill bit requires circulating a fluid down the drill string and back up and out of the borehole. If fluid circulation is lost, the

■ Clockwise from left: Don Brown, Bob Potter, Bob Mills, B.B. McInteer, Morton Smith, John Rowley, and Dale Armstrong—many of whom were involved in the Hot Dry Rock Program.

■ Los Alamos scientists Morton Smith and Francis West examine a core sample taken from a depth of 13,700 feet at the Fenton Hill geothermal test site.
Photo: AIP Emilio Segrè Visual Archives

progress of the drilling stops, and the drill string may get stuck in the borehole.

Over centuries, the limestone beneath Fenton Hill has been partly dissolved by fluids (such as rainwater and snow melt) and is characterized as "cavernous." And so, perhaps not surprisingly, on multiple occasions the drilling process lost fluid circulation while getting through the layer of limestone. "They were basically drilling into large caves," recalls Los Alamos geophysicist Scott Phillips. "When you're drilling, you have fluid moving around, and the fluid is contained. If you hit a cave, the fluid is gone, which is a tough drilling problem." Stopping the drilling to fix a lost-circulation problem is expensive, as a drill rig costs thousands of dollars a day to lease and operate.

To solve the problem, everything from trees to walnut shells to shredded tires were thrown downhole to try to regain fluid circulation. "Drillers get desperate sometimes and pretty ingenious," House says. "We might have done better pumping dollar bills down the well to fix the lost circulation zones."

Eventually the drill pressed on, and on December 9, 1974, Geothermal Test Well No. 2 (GT-2) was completed. The hole stretched 9,619 feet (1.8 miles) into the ground, and the temperature at the bottom was 386 degrees Fahrenheit.

"Soon thereafter," Brown wrote, "a favorably oriented joint was opened by hydraulic pressurization near the bottom of GT-2" and a second borehole, Energy Extraction Hole No. 1 (EE-1), was drilled.

However, 18 months after the second hole was completed, researchers had failed to establish a satisfactory connection between the two wells. They decided a new course of action was necessary.

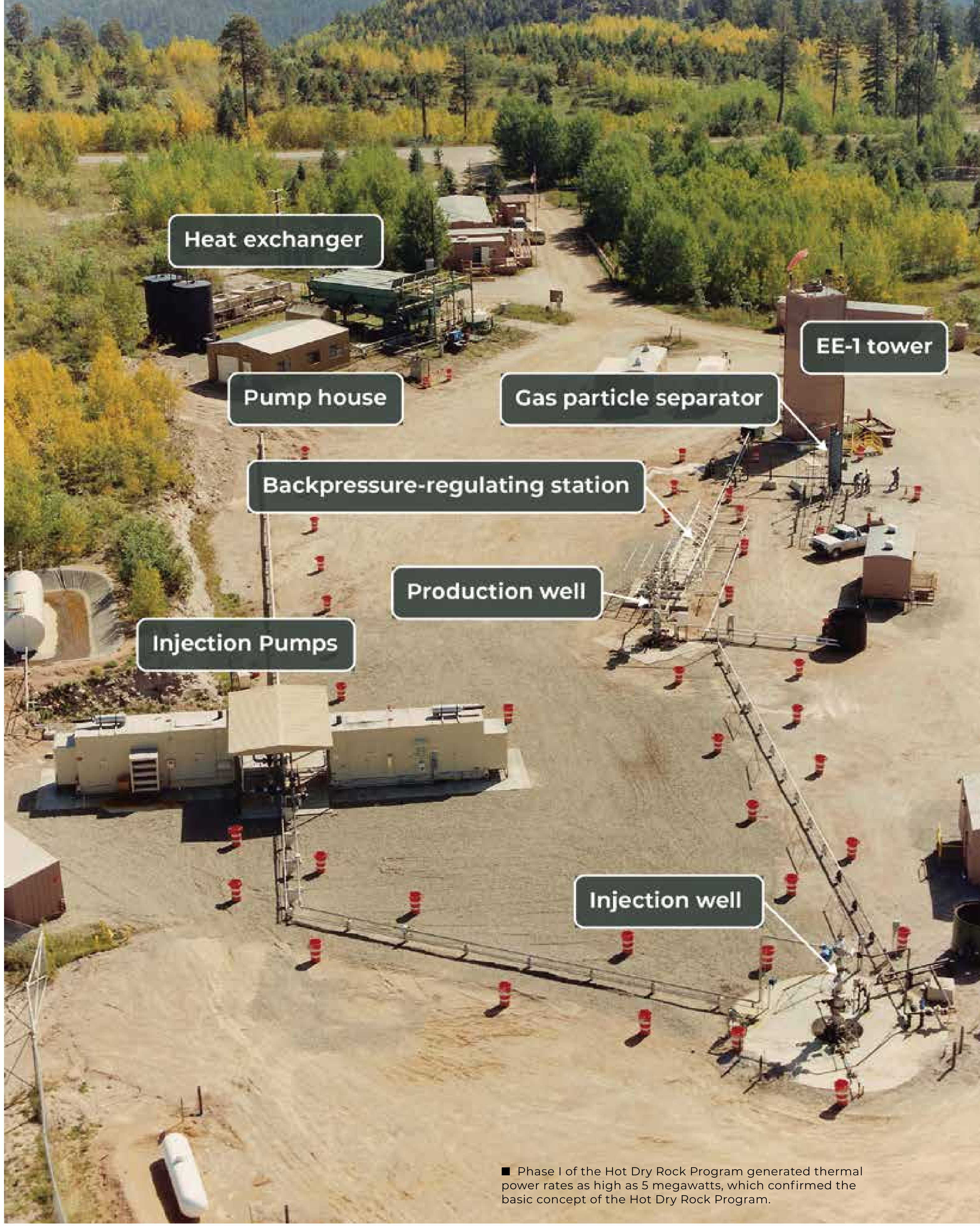
"Thus, there was no longer any alternative: If an adequate flow connection was ever to be achieved, one or the other of the two deep boreholes would need to be redrilled," Brown explained. Between December 1976 and March 1977, a series of experiments took place to determine which hole would be modified, and which direction it would go. (At this time directional drilling, especially in the hard granitic rock, was a relatively new technology. According to Phillips, "the strange combination of oil patch drillers and egg heads" figured it out as they went along.)

In the end, the lower portion of GT-2 was redrilled twice, directionally, giving it legs: GT-2A and GT-2B. With continued hydraulic fracturing and seismic monitoring, a reservoir connection was finally achieved, and the first hot dry rock system was established. A fluid circulation system operated until late 1979 and generated thermal power rates as high as 5 megawatts, which confirmed the basic concept of the HDR Program.

Phase II

A second HDR system—called the Phase II system—was then planned to produce power at a larger scale, more similar to a commercial power plant. This

> The earth is a complicated system; it doesn't always do what you want it to do."
>
> —MIKE FEHLER



■ Phase I of the Hot Dry Rock Program generated thermal power rates as high as 5 megawatts, which confirmed the basic concept of the Hot Dry Rock Program.

meant drilling deeper (nearly three miles) to reach hotter rock and hopefully establishing a reservoir large enough to extract more heat.

However, around this time, "the oil and gas industry became very busy," House explains. "Drill rigs became very expensive and very in demand. We worried if we released our leased drill from the Fenton Hill site, we might not be able to get it back in time to carry on the program," House says. "So we decided to drill *both* holes early on and *then* try to establish the reservoir between them."

He pauses. "That decision came back to bite us."

Scientists expected that the hydraulic fractures would be simple, largely planar features that would intersect both holes, EE-2 and EE-3. After many unsuccessful attempts to create a fluid connection between the two wells, the HDR Program decided that better seismic monitoring of the hydraulic fracturing was needed.

With additional monitoring in place, in December 1983, 21,600 cubic meters of water (more than eight Olympic-size swimming pools) were injected during a hydraulic fracturing operation that still failed to establish the needed fluid connection between the two holes. However, analysis of the newly acquired microearthquake data finally showed the reason for the many failed attempts. Rather than the fracture system extending oblique to the trajectories of the two holes, it was oriented nearly parallel to them.

"The earth is a complicated system; it doesn't always do what you want it to do," says Mike Fehler, a seismologist who started working on the program as a graduate student in 1974. "That's what makes it interesting, challenging, and frustrating."

Results from analysis of the microseismic data were used to plan the path for redrilling one of the wells. After the redrilling, which required careful directional drilling, several more hydraulic fracturing attempts were carried out. Finally, the long-sought connection between the two wells was achieved in early 1985.

Despite the various setbacks, Fehler says the team's spirits were always high. "We had parties all the time," he remembers. In May 1985, Brown threw a "Thank God it's Connected Party" at his home to celebrate the success of Phase II.

Both HDR systems at Fenton Hill operated for almost a year each. Thermal power production ranged from 4 to 10 megawatts, "proving beyond a doubt that it is technically feasible to recover useful amounts of thermal energy from HDR," wrote Brown, who noted that at the time of his writing in 2012, the reservoirs at Fenton Hill were the only true hot dry rock reservoirs anywhere in the world.

> "In addition to the pioneering work on drilling and fluid technologies, we did something no one else had been able to do up to that point in terms of the rate we could collect seismic data."
>
> —LEIGH HOUSE

An important attribute of a usable hot dry rock reservoir, Brown explained, is that the reservoir is confined—the pressurized water is totally contained within it. This is in contrast to a natural hydrothermal system, such as California's The Geysers, which is the largest complex of geothermal power plants in the world and draws steam from already existing natural reservoirs. The number and locations of natural geothermal systems world-wide is quite limited. A major appeal for an engineered system, such as Hot Dry Rock, is the ability to exploit geothermal energy in many more places.

■ Geothermal research is conducted by Los Alamos researchers in the Jemez Mountains west of Los Alamos, New Mexico.
Photo: AIP Emilio Segrè Visual Archives

The Hot Dry Rock site at Fenton Hill in 1991.

The end of an era

"Hot Dry Rock went on for a long time, and it died a slow death," Fehler says. "It would be slated for dissolution, and then New Mexico Senator Pete Dominici would rescue it." DOE finally stopped funding the program in 1995.

After nearly a quarter century of existence, the boreholes at Fenton Hill were plugged and the site was remediated. House remembers the program with a mix of satisfaction and frustration. "In addition to the pioneering work on drilling and fluid technologies, we did something no one else had been able to do up to that point in terms of the rate we could collect seismic data," he remembers. "We recorded and located more than 20,000 seismic events, most of which were about a magnitude −2 or −3. Even the tiniest events helped show the boundaries of the fractured fluid system."

Geothermal energy today

In the years since the Los Alamos HDR Program, researchers in Australia, France, Germany, Japan, Sweden, Switzerland, and the United Kingdom have experimented with their own hot dry rock programs, all with positive results. (British, German, and Japanese scientists were involved in the Los Alamos HDR Program.)

Yet, "in spite of its enormous potential, the geothermal option for the United States has been largely ignored," according to a 2006 study by researchers at the Massachusetts Institute of Technology (MIT). "This has led to the perception that insurmountable technical problems or limitations exist."

The MIT team delved into these problems and limitations and concluded that "while further

Joe Skalsky, manager of the Fenton Hill Site, cooks a steak using the Earth's heat.

■ The Utah FORGE project.
Photo: Eric Larson

> HDR researchers over the next 20 years will look back at the pioneering work done at Los Alamos National Laboratory and ask only why it took so long for the country to finally discover HDR."
>
> —DON BROWN

advances are needed, none of the known technical and economic barriers… are considered to be insurmountable." Not to mention that drilling knowledge and technology have greatly improved since the Los Alamos HDR days, which would likely reduce costs. Seismic technology has also improved, so reservoir mapping would likely be more accurate.

Today, the conversation is starting to shift. Climate and clean energy are back on DOE's radar. The hot dry rock—now called the enhanced geothermal system, or EGS—concept is back on the table as an option for sustainable energy.

At Los Alamos, current geothermal research includes EGS modeling and monitoring, imaging of hydrothermal reservoirs, and developing machine learning applications in support of geothermal energy.

Farther afield, the DOE Frontier Observatory for Research in Geothermal Energy (FORGE) initiative has awarded a $220 million grant to the University of Utah to establish an underground EGS laboratory in Milford, Utah. Researchers from all over the world can utilize the site at Utah FORGE to develop and test EGS technologies, including those having to do with drilling, instrumentation, reservoir stimulation, flow testing, data collection, and data dissemination.

"In a nutshell, we are working on procedures for creating a geothermal system where none exists naturally with the long-term goal of making EGS technologies both replicable anywhere in the world and commercially viable," says Joseph Moore, the managing principal investigator for Utah FORGE. "Already, significant progress toward reservoir creation in low permeability rocks has been achieved by merging ideas developed at Los Alamos more than four decades ago with advances in drilling and fluid extraction technologies developed by the oil and gas industries."

According to DOE, EGS could one day result in commercially deployable systems that might collectively produce more than 100 gigawatts of electrical power. For context, 1 gigawatt—or 1 billion watts—is the amount of energy generated by approximately 3 million solar panels or 430 wind turbines. One gigawatt will power 110 million LED lights or 9,000 Nissan Leaf electric automobiles. More than 100 gigawatts could easily power 100 million homes.

In 2012, Brown reflected that "HDR researchers over the next 20 years will look back at the pioneering work done at Los Alamos National Laboratory and ask only why it took so long for the country to finally discover HDR."

Ten of those 20 years have passed. But HDR—now in the form of EGS—appears to be on the cusp of a renaissance. "The Los Alamos HDR Program was a pioneering effort that paved the way for all subsequent EGS projects," Moore says. "If EGS can be developed, the potential for this type of renewable energy is multifold." ★

TAKEAWAY

BETTER SCIENCE = BETTER SECURITY

The Los Alamos Hot Dry Rock Program proved that heat from the Earth could be harnessed for power. The program paved the way for modern-day geothermal work that may one day help power hundreds of millions of homes around the world.

STUDYING, LEARNING, CONTRIBUTING

Whether he's navigating the outdoors or complicated technical information, Marvin Adams, the new head of Defense Programs, demonstrates a steady, academic, and team approach to challenges.

BY WHITNEY SPIVEY

Last summer, Marvin Adams backpacked 560 miles through California on the Pacific Crest Trail. "My youngest son was with me all the way, and my eldest son joined us for the first 125 miles," he says of the trek from Dunsmuir to Tuolumne Meadows.

This summer looks a little different for the former Texas A&M nuclear engineering professor. In April, Adams was confirmed by the United States Senate as the deputy administrator for Defense Programs of the National Nuclear Security Administration (NNSA) at the U.S. Department of Energy. In this role, Adams oversees programs for the design, maintenance, assessment, manufacturing, and dismantlement of all U.S. nuclear weapons. He's also in charge of related programs that develop and maintain all the science, engineering, technology, supply-chain, and manufacturing capabilities associated with the U.S. nuclear stockpile.

The new job is a natural progression for Adams, who is considered by many to be America's top academic expert on the stewardship of the nuclear stockpile and who has for decades served in advisory roles at Los Alamos, Lawrence Livermore, and Sandia national laboratories.

Earlier this year, Adams spoke to *NSS* about his career path and his new role at NNSA.

After earning three degrees in nuclear engineering, you worked at Lawrence Livermore National Laboratory and then, in 1992, began teaching at Texas A&M. Why did you decide to transition into education?

At Livermore, I worked as a code developer in the nuclear weapons program. An important factor in my decision to work there was my belief that I benefited from deterrence and my conclusion that I should therefore be willing to contribute to maintaining the deterrent. When I started at Livermore, I had already formed a positive impression of national laboratories, having spent time as a student at three labs, and this impression has only grown stronger. I view the national laboratories as national treasures, and I think they are outstanding places for people who want to help solve important problems.

While I greatly enjoyed my work at Livermore, I always had in mind the possibility of returning to academia after several years of learning and growing at the lab. One reason was the joy of those "light-bulb" moments when students grasp exciting, important, fascinating concepts. Another was the freedom to work on any interesting problem for which I could find support, including the freedom to participate in service related to national security. Texas A&M offered the opportunities I sought, and as a bonus was much closer than Livermore to our extended family.

What advice do you have for young people who are interested in working as scientists or engineers at one of our national laboratories?

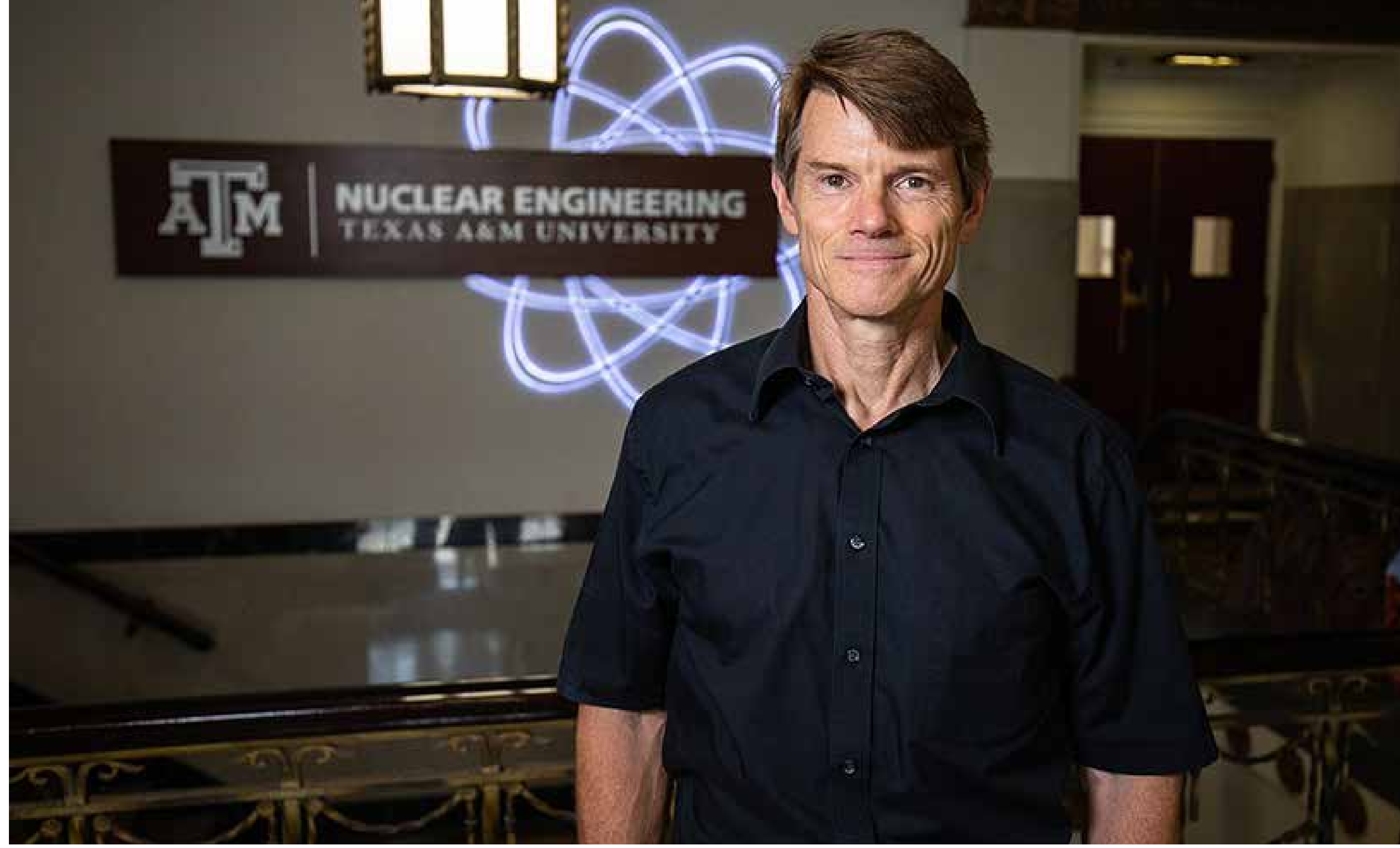
Focus on becoming a technical expert with deep knowledge in your field, but also learn about activities and unanswered questions in other fields. Stay conscious of uncertainties, for example in the quantitative understanding of how a complex natural or engineered system operates. Learn how to communicate technical truths, including the reality of uncertainties, to people in different fields and to nontechnical audiences.

During your time at Texas A&M, how did you stay involved with the national labs? Is there a committee, advisory group, or professional society that was particularly meaningful for you?

During my first decade in academia, my interactions with the national labs were almost entirely technical, as I collaborated with laboratory researchers to develop improved computational physics methods. In the past two decades, these technical collaborations have continued, but most of my involvement has become participation in review committees, advisory panels, oversight committees, and in-depth study groups. My participation in the Jason [independent scientific advisory] group has been particularly meaningful because I think the group provides significant value to the country. Jason work has also required and enabled me to learn about many aspects of national security.

You are the new deputy administrator for Defense Programs. How will you lead this branch of the NNSA?

A partial answer is that I will emphasize teamwork. Defense Programs is a huge, diverse team that must overcome daunting challenges in the next few years to deliver long-awaited results on which national security depends. Success requires capable team members who are motivated to expend great effort. Leaders can help to foster the necessary motivation and sense of shared purpose. I want individuals to understand what they must do, how it contributes to national security, and why it is worth significant effort. I want them to see that their leaders value their opinions and contributions. I want team members to anticipate the excitement and satisfaction they will gain when the team succeeds at its difficult, important missions.



▲ Adams has served on the President's Council of Advisors on Science and Technology, the Stockpile Assessment Team of the U.S. Strategic Command Strategic Advisory Group, the National Academies Committee on International Security and Arms Control, and the Predictive Science Panel for Livermore and Los Alamos national laboratories. For Los Alamos, he also chaired the Mission Committee and served on the Science, Technology, and Engineering Committee. At Texas A&M, Adams was the HTRI Professor of Nuclear Engineering, a Regents Fellow, and the director of National Laboratories Mission Support for the Texas A&M University System. He is a fellow of the American Nuclear Society.

U.S. Secretary of Energy Jennifer Granholm called you "the nation's foremost academic expert on safeguarding our nuclear stockpile." How does one become an academic expert on safeguarding the stockpile, and how has this experience prepared you for your new role?

Just over two decades ago I started encountering and accepting opportunities to serve on committees that reviewed and advised on stockpile work at the three nuclear-weapons laboratories. I studied and learned a great deal about the stockpile, and stewardship thereof, from this work. This began a cycle: an opportunity to serve required studying, learning, and contributing, which led to more opportunities, and so on. This cycle has continued through the present time. I am grateful for these opportunities and grateful to the many people who have patiently taught me over the years. I look forward to continued studying, learning, and contributing in the Defense Programs role.

Secretary Granholm also said that you "will work to keep our nation—and our world—safe from nuclear threats." How do you approach this huge responsibility, especially given the often unpredictable and competitive state of the world?

One part of the U.S. strategy to keep the nation and world safe from nuclear threats is to maintain a safe, secure, effective nuclear deterrent. Defense Programs obviously plays a central role in this, and I will do my best to help the organization deliver on this vital mission.

Defense Programs plays a supporting role in other efforts to keep us safe from nuclear threats. Defense Nuclear Nonproliferation, headed by Corey Hinderstein, is the lead organization for many such efforts, and I look forward to working with her as Defense Programs supports her team. Defense Programs also supports efforts led by the NNSA Counterterrorism and Counterproliferation organization, headed by Jay Tilden, and efforts led by the intelligence community. I look forward to working with them in support of their important work.

As the next deputy administrator for Defense Programs, how will you continue to work specifically with Los Alamos?

Los Alamos and its employees form a large portion of the Defense Programs team. They have been responsible for many of the most difficult, high-consequence, high-visibility tasks in the weapons complex in recent years, and this will continue. I expect to maintain excellent relations with Los Alamos and the other NNSA laboratories as we work together for the good of the nation. I expect Los Alamos employees to continue their excellent contributions to national security and to continue getting even better as they learn from their experiences. ★

■ Mark Schraad takes photos at the Valles Caldera National Preserve, just west of Los Alamos. Below: Schraad's wildlife photos include these images of a bobcat, coyote, badger, and black bear. "I am still waiting to photograph my first mountain lion," he says.

ONE SEASON AT A TIME

Computational Physics division leader Mark Schraad approaches work and photography with patience, awareness, and a little bit of luck.

BY OCTAVIO RAMOS

"My job changes throughout the year," explains Mark Schraad, Computational Physics (XCP) division leader at Los Alamos National Laboratory. "During different parts of the year, we focus on different aspects of the division's mission and responsibilities, although our principal driver is always the development and evolution of software used by Laboratory weapons designers to address complex, multi-physics applications associated with national nuclear security."

Schraad's approach to wildlife photography also changes throughout the year. "Nature, the seasons, and the weather pretty much dictate what animals I encounter during my time outdoors," he says.

LEADING XCP DIVISION

The United States has not tested nuclear weapons since 1992. Since then, the Laboratory—which stewards a majority of the weapons in the U.S. nuclear stockpile—has relied on advanced modeling and simulation software (rather than testing) to resolve the often-complex integrated physics questions and concerns about these weapons.

The scientific staff in XCP develop physics theory and models, advanced numerical methods, verification and validation methodologies, and advanced scientific software, all of which address a spectrum of multi-physics problems.

"As division leader, my role is to facilitate bringing all of these capabilities together, as XCP is responsible for delivering these mission-critical software tools to the design community, who in turn use our tools to perform weapons design, certification, and assessment," Schraad says. "It's an honor to be the division leader and to lead the 200-or-so talented people who actually make things happen."

BECOMING A PHOTOGRAPHER

Schraad gained a passion for photography in a roundabout way. "I've always been active in outdoor activities," he says. "And as part of these activities, I would bring a basic camera to capture whatever I happened to be doing. For example, after an early morning hike in the mountains, I might stand at the summit and photograph the sunrise. If I was lucky, sometimes I would get a photo of some wildlife in the area."

At first, Schraad used a point-and-shoot camera because he was more focused on his outdoor activity, be it rock climbing, backcountry skiing, or mountain biking. Over time, he learned the basics of good photography, which led him to researching and purchasing better equipment.

"My first wildlife subjects were birds, because although they are common, they can be challenging to photograph well," Schraad explains. "As I grew more comfortable with my equipment, I focused on the wildlife itself, learning the habits of animals and how to approach them to take the best photo. Animals will sense your approach long before you see them. When it comes to getting as close as possible, it's a combination of knowing how animals behave and being in the right place at the right time."

An avid hiker, Schraad always has a camera on hand. "Last autumn, while I was hiking, I encountered a black bear," Schraad remembers. "When I saw it, it was lumbering toward me rather quickly and directly. What works well in discouraging a bear's approach is shouting and raising your arms to appear bigger, so I did just that. But this time, the bear kept approaching. I made more noise and stood on some rocks, and it did finally stop. But I could tell it was nervous and didn't like me being there—I could hear it huffing and clicking its teeth. So, I got out of there quickly, and I was lucky that the bear did not follow … but I did get the photo."

Although patience was not necessary during the bear encounter, Schraad says he's learned a lot about patience by photographing wildlife. "I like following elk herds, as they often lead to other wildlife," he explains. "Having patience when it comes to interacting with wildlife has paid dividends."

And, he continues, "I'd like to think that I am learning to be more patient in my work as a division leader as well." ★

■ Mark Schraad

THE DISTINGUISHED ACHIEVEMENTS OF LOS ALAMOS EMPLOYEES

John Scott of the Lab's National Security and International Studies Office was named the co-director of the Joint Center for Resilient National Security, a collaboration between the Laboratory and the Texas A&M University System focused on capabilities relevant to nuclear weapons and global security.

Mark Short of the Shock and Detonation Physics group was elected as a fellow of the Combustion Institute for his outstanding contributions to combustion. In particular, Short was cited for "innovative contributions combining asymptotic and numerical analysis that significantly advanced the understanding of gaseous- and condensed-phase detonation physics." He is the first fellow of the Combustion Institute elected from Los Alamos.

Candace Culhane was named one of HPCwire's 2022 People to Watch. The recognition highlights Culhane's leadership at the Laboratory and her accomplishments within the field of high-performance computing.

Laboratory postdocs John Greenhall and Meng Meng received top honors for significant contributions to engineering science. Greenhall, of the Materials Synthesis and Integrated Devices group, was awarded the Postdoctoral Publication Prize in Engineering Science, while Meng, of the Earth System Observations group, was recognized with an honorable mention. Administered through the Lab's Postdoc Program Office, this award honors the best single publication that describes high-impact innovative research in engineering science published or accepted for publication in an engineering journal.

The Curiosity Rover ChemCam Engineering Team was awarded the Citation of Merit by the Explorers Club, a society that promotes exploration and scientific field study. The team was nominated for its hard work to recover the use of the ChemCam laser on Mars after the high-voltage power supply started behaving off-nominally in 2021. ChemCam is a tool that has a laser, camera, and spectrometers that all work together to identify the chemical and mineral composition of rocks and soils. The ChemCam Engineering Team members from Los Alamos are Roberta Beal, Nina Lanza, Cindy Little, Tony Nelson, Margie Root, and Amanda Sheridan.

Former Los Alamos intern Enrico Ramirez-Ruiz, who is now a professor at the University of California, Santa Cruz, was recently honored with the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring.

Los Alamos National Laboratory and Triad National Security, LLC, were recognized by the Department of Defense for their outstanding support of employees serving in the Army National Guard and Reserve. The Laboratory and Triad received the Seven Seals Award, the Above and Beyond Award, and two Pro Patria Awards for establishing policies that make it easier for employees to serve our nation in the National Guard and Reserve.

Los Alamos made the 31st Annual "Top 20 Government Employers" in *Woman Engineer* magazine. The Lab is the highest ranked Department of Energy national laboratory in the spring 2022 edition.

The Laboratory received eight Defense Programs Awards of Excellence, which were presented to winners by Brigadier General Stacy Jo Huser, principal deputy administrator for Military Application at the National Nuclear Security Administration, at a ceremony on May 18. Four of the awards were for exceptional achievement.

Microbiologist Anand Kumar was recognized as a "Future Leader in the Field of Host-Microbe Interactions" by *Infection and Immunity*, a journal of the American Society for Microbiology. Kumar studies host- and microbe-microbe relationships within the human body. This research holds promise for identifying novel therapeutics to treat infectious and non-infectious diseases, including diabetes, obesity, and cancer.

BETTER SCIENCE = BETTER SECURITY

Hardworking people—the Laboratory's most important asset—enable Los Alamos to excel at its national security mission.

Laboratory Fellow Bette Korber received the Distinguished Alumni Award from her doctoral alma mater, the California Institute of Technology. The award is Caltech's highest honor and is presented to a small number of alumni in recognition of personal and professional accomplishments. Korber has made significant achievements in virology research and computational vaccine design, and she continues to equip the scientific community with insights into HIV and SARS-CoV-2, the virus that causes COVID-19.

The Laboratory's *National Security Science* (*NSS*) magazine was honored by the Southwest Science Writers Association at its annual awards ceremony, which recognized the best science communications from or about the southwest United States in 2021. *NSS* summer student Jake Bartman received two awards for his article "Building a better balloon," about air-buoyant solids. The piece won the best college writing and best short-form (fewer than 500 words) awards. Weston Phippen won best multimedia for the podcast "The Trinity Test: Then & Now," which he recorded and produced. Editor Whitney Spivey and art director Brenda Fleming won the Best of the Southwest award for "HerStory," a timeline that highlights notable women at the Laboratory and their achievements, as well as changes in federal legislation and the workplace that continue to make Los Alamos a great (and always improving) place for women to work. ★

52 YEARS AGO

In 1970, researchers from Los Alamos Scientific Laboratory conducted the Birdseed experiments to study the chemistry and physics of the ionosphere, an atmospheric layer that extends about 40 to 600 miles above the Earth's surface. "The reason for such interest in the ionosphere is that this relatively thin layer is held by Earth's gravitation and ionized by solar radiation," explained writer Charles Mitchell in the October 1970 issue of *The Atom* magazine. "Fluctuations in the characteristics of the ionosphere can govern our environment" here on Earth.

During the Birdseed series, which took place at the Pacific Missile Range on the island of Kauai, scientists used Nike Tomahawk rockets to launch barium and plasma guns to gather massive amounts of data about the ionosphere.

Here, the Duck (plasma gun), Sapsucker (barium), and two diagnostic probe launches are shown over a period of about three hours. ★

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THEN & NOW

The Los Alamos Fire Department (LAFD) traces its roots back to 1943, when enlisted Army soldiers, led by a civilian chief, worked to protect Project Y—the Los Alamos branch of the Manhattan Project—from the ever-present threat of wildfire. In June 1944, Fire Station No. 2 (pictured above in 1946) was commissioned to respond to brush fires around S-Site, a Project Y high-explosives facility.

Today, six fire stations operate in Los Alamos County, two of which are located at Los Alamos National Laboratory. Every year, LAFD responds to more than 20 wildfires, such as the Cerro Pelado fire, which started on April 22, 2022. More than 1,000 personnel from around the country traveled to northern New Mexico to help LAFD battle the fire, which by May 15 had already burned more than 45,600 acres southwest of the Laboratory. Here, Utah's Lone Peak Hotshots work the night shift. ★

Photo: Lone Peak Hotshots