NEW HORIZONS IN SAFETY SCIENCE

Novel solutions are needed to safeguard Earth's security, health—and future

RETHINKING FIRE PROTECTION

HOW TO REDUCE DIGITAL DANGERS

NEW SAFEGUARDS FOR GLOBAL HEALTH

SCIENTIFIC AMERICAN CUSTOM MEDIA

What Safety Takes in a Fast-Changing World

• • • *By Christopher J. Cramer*

Today's world is changing fast. Powerful and transformative technologies are emerging to generate clean energy and novel chemicals, perform once-impossible computations, print 3D products and more. Yet new technologies bring new risks. And in the meantime, our climate is changing, forever chemicals are turning up everywhere, fires spread and digital dangers proliferate.

At UL Research Institutes (ULRI), where I'm chief research officer, we face down those dangers with safety science. For more than a century, we have saved lives by testing current and emerging technologies and doing rigorous, independent research to reduce their risk. This ensures that electrical technologies, chemicals, materials and building construction do not burn, combust, poison or otherwise endanger the public. Our essential work continues, and it makes everyday life safer.

But in a rapidly changing world, the science of safety must adapt as well. To build a safer world where everyone can thrive, the safety science is expanding in scale and scope. This means inventing materials for novel technologies that are safer than those on the market today.

To discover more about this cutting edge of safety science, I invite you to explore this special edition, which we are proud to sponsor. In these pages, you can explore how safety scientists are making today's technologies safer, and how they are building next-generation technologies with safety built into them from the start.

Why the new focus on innovation and discovery? The speed of technological innovation requires it. The only way for safety science to keep pace with today's rapid advances is to conduct the basic research that can help inform and shape them.

> The only way for safety science to keep pace with today's rapid advances is to conduct the basic research that can help inform and shape them.

At ULRI, we focus our efforts on three grand challenges: building resilience for a sustainable future, advancing individual and societal health in the 21st century, and promoting safety at the human-digital interface. In these pages, you can sample these efforts.

Learn about work to help prevent lithium-ion battery fires, as well as fires that flare where towns and cities meet undeveloped wildlands, like the ones that devastated Lahaina, Hawaii, in 2023, and Southern California earlier this year. Explore how safety science is supporting the world's clean-energy transition and get a glimpse of our new artificial-intelligence-powered laboratory, where we seek to discover new materials for safety breakthroughs. Discover how we're working to meet health challenges from exposure to PFAS, or forever chemicals, which have raised increasing global concern. Peek into the frontier of AI safety, where we have efforts underway to help ensure the digital ecosystem is both safe and ethical.

It will take global scientific collaboration to tackle today's enormous challenges, and we believe it will take open science. To that end, we make our research easily accessible to other scientists and to the public. We invite partnership. We aim to serve as a catalyst to spark the ingenuity the world needs to meet the complex future.

In that spirit, I welcome you to explore this snapshot from the frontiers of safety science, where we're working to mitigate today's safety risks and to build safer technologies for tomorrow.

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CHRISTOPHER J. CRAMER is UL Research Institutes' interim president and chief research officer.

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ANTOINE DORÉ

THE CUTTING EDGE OF SAFETY

Climate change, deepfakes, forever chemicals. Managing the risks that come with progress is the mission of safety scientists

• • • *By Michael Greshko*

The first planes often crashed. The first boilers heated houses, but often exploded. The first electric toasters burned bread and sometimes the cook. But eventually these technologies were accepted, and they caught on widely.

The history of technological advances suggests that industries, regulators and customers accept a new technology only once it establishes a baseline of trustworthiness. But who determines what's trustworthy? How is that gauged?

To inform such decisions, people need an independent source of knowledge about what's safe, dependable and worthy of confidence. One such source—known by the holographic UL stickers on your extension cords or the stamps on your appliances—is Underwriters Laboratories.

Since its founding in 1894, the organization has been at the forefront of bringing safety to life through science, essentially creating the field

As new technologies emerge, safety scientists seek to minimize their risk of harm.

ANDREW MERRY/MOMENT/GETTY IMAGES

As climate change brings more heat and droughts, wildfire dangers are rising.

known as safety science. Through more than 130 years, it has developed standards and safety tests for a bewildering array of consumer products and services—and paved the way for our trust in many technologies we take for granted today.

But now the world is changing. New technologies are entering the marketplace faster than ever before, making the pace of testing that much faster—and that much more urgent. After its invention in the 1870s, the telephone took 75 years to reach 100 million users worldwide. Social platforms and other online services can now accrue hundreds of millions of users in a matter of months. A convincing deepfake of a politician calling for violence, sent to hundreds of millions, can be just as deadly as a badly wired home appliance.

> By studying other places with conditions like Maui's, "something can be done now to prevent a catastrophic loss."

To meet this pivotal moment, the entity once known as Underwriters Laboratories has transformed itself. In 2022 it rebranded and restructured, supercharging its research efforts with $1.8 billion in the process. UL Solutions, a for-profit business, partners with companies to test, inspect and certify consumer products. UL Standards & Engagement, a nonprofit organization, develops rigorous safety standards and drives safety advocacy campaigns. UL Research Institutes (ULRI), an affiliated nonprofit, does independent research into ongoing and emerging safety risks.

In our globalized, interconnected world, understanding safety risks means considering all of society, notes Christopher J. Cramer, interim president and chief research officer at ULRI. "The definition of safety has broadened."

ULRI has set ambitious goals that the organization considers grand challenges for the planet: building resilience for a sustainable future; advancing individual and societal health in the 21st century; and promoting safety at the human-digital interface. To build a future that is simultaneously safer and more sustainable will require addressing complex issues in fast-moving fields ranging from digital security to environmental health.

ANDREW MERRY/MOMENT/GETTY IMAGES

"These are big problems," says Cramer. "They're not going away tomorrow."

The city unburnable

These goals trace back to Underwriters Laboratories' founding at the end of the 19th century and an event that was a great harbinger of economic change: the Chicago World's Fair of 1893.

With the Industrial Revolution at full steam, countries around the world were changing rapidly—and competing to showcase the latest technological wonders. The growing city of Chicago won 1893's bid. Across 686 acres on the city's south side, architects Daniel Burnham and John Root built a complex so resplendent, it became known as the White City. The area contained hundreds of buildings, 57 miles of roadway, and a world first in urban design: miles of electrical wires and connections snaking beneath the city's jute and plaster facades.

The novelty—and flammability—of the fair's electrified buildings presented substantial fire risks. Chicago was also haunted by a grim specter: the Great Fire of 1871, a conflagration that had killed 300 people and destroyed more than 17,000 buildings. To better understand the electrical safety hazards of the White City's wiring, a young, MIT-trained engineer named William Henry Merrill, Jr., was recruited.

Blazes still broke out: 17 people died at the fair in July 1893 when a poorly designed smokestack at a large refrigerated building caught fire. But electrical fires were kept to a minimum, and Merrill had demonstrated his mettle. In so doing, the fair provided Merrill with the opening—and the opportunity—to test the safety of new electrical technologies, in experiments funded by insurance underwriters and equipment manufacturers. The nonprofit Underwriters Laboratories was born.

In 1894, UL set up shop on the third floor of a fire patrol station on Chicago's Monroe Street. Its first test: an asbestos-based paper that claimed to be both fireproof and nonabsorbent (the material failed on the latter point, according to Merrill). Within a year, Merrill and his small team completed 75 tests on a budget of $3,000, evaluating various electrical products, automatic sprinklers and devices that burned a newfangled fuel called acetylene.

Over the next three decades, UL grew significantly and expanded to a 55,000-square-foot complex on Chicago's East Ohio Street, a brick and terracotta fortress that some employees nicknamed "The City Unburnable." The three-story building's test furnaces roared constantly, as engineers devised ever more ingenious ways to subject products to hellish testing conditions. In one eye-catching 1923 experiment, engineers baked a safe until it was red-hot and then dropped it from a 30-foot-tall crane onto a pile of bricks, to simulate whether the safe could protect its contents through a fiery building collapse. Along the way, the laboratory picked up its oldest motto: *Ignis Servus Non Dominus.* Fire is our servant—not our master.

UL engineers also tested plenty of products that didn't meet the mark. In an August 1903 article, a reporter for *Scientific American* recounted the story of a man who visited UL's laboratory and challenged its engineers to find any fault with his homemade, acetylene-burning generator. "A very moderate test sufficed to blow the apparatus to pieces and cover the inventor with plaster and fragments," the author dryly noted. "He was taken out into the yard and put under a hose, after which he went away convinced of his error."

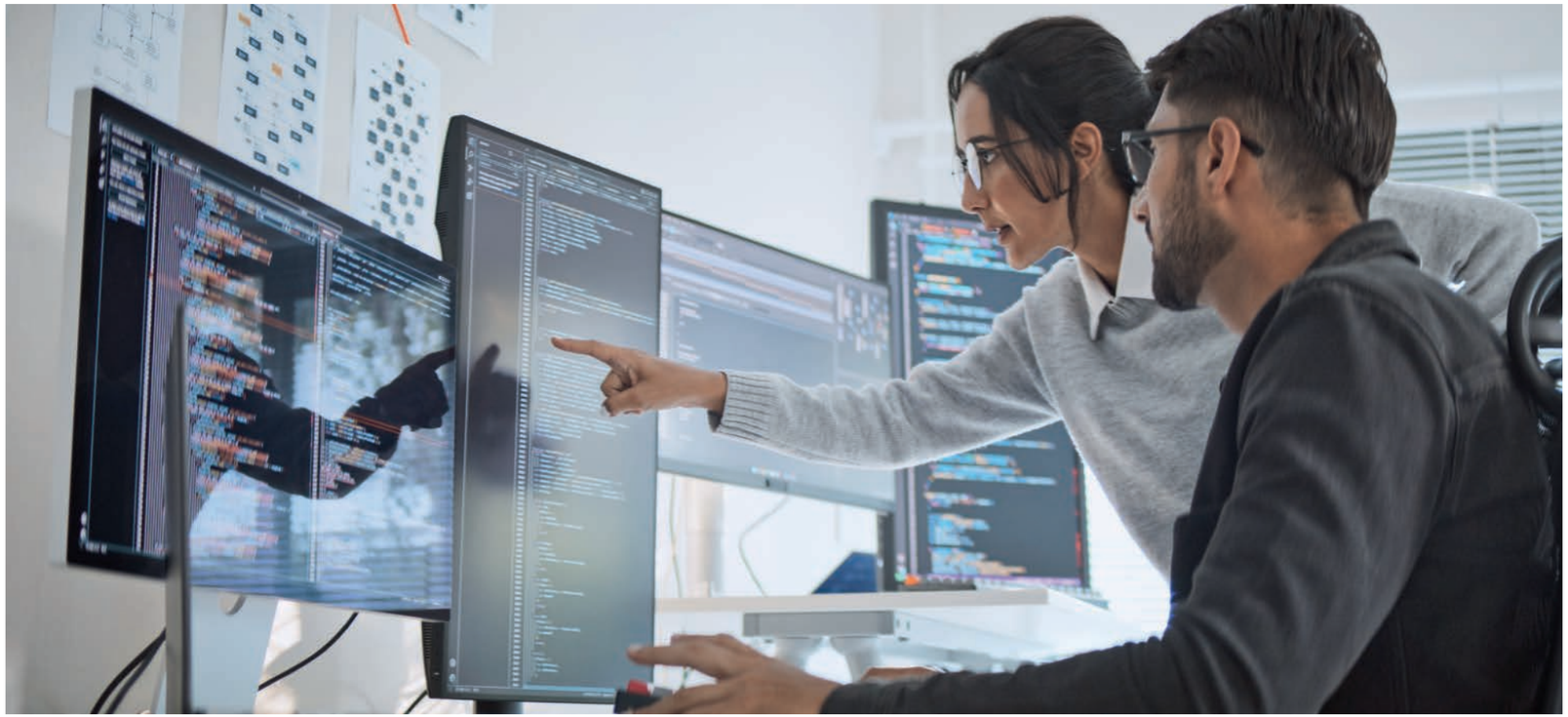
As technologies and consumer trends changed, the number of

product categories that UL tested ballooned: home radios, seatbelts, microwave ovens, personal computers. And as its remit grew and grew, UL often introduced voluntary safety standards that were years—and in some cases decades—ahead of government action.

In 1915, with more than two million cars on U.S. roads, UL established a department focusing on automobiles. It began testing car parts the following year—and has a claim to designing one of the world's first automotive crash test dummies. UL's work predated the first major U.S. car safety law, the National Traffic and Motor Vehicle Safety Act of 1966, by more than 50 years. From 1921 to 1925, UL ran the first national organization anywhere that certified airplanes' airworthiness and kept records on pilots' qualifications and training. The organization's safety efforts laid the groundwork for the passage of the Air Commerce Act of 1926, giving rise to what is now the Federal Aviation Administration (FAA).

When it comes to airplane and automobile safety, "everyone thinks, 'the federal government takes care of that.' Well, yes, they do now, but not always," says Alan Akers, ULRI's lead archivist. "You see time and time again where we've been able to fill that void and help advance the cause of safety science and public safety."

The institutes advance these causes by conducting research that's independent of outside influences and grounded in rigorous science, then sharing it with professionals and institutions worldwide. ULRI also cultivates future scientific thinkers by translating its leading-edge research into educational resources and programming focused on real-world safety science. ULRI's Office of Research Experiences & Education (OREE) creates open-access learning materials for middle and high schools, as well as workforce and professional development programs. OREE Senior Director Kelly Keena says the goal is threefold: "Build access. Build resources. Build the field. Through each of these priorities, our office is preparing future safety scientists."



KINDAMORPHIC/E+/GETTY IMAGES

Safety science researchers focus on fast-moving fields such as digital security.

Taming digital technology

The experts who make up ULRI's research corps know what it means to lead on emerging safety concerns. Here's how Jill Crisman, vice president and executive director of ULRI's Digital Safety Research Institute (DSRI), frames that quest for safety. How can Internet service providers build in defenses "against cyberattacks, scams, frauds and malicious use? How do we make sure algorithms protect individuals' rights and society's integrity?" As safety scientists in this century, she says, "We have to be checking for these things."

DSRI's subject-matter experts are already laying the groundwork. While pursuing a Ph.D. at Oregon State University, Sean McGregor focused on fire safety and built a computer model that used artificial-intelligence techniques to forecast how forests would respond to a given wildfire policy up to a century into the future. Along the way, McGregor found himself humbled—and unnerved—by the power of the AI tools he was using and creating. As a result, McGregor switched his focus to the safety of AI systems themselves. Now he's the director of advanced test research at DSRI, where he and his colleagues are racing to build the tools and testing procedures that can help ensure—and define—safety at the human-digital interface.

More broadly, standards, regulations, established tests and trustworthy certification all will be essential, Crisman says. But the need for such requirements creates another question, she notes: "Who is going to actually certify that companies are compliant with these standards?"

Fire's root causes

Though all aspects of ULRI's work are at the leading edge of safety, some of its work would also be surprisingly familiar to a time-traveling William Henry Merrill, Jr. After all, UL was founded to study electrification and conflagration. Both are still at the center of modern safety science.

At the organization's Fire Safety Research Institute (FSRI), researchers are using revolutionary methods to analyze fire dynamics, how fire spreads from structure to structure, and the safety risks that firefighters face. Now, FSRI is focusing on fires that break out along what are known as wildland-urban interfaces, where human structures mix with undeveloped wilderness. Nearly a third of U.S. homes—more than 44 million in all—stand in these areas, which are fast becoming the front lines of many modern wildfires, especially as climate change has increased the frequency of extreme heat events and droughts in some regions of the U.S.

> ULRI "remains rooted in its founder's ideals: a commitment to a safer world for all."

One sobering example of these blazes' danger occurred in August 2023, when a series of wildfires on the Hawaiian island of Maui swept through the community of Lahaina, killing more than 100 people and destroying many buildings.

Within days, Hawaii's attorney general selected FSRI to analyze the fire's root causes and provide recommendations to lessen the risk of similar disasters. Since then, FSRI has released a three-part report on the Lahaina fire, including a 518-page analysis published in September 2024. FSRI experts concluded that a variety of factors—including widespread complacency in the face of wildfire risk, underinvestment in infrastructure and communication breakdowns—combined to let the fire spread rapidly while stymieing evacuation efforts.

"We've got to learn from this event," says Steve Kerber, FSRI vice president and executive director. "There are other places in the U.S. that have the same symptoms, and something can be done now to prevent a catastrophic loss."

Clean-energy safeguards

Other new fire risks have been linked to emerging technologies. For example, scientists at the organization's Electrochemical Safety Research Institute (ESRI) are also examining the safety risks of today's fastest-scaling clean-energy technologies, such as lithium-ion batteries.

Since entering the commercial market in the 1990s, these batteries have seen meteoric uptake in everything from electric vehicles to large-scale energy storage for power grids. And for good reason: Lithium-ion batteries don't degrade much with each charge cycle, they self-discharge slowly and they pack a lot of energy storage into a small unit.

But like all technologies, lithium-ion batteries can also pose some safety challenges. "Associated with this high energy density is the potential for lithium-ion cells to undergo

catastrophic failures that can generate fire and toxic gases when they fail to be designed, manufactured, charged or used correctly," Judy Jeevarajan, ESRI's vice president and executive director, told a House of Representatives committee in February 2024.

Today, not every product that uses lithium-ion batteries is designed to prioritize emergency responses to battery fires. The batteries in many current electric vehicles are built into the vehicles' undersides, in a well-sealed container designed to keep water out. This is meant to keep the car's center of gravity low and protect the battery from water. But if an electric car catches fire, firefighters may have to roll it over to access its underbelly—if they can identify that the car is electric at all. At present, the U.S. doesn't have regulations that require consistency in labeling a vehicle as gas, hybrid or fully electric.

The materials of tomorrow

The work of ULRI makes one thing clear: In the world of safety, everything is now interconnected. Dangers in one domain may multiply across others. Yesterday's safety solution may pose risks now and in the future. The more researchers can understand a product's full safety risks across its entire life cycle, the more health can be safeguarded at both the individual and the societal level.

Firefighting foams illustrate the challenge. For decades, foams used to cool and suppress fires relied on compounds called per- and polyfluoroalkyl substances (PFAS). After decades of buildup and use, an estimated 97 percent of Americans have traces of these "forever chemicals" in their body. And now scientists know that they can cause a litany of health issues.

In partnership with Emory University's Rollins School of Public Health, ULRI's Chemical Insights Research Institute (CIRI), which evaluates the health impacts of chemicals in everyday products, has been working on a multiphase study of PFAS's presence in consumer textiles, with the goal of better understanding how the chemicals enter the body. "Some data suggest that fetal development and cognitive capacity of young children may be altered," says Marilyn Black, CIRI's executive director, emerita.

Climate change itself poses enormous health risks: from individual exposure to heatstroke or illnesses borne by mosquitoes, to the societal calamities dealt by extreme weather events. Transitioning off fossil fuels is an imperative—and will require one of the biggest, fastest technological transitions in human history.

So to make the future safer, ULRI orients its research toward invention. With its new Materials Discovery Research Institute (MDRI), founded in September 2022, the nonprofit hopes to accelerate the discovery of materials that can contribute to the fast-moving climate transition.

"I would call it ecoremediation," says Stuart Miller, MDRI's vice president and executive director. "One of the things that we've seen over the past 100 years is that energy storage and generation ... really raises classes of individuals out of poverty to give them a better standard of living."

In March 2024 MDRI entered a four-year partnership with Scotland's University of St. Andrews to search for new types of highly porous compounds called zeolites, which could help remove warming greenhouse gases from the atmosphere or pull water vapor from the air to make potable water. In September 2024 the institute launched an advanced materials science laboratory in Skokie, Illinois, that will heavily rely on automated instruments to get experimental results much faster.

Reinventing safety science

This kind of forward-thinking approach defines the future of safety science—and the future of ULRI today. Cramer, ULRI's interim president, notes that from the early days of Underwriters Laboratories, the mission was largely one responding to the marketplace: identifying and mitigating risks in products that were already on the shelves or were making their way soon.

Now ULRI has the mindset, resources and research capacity to reduce risks before they arise. "Instead of just figuring out how to make lithium-ion batteries safer, which is important, what about creating a different battery chemistry?" Cramer says. "We're in that discovery mode—that innovation mode."

But for all the change that ULRI represents, the story of the institutes' work is also one of continuity, according to Akers, the archivist. The organization remains rooted in its founder's ideals: a commitment to a safer world for all, and relentless zeal to meet the moment.

"The specifics of the time are just different" than 130-some years ago, Akers concludes. "Our DNA is the same."

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MICHAEL GRESHKO is a freelance science journalist based in Washington, D.C., whose work has appeared in many publications, including the *New York Times*, the *Washington Post*, *Science*, *Nature* and *National Geographic*, where he worked as a staff writer.

MUSEUM OF SCIENCE AND INDUSTRY, CHICAGO/GETTY IMAGES

Underwriters Laboratories was founded in 1894 by engineer William Henry Merrill, Jr., after his work at the Chicago World's Fair and its exhibit buildings.

The Safety Scientists Forging a More Secure Tomorrow

A peek behind the scenes at the researchers taking on the biggest threats to our environment, public health and digital safety

By Rachel Hartigan and Michael Greshko

The digital ecosystem is complex, interconnected—and not always trustworthy.

CARLOSCASTILLA/ALAMY STOCK PHOTO

"When more people make a breakthrough discovery or build a coalition for progress, it helps advance a vision of the world in which we all want to live." That statement of philosophy reflects how UL Research Institutes (ULRI) employees have long approached their work.

Known for boundary-pushing research, ULRI, formerly known as Underwriters Laboratories, seeks to identify and mitigate threats to the environment, public health and digital safety that are not well addressed elsewhere, and includes institutes focused on electrochemical, digital, chemical and fire hazards. Researchers there pursue innovative projects, often in partnership with distinguished academic and scientific organizations around the world. Here we take a look at the minds behind the science at three ULRI institutes.

A long hunt for safer batteries

In 1999 American astronauts wanted to bring a digital camcorder on a space shuttle mission. But the camcorder was powered by a lithium-ion battery, a relatively new technology that hadn't yet been approved for human space flight. To ensure the device wouldn't introduce unknown hazards to the mission, Judy Jeevarajan, then a research scientist at NASA's Johnson Space Center, ran rigorous tests on the battery to make sure it was safe. In the process, she became the first person to certify a lithium-ion battery for human space flight.

A quarter-century later, lithium-ion batteries are everywhere, from our ubiquitous phones to implanted medical devices to satellites blinking at us in the night sky. And Jeevarajan, now vice president and executive director of the Electrochemical Safety Research Institute (ESRI) at ULRI, continues to lead the charge toward making them safe, wherever they're used.

As much as she relished her time as a senior scientist at NASA, Jeevarajan joined ULRI in 2015, eager to embrace the organization's broader safety goals. In 2021, she was tapped to lead ESRI, newly created with the mission to "advance safer energy storage through science." She quickly built the institute to a staff of 21 chemical engineers, electrical engineers, fire engineering scientists, materials scientists, computer-modeling experts and other specialists.

Located in a University of Houston technology park, the team collaborates with researchers in academia and industry to understand the workings of different energy-storage systems—particularly advanced batteries and hydrogen—including what may cause them to break down and when they may become dangerous. The question that drives ESRI's work, says Jeevarajan, is "what can we do to make the world a safer place, especially with respect to energy . . . and sustainability?"

It's a question of particular pertinence now, as battery-powered devices are crucial in the move toward renewable energy. Lithium-ion batteries—light, powerful, rechargeable—are the most widely used. But if improperly manufactured or managed, they are subject to uncontrollable overheating known as thermal runaway, which can lead to disastrous fires, smoke and chemical emissions.

> "What can we do to make the world a safer place, especially with respect to energy?"

Newer energy-storage alternatives could help mitigate these threats, says Dhevathi Rajan Rajagopalan Kannan, a research scientist at ESRI who is in charge of that project. Among the alternatives: sodium-ion batteries which, given the abundance of sodium, are cheaper and more sustainable to produce. "What I'm trying to understand is whether the sodium-ion battery that is being used, or that is available, is safe or not," he says. And it's a race against time: "That is a fundamental understanding we are trying to get to before it gets more commercialized and mass-produced and adopted within the U.S."

To that end, Kannan is performing a series of experiments on a small set of sodium-ion commercial cells, including discharging and charging the batteries and subjecting them to off-nominal electrical and thermal conditions to see if combustion, explosion or "any kind of thermal runaway" results. So far, the results show that they are not very different from lithium-ion batteries, he says. "At ESRI, we plan to test sodium-ion cells from various manufacturers to assimilate more data on their performance and safety."

Under Jeevarajan's leadership, ESRI is marshaling its resources to address the public's immediate needs and get a jump on the future. For example, Jeevarajan points to the institute's work relevant to fast-charging stations, which are already available to drivers of electric vehicles. "People don't fully understand what happens inside a cell when you do the fast charge," she says. "We open up the cells and study them analytically, spectroscopically and so on, to understand what changes are going on."

Jeevarajan's ultimate goal is to be proactive: ESRI is also studying the safety aspects of using hydrogen as fuel. "If we can get ahead of the game," she says, "we can help with setting up standards and regulations." And that will make everyone safer. —Rachel Hartigan

Safety research at the speed of artificial intelligence

Before Jill Crisman joined ULRI's Digital Safety Research Institute (DSRI) in 2022 as its executive director and vice president, she spent three decades leading artificial-intelligence efforts for the U.S. government as well as private and academic institutions. "I can remember the day when the digital ecosystem was first set up," Crisman says—and she has watched it evolve from "a trusted place" to one beset by scams, disinformation and cybercrime. Her goal for DSRI is to help restore the digital realm's trustworthiness, in part by ensuring that new and emerging technologies "are deployed safely," Crisman says. Among the fastest-growing and trickiest of these safety challenges: how to "align" the behavior of AI systems called large language models (LLMs).

Once trained on gigantic sets of data scraped from the Internet, LLMs

are remarkably proficient at predicting the strings of words or synthesizing the images and videos that most likely respond to a given prompt. At present, these systems can't be said to reason; LLMs' outputs can change markedly in response to seemingly minor changes to the original prompt. Even so, these systems' conversational and generative skills have attracted more than half a trillion dollars in investment and hundreds of millions of users in just the past few years. Many technology companies deem LLMs as essential to the future of computing.

But as these systems become more powerful, the potential risks they pose may also increase. If improperly trained or without the proper guardrails in place, an LLM can generate all sorts of unwanted and unsafe outputs, such as hate speech or hallucinated claims that innocent people committed heinous crimes. What's more, creative hackers are quickly poking holes in existing safety systems: In September 2024 a hacker prodded OpenAI's LLM product ChatGPT into creating a fantasy story that contained within it detailed instructions for making fertilizer bombs.

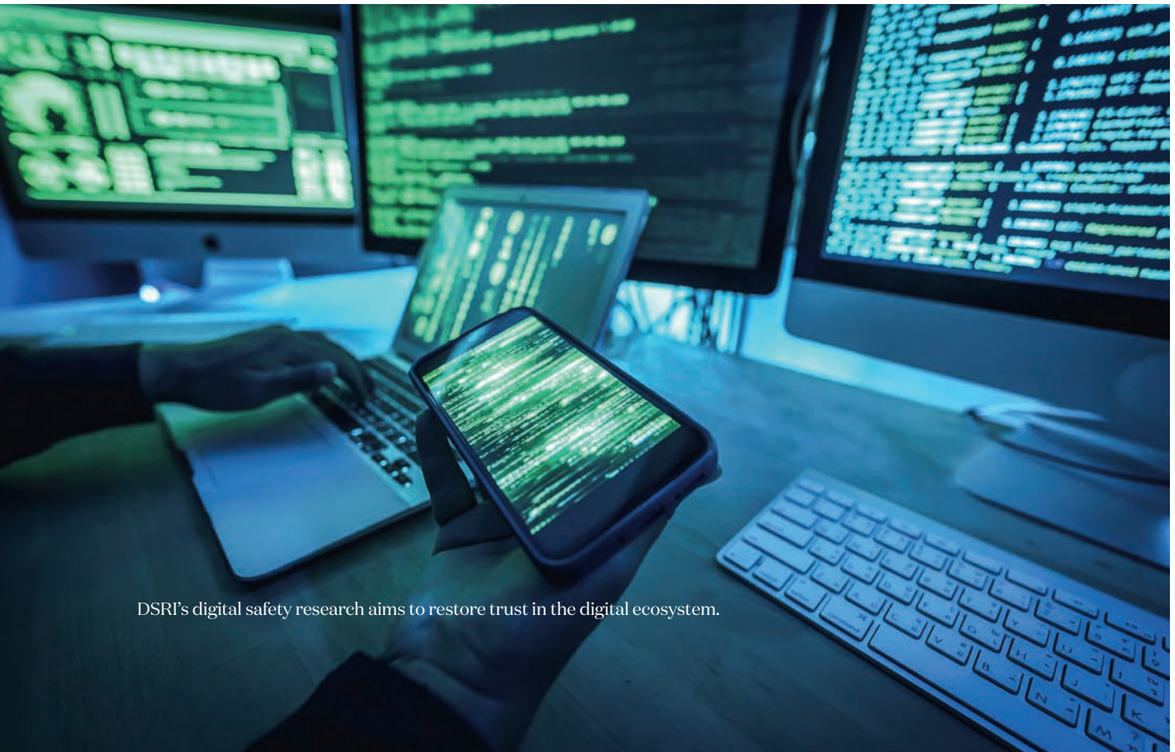
> As AI systems become more powerful, the potential risks they pose may also increase.

The field is moving rapidly—and government efforts to provide frameworks for LLM safety are still in their infancy. In October 2023 President Joe Biden issued a landmark executive order focused on the safety of LLMs and other so-called "generative" AI systems. Some groups created by this executive order, such as an AI safety board within the U.S. Department of Homeland Security, came online in 2024.

So just as Underwriters Laboratories developed its own safety standards for airplanes during the Wild West aviation industry of the early 1920s, DSRI is moving swiftly to conduct its own AI safety research in collaboration with other enterprises. In July 2024 DSRI announced a partnership with the nonprofit Allen Institute for Artificial Intelligence (Ai2) to develop safety evaluation practices for LLMs, starting with Ai2's very own Open Language Model (OLMo).

In August 2024 the two institutes partnered to stage a challenge at the major hackers' convention DEF CON, in which teams attempted to poke holes in a model card that described OLMo's capabilities, safety features and performance against benchmark tests in intentionally lofty language meant to goad the event's hackers. The contest yielded 200 flaw reports, including a set of previously unaccounted-for prompts that could "jailbreak" OLMo—alter it to allow unauthorized modifications or software installation—and bypass its existing guardrails.

Eventually, this work could yield well-defined tests for what constitutes safe LLM behavior, as well as a framework in which hackers can flag any flaws they discover for an LLM's creator. —Michael Greshko



BOONCHAI WEDMAKAWAND/MOMENT/GETTY IMAGES

DSRI's digital safety research aims to restore trust in the digital ecosystem.

Keeping air breathable, indoors and out

When it comes to the air we breathe, now is a critical time in environmental history. So says Marilyn Black, a public health scientist and former head of the Chemical Insights Research Institute (CIRI) at ULRI. Both outdoor and indoor air are at risk, she adds. "Wildfires are striking in urban interface areas with increased frequency in places like Hawaii and Canada; 3D printers are growing in popularity in school systems with unknown health consequences; and building materials are impacting the built environment and occupant health."

LANASTOCK/ISTOCK/GETTY IMAGES PLUS

3D printers, widely used in education, generate vapors and particulates.

CIRI is building on Black's decades of work in environmental science. In 1989 Black founded Air Quality Sciences, a research company focused on measuring indoor pollution and its effects. Eleven years later, she created GREENGUARD Environmental Institute, a nonprofit that certifies chemically safe products. In 2011 Underwriters Laboratories, as ULRI was then called, bought the two organizations and hired Black. Soon, she added CIRI to her portfolio to expand on nonprofit research and outreach efforts on environmental exposures. Since then, CIRI has grown to include 25 research and amplification specialists and a 3,000-square-foot lab space in Marietta, Georgia, equipped with state-of-the-art analytical technology.

Black stresses that CIRI doesn't do research for its own sake, but as a springboard for action. That approach is fundamental to UL Research Institutes overall, says Christopher J. Cramer, ULRI interim president and chief research officer. "We want to provide tools to mitigate risk, and we want to modify behavior by providing convincing evidence of how risks can be avoided or mitigated."

> "We want to provide tools to mitigate risk."

CIRI prioritizes research into environmental problems that are particularly widespread. For instance, wildfire smoke can generate air pollution more than 600 miles away from the initial blaze—think of Canadian wildfires darkening New York skies in recent summers. The institute's scientific research into the impact that has on indoor air quality led to practical guidelines for consumers on how to build a DIY box fan air filter, especially important when there's a run on home air purifiers.

CIRI also examines the effects of new technologies that are rapidly spreading: 3D printers are a prime example. Eagerly embraced as an educational tool, the printers were incorporated into classrooms, libraries and community centers, often with little forethought about potential hazards. CIRI identified exposure risks associated with vapors and particulates generated during the printers' operation—and proposed mitigation strategies, such as better ventilation. The institute also made sure schools were informed about their findings.

In the next year or two, researchers at CIRI plan to investigate how air quality is affected by two ramifications of climate change: extreme temperatures and the construction of resilient and more energy-efficient buildings. New chemical and biological assessment tools will be front-and-center, Black says, especially for "identifying human risks and measuring biomarkers to explain why exposure to certain chemicals leads to adverse human health responses."

This research could affect millions of people. That's intentional, says Cramer: "We want to make the greatest impact we can." —Rachel Hartigan

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RACHEL HARTIGAN, who writes about history, culture and science, will publish a book about the search for Amelia Earhart in 2026.

MICHAEL GRESHKO is a freelance science journalist based in Washington, D.C., whose work has appeared in many publications, including the *New York Times*, the *Washington Post*, *Science*, *Nature* and *National Geographic*, where he worked as a staff writer.

A Quest to Stop Fires Before They Turn Lethal

It takes sophisticated science to prevent fires caused by lithium-ion batteries and blazes that start where wild and developed lands meet

• • • *By Rachel Hartigan*

After the catastrophic August 2023 fire in Lahaina, Hawaii, the state's attorney general selected ULRI's Fire Safety Research Institute (FSRI) to analyze the fire and suggest risk-reduction strategies.

MATTHEW THAYER/THE MAUI NEWS VIA AP/ALAMY STOCK PHOTO

On November 23, 1903, the Iroquois Theatre opened in Chicago to rave reviews. "Few theaters in America can rival its architectural perfections," applauded one commentator. The venue was "absolutely fireproof," its playbills boasted.

Five weeks later, during a December 30 holiday matinee performance with 1,800 people in the audience, the Iroquois was engulfed in flames. Until the September 11 attack on the World Trade Center in 2001, it was the worst building disaster in the U.S.

Underwriters Laboratories, founded in 1894 to promote safety, joined the investigation into what went wrong at the Iroquois. The building didn't have a single fire alarm. Crucial escape routes were barred with locked doors. And the one safety tool that could have stopped the fire at its initial spark, when an electric light ignited a curtain backstage, didn't work: the fire extinguisher.

"A man put 10 cents' worth of baking soda in a 5-cent tin tube. He sold it for $3 as a fire extinguisher," fumed UL founder William Henry Merrill, Jr., likening the contraption to a phony magic wand. "Unfortunately, there was nothing 'make-believe' about the fire, and the result was very real to the families and the friends of over 600 women and children, whose lives were sacrificed that a man might make a profit of $2."

Determined to prevent such pointless tragedies in the future, Merrill created a certification operation to assure the public that products with its distinctive mark had been scientifically tested and could be used safely. More than a century later, UL is still at the forefront of fire prevention.

"What made us relevant in the late 1800s is the same thing that has us relevant today, if not more," says Steve Kerber, vice president and executive director of the Fire Safety Research Institute (FSRI), a part of UL Research Institutes (ULRI). "We're trying to understand these new products or behaviors or technologies when they're a concept … to understand the impact they have before people die."

Danger at the edge of town

FSRI and its partners among ULRI's other research institutes are focused on two main issues, both born of new technological and societal developments: fires caused by lithium-ion batteries and fires that ignite where wildland and urban development meet.

Wildland-urban interface fires, as they're called, are especially hazardous. Not only do they threaten homes and businesses but "the fuel that can burn includes many things of human origin: plastics, fuels, energy-storage systems, solar panels and more," says Christopher J. Cramer, interim president and chief research officer at UL Research Institutes. "The gases and particulates that are produced under these circumstances are likely to be much more dangerous."

The fire that destroyed much of the historic Maui town of Lahaina in August 2023 is one of the most devastating examples of a wildland-urban interface fire. Sparked near a school during a period of high winds and low humidity, the brush fire spread quickly. Before it was extinguished the fire killed 101 people, incinerated some 2,000 structures, and inflicted $5.5 billion in damage. At the request of Hawaii's attorney general, Kerber and an FSRI team led an independent review of the tragic fire. In addition, a team from ULRI's Chemical Insights Research Institute (CIRI) collected dust, soil and ash samples to determine what environmental hazards lurk in the rubble.

As the foundation of its analysis, the FSRI team compiled a comprehensive timeline of the event, a huge undertaking. "You're interviewing every single person involved, from the fire department to the police department, the emergency management agency, people from the state, people from the feds, private companies," Kerber says.

What they've learned so far is "there was no single factor, or set of factors, that led to the tragic outcome," as the team put it in their second report on the conflagration. Fed by hurricane-force winds and unmanaged, dry vegetation, the fire accelerated—and the region lacked sufficient resources to stop such an aggressive burn.

"This is not just a Hawaii problem," Kerber emphasizes. Climate change

> “Our homes are not as strong as they used to be.”

has created warmer, drier conditions ripe for fires while urban development continues to encroach into wildland areas. As a result, he says, “this is an issue that is happening all over the country in different ways, at different risk levels.”

Faster burns and dangerous gases

One ubiquitous risk factor is that residential fires are burning faster. In house fires 40 or 50 years ago, residents would have an average of about 17 minutes to escape; now it’s just three. Open floor plans increase the amount of oxygen available to feed the flames. New furniture and housing construction use synthetic materials that take less energy to catch fire and release more energy when they burn. Kerber’s bottom line: “Our homes are not as strong as they used to be.”

The prevalence of lithium-ion batteries, FSRI’s second big issue these days, quite literally adds fuel to the fire. Not only can they ignite fires, explains Adam Barowy, a lead research engineer at FSRI, but “when they react in a thermal runaway process”—uncontrollable self-heating—“they also fuel a very fast-growing fire.”

These batteries are turning up in virtually everything. “If it used to have a cord,” Barowy says, “it probably has a battery now—and it’s probably a lithium-ion battery.” His colleagues at ULRI’s Electrochemical Safety Research Institute (ESRI) are examining whether other options, such as batteries based on sodium-ion chemistry, are less prone to thermal runaway. So far, ESRI’s studies of sodium- and lithium-ion cells appear to produce similar results.

ULRI’S OFFICE OF RESEARCH EXPERIENCES & EDUCATION

Through ULRI’s Xplorlabs, students learn about fire causes and prevention at firefighter-supported camps.

As they explore future options, Barowy and his team are working with fire service professionals to learn more about today’s fires. To do that, they need to ignite them. FSRI utilizes an enormous lab outside Chicago where researchers can build multiple houses and then burn them under controlled conditions. Other tests are done in the field. Kerber, who comes from a long line of firefighters and began his career as one, jokes that he’s spent the last 20 years burning buildings around the country—“a high-rise in downtown Chicago, a strip mall in Ohio.”

This time around, Barowy and his team were headed to a Delaware train yard. They partnered with Amtrak and the Fire Department of the City of New York to conduct an experiment there: What could happen if an e-mobility device (an e-bike, say) caught fire on a train car? How fast might the fire grow? How big could it get? How long could it last?

Amtrak supplied a railcar that the team equipped with a multitude of instruments, including cameras, temperature sensors and pressure sensors. “We’ll measure for things like gases that could cause respiratory problems,” says Barowy. “All the things that would affect your well-being inside that closed space.”

Barowy and his colleagues are worried about passenger safety, of course—e-bikes are a common sight on commuter trains and subways—but also about the well-being of the fire service professionals called to extinguish the fires. When gases are captured from an e-bike battery fire during a controlled scenario, “it helps first responders know what types of chemical exposures they could have and how to reduce them,” says Barowy.

Partnering with fire departments is a crucial part of FSRI’s mission, Kerber says. A council of prominent firefighters advises them, and firefighters are often involved in planning experiments, a culture shift for a profession that has tended to rely on tradition as a guide.

“If I’m proud of anything that we’ve done over the last couple decades,” Kerber says, “it’s been that we’ve completely changed, in my opinion, the fire service culture to be accepting of research, accepting of science, and to be willing to question what you experience on the street.”

Teaching teens about fire safety science

ULRI’s Office of Research Experiences & Education (OREE) aims to foster that type of evidence-based thinking early on. Through its open-access, online program Xplorlabs, aimed at middle and high schoolers, students are introduced to fire forensics and the science behind fire safety, drawing on ULRI’s expertise in fire forensics, fire safety, thermal runaway and more.

For an educational program on fire forensics, which is based on FSRI research, one virtual study unit “puts them in the burn scene,” says Kelly Keena, OREE’s senior director. “They can pick out the evidence that they think is going to tell them where the fire started and how it started.”

Launched in 2016, Xplorlabs is now used in some 4,000 cities around the world. Its community model pairs local fire departments with classroom teachers to educate students about the dangers as well as the science of fire. In metropolitan Atlanta, for example, four school districts have brought Xplorlabs resources into STEM classrooms and integrated their teachers with area fire service personnel in teaching partnerships.

> “We can point to all these places that research and science actually keep us safer because we understand how fire works.”

The idea is to make students aware, not afraid. “We can point to all these places that research and science actually keep us safer because we understand how fire works and how fire behaves,” says Keena.

Science has come a long way from the time when a man could claim—lethally—that a tin tube of baking soda would extinguish a fire. Yet the threat of conflagrations hasn’t gone away in the century since then. Sometimes people think of fire as “an old problem that’s been dealt with a long time ago,” says Kerber. “The truth of the matter is, it really hasn’t.”

Today, fires are adaptable, igniting from new sources and burning in new ways. But science is adaptable, too—and Kerber, Barowy and their colleagues are determined to marshal it to make the world much less combustible.

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RACHEL HARTIGAN, who writes about history, culture and science, will publish a book about the search for Amelia Earhart in 2026.

STERLING LORENCE PHOTO/MOMENT/GETTY IMAGES

The popularity of e-bikes—whose lithium-ion batteries can pose combustion risks—lends urgency to ULRI’s safety testing.

PIRANKAJE/GETTY IMAGES

New chemicals and materials are needed to make the world sustainable.

Building the Pieces of a Sustainable Future

Safety scientists are speeding the invention of materials to help harvest water from air, capture carbon and produce hydrogen power

• • • *By Neil Savage*

Though his lab in Skokie, Illinois, is thousands of miles from the deserts of Africa, Timur Islamoglu spends his days thinking about how to find enough water in that arid environment.

Islamoglu, a lead research scientist at the Materials Discovery Research Institute (MDRI), is working to develop substances with just the right combination of qualities to capture moisture from dry air and turn it into a sustainable source of drinking water. He's targeting arid regions with relative humidities below 30 percent. "Those are the areas that require these technologies, because climate change is expected to exacerbate droughts and reduce precipitation in these already dry regions, intensifying the need for alternative water sources," Islamoglu says.

Sustainability is the primary focus for MDRI, the newest division of UL Research Institutes (ULRI). Launched in 2022, MDRI opened its state-of-the-art laboratory in September 2024, complete with equipment for automating chemical synthesis and data collection for use with machine-learning techniques. The lab's goal is to tackle the problems of climate change and energy storage with projects aimed at providing safe drinking water, removing excess carbon and finding more efficient ways to create, store and use hydrogen as an alternative and clean fuel source.

"Everyone in the world deserves safe drinking water," says Stuart Miller, vice president and executive director of MDRI, and providing cheap access to power has great

potential to lift people out of poverty. “The greatest challenge that we have now is, how do we do that and still be good stewards of the planet so that we don't add any carbon dioxide?” Miller says. Developing better materials can help.

To increase water supplies in arid parts of the world, MDRI scientists are developing substances that could capture moisture from dry air.

HADYNYAH/ISTOCK/GETTY IMAGES PLUS

Digital-first materials

In the 170 years since the beginning of the Industrial Revolution, humans have developed all sorts of useful materials to create our modern world. Many of them are petroleum-based. But with carbon from fossil fuels rapidly heating the planet, and a population that could reach 10 billion in the 2050s, humanity needs to move away from petroleum and discover new materials for energy storage and production, Miller says. Finding candidates through trial and error would involve sifting through many combinations of different materials, “and we don't have the time,” he says. “We don't have 170 years.”

So MDRI is taking what its leaders call a digital-first approach. That means combining the expertise of materials scientists and chemists with automated equipment for synthesizing chemicals; a nanoprinter for uniting the generation, combination and deposition of nanoparticle catalysts in one automated process and sensors that collect a wide range of data, including the humidity in a given lab on a given day. All that is fed into machine-learning models that can accelerate the discovery process.

To supply arid regions with water, Islamoglu is working on porous materials that can draw moisture out of low-humidity air much as a sponge would. The approach is material-agnostic, so the MDRI team is looking for an inexpensive candidate to capture water from the air. The trick lies in finding the right balance of various characteristics: for example, in low-humidity conditions the pores have to be small enough to capture the water molecules and concentrate them so they can condense. The materials can’t be too hydrophobic—water-repellent—or they won’t collect the moisture. But they can’t hold the water too tightly, either, or they’d require high temperatures (200 to 300 degrees Celsius) to release it, and generating the energy to reach such temperatures would be expensive.

Humanity needs to move away from petroleum and discover new materials.

Because different climates, such as mildly or highly humid regions, often require different porous material specifications to optimize water harvesting from the air, that’s also an active research area at MDRI. Water shortages are a growing problem, even in the U.S. and Europe, where food production consumes large quantities of fresh water and climate change alters rainfall patterns. A recent United Nations report lists several developed countries that could suffer from water scarcity by 2040.

Water into fuel

A slightly different version of the same material could capture carbon dioxide either directly from air or industrial sources; then it could be converted into something harmless or used to produce new petrochemicals without extracting more oil from the ground. For carbon capture, the pore size of a material is less important than its chemical composition, which allows it to interact with and trap the carbon dioxide, Islamoglu says.

Another way to combat carbon emissions is to use hydrogen-fed fuel cells to produce energy. One important component of a hydrogen-based system is the electrolyzer, which splits water into hydrogen and oxygen. At MDRI, lead scientist Jeff Wu is working to develop better catalysts that make the splitting process more efficient. Existing electrolyzers use rare and expensive precious metals, including platinum and ruthenium. Wu is searching for catalysts that work just as well but are made of cheaper and more abundant metals, such as iron, nickel or copper.

Beyond that, Wu aims to develop technology to store the hydrogen, perhaps building on Islamoglu’s porous material. He’s also experimenting with using a nanoprinter to accelerate the discovery of Earth-abundant and sustainable catalysts that help fuel cells convert hydrogen into power more efficiently. That power, in turn, might be stored long term in a flow battery, a large energy-storage system that’s based on liquid solvents and that is generally cheaper and safer than lithium batteries.

MDRI’s ambitious mission is to develop revolutionary materials that are demonstrably safe and sustainable. In keeping with that, Wu runs tests that exceed those conducted in an academic laboratory, where scientists tend to work with a small model under controlled conditions. “Our focus is going to be to make a real impact,” he says. “We are going to make a fuel cell prototype, an electrolyzer prototype and a flow battery prototype up to a kilowatt scale.” Such a prototype would be tested in real-world conditions, including temperature swings, loading swings and variations in humidity.

UL RESEARCH INSTITUTES

Lead research scientist Jeff Wu uses MDRI's cutting-edge nanoprinter to speed discovery of safe and sustainable materials.

Laboratory of the future

Helping to speed the discovery of such materials is Varinia Bernales, the lead researcher in charge of MDRI's computational section. She is developing ways to identify desirable materials for colleagues such as Wu and Islamoglu, as well as for her own projects. In one of Bernales's current projects, for instance, she is seeking a way to selectively separate lanthanides in collaboration with scientists from Northwestern University and the University of Toronto. These metals are widely used in modern technologies, including electronics, LEDs and fuel additives—but the process of extracting them from mine ores can contaminate waterways.

One of Bernales's collaborators working on the problem of extracting rare earth metals from complex mixtures is Alán Aspuru-Guzik, a chemist at the University of Toronto. Figuring out how to do that "will pave the way for more sustainable mining as well as for a more robust supply chain," Aspuru-Guzik says.

The institute aims to develop revolutionary materials that are demonstrably safe and sustainable.

Bernales is building machine-learning-augmented high-throughput computational screening, streamlining methods that try different potential formulations of molecules without synthesizing them or running them through slower, more complex simulations that don't use machine learning. "You can train the model to tell you if something is going to have the property that you are looking for at a much lower cost than running the full computations," she says.

That, combined with robotic systems to take over much of the work of synthesizing samples, should speed up the whole discovery process, Bernales says. "It's like the laboratory of the future. We'll have the experimental component, the computational component, and these robotic frameworks that will help us to accelerate the process and give the scientists time to think more about other problems."

Miller wants MDRI to move quickly toward prototypes that might lead to the commercialization of various products. But he doesn't expect quick solutions for issues related to sustainability. "This is not a short-term problem. I see this as a generational thing," he says. "I think we're the generation to build the infrastructure to really deepen the learning, to provide better solutions. And I think the people that solve the problems, they're sitting in schools now."

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NEIL SAVAGE is a freelance writer covering science and technology.

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