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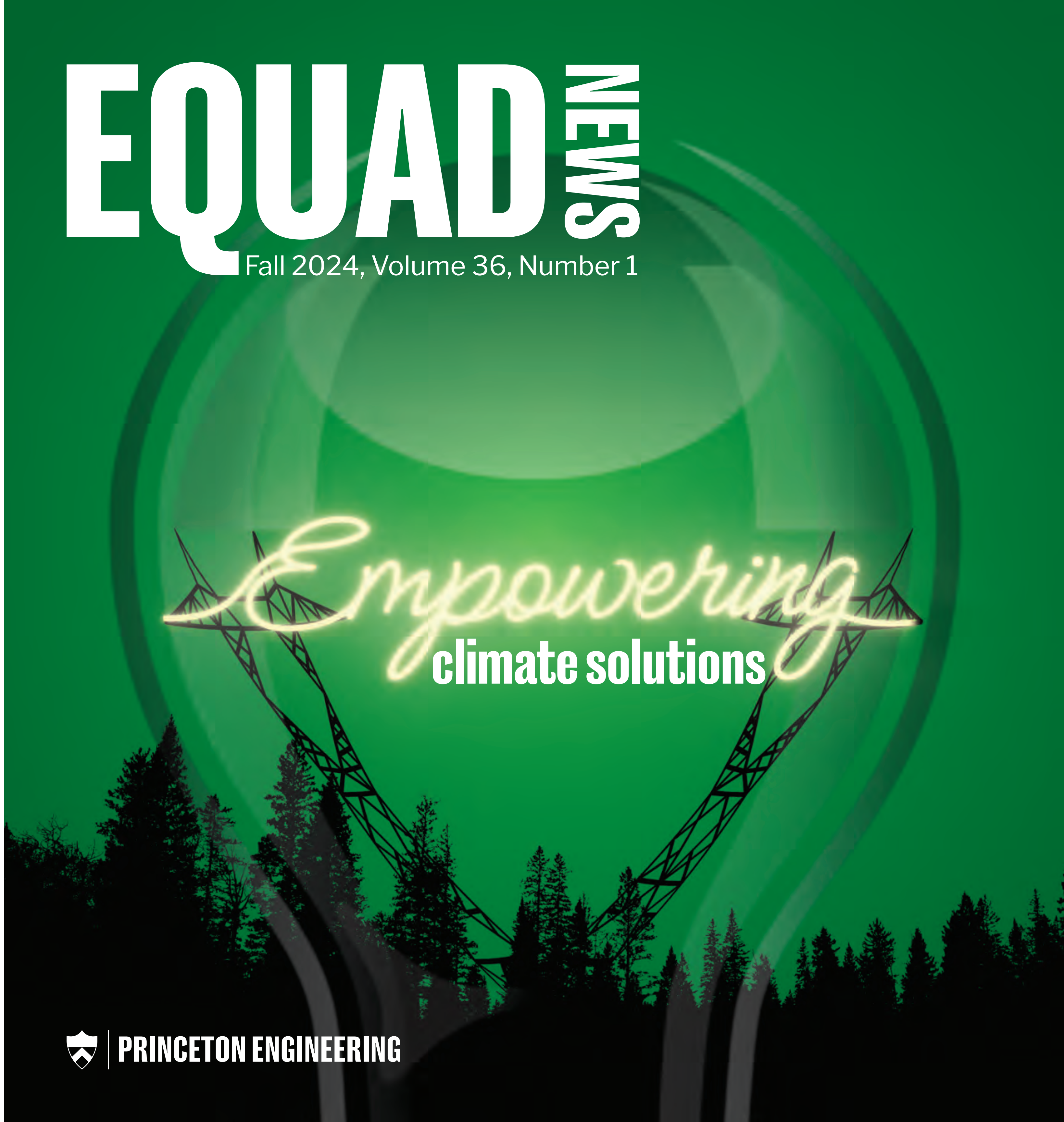

PRINCETON ENGINEERING

DEAN'S NOTE

Knowledge, creativity, and collaboration put climate solutions into action

Photo by David Kelly Crow

The root of the word "engineer" is ingenuity. As engineers, we apply deep knowledge along with creativity, collaboration, design, and innovation to address some of the world's greatest challenges. Today, no challenge is more daunting or important to address than climate change.

Crafting solutions to mitigate climate change requires both disciplinary and interdisciplinary knowledge, bold thinking, and broad partnerships across academia, industry, and government. In this magazine we tell stories of how Princeton Engineers are not just pushing the boundaries of knowledge to address energy and climate problems but are also putting these solutions into action through partnerships and entrepreneurial ventures around the globe.

It's fitting that this is also the edition of EQuad News in which we introduce our new visual identity. Rooted in the timeless identity of Princeton University, our new look reimagines the iconic Princeton chevron to convey our lively, intersecting culture. In all our areas of growth — AI, robotics, bioengineering, quantum engineering, next-generation wireless, and more — we bring together diverse expertise and work with public and private sectors to benefit humanity through the technologies we create.

Andrea Goldsmith
Dean | Arthur LeGrand Doty Professor of Electrical and Computer Engineering

EQuad News
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In the Nation's Service and the Service of Humanity

RECENT HIGHLIGHTS

Gilbert Omenn '61, Martha Darling *70, President Christopher L. Eisgruber '83 and Cliff Brangwynne. Photo by Kevin Birch

University dedicates Omenn-Darling Bioengineering Institute

At an event dedicating the Omenn-Darling Bioengineering Institute, Princeton University emphasized its commitment to innovative research in the life sciences and engineering, informed by collaboration with Princeton's world-class experts in the humanities, ethics, and policy.

Members of the Princeton University community gathered on May 6, 2024, for a dedication event for the new institute, which included a guest lecture and panel discussion on the vast potential for bioengineering inquiry to benefit medicine, health care, and the environment.

A transformative gift in the Venture Forward campaign from alumni Gilbert Omenn '61 and Martha Darling *70 named the institute, which is promoting new directions in research, education, and innovation at the intersection of engineering and the life sciences while serving as the home for new interdisciplinary bioengineering postdoctoral, graduate, and undergraduate programs.

"Gil and Martha, I want you to know how meaningful it is for us to be naming this bioengineering institute in your honor," said President Christopher L. Eisgruber '83 at the event at the event. "We are deeply grateful for your generosity and for your partnership with Princeton in imagining the future of this transformative scientific enterprise."

A welcome from Andrea Goldsmith, dean of the School of Engineering and Applied Science and Arthur LeGrand Doty Professor of Electrical and Computer Engineering, kicked off the event, followed by remarks from Cliff Brangwynne, director of the Omenn-Darling Bioengineering Institute and June K. Wu '92 Professor of Chemical and Biological Engineering.

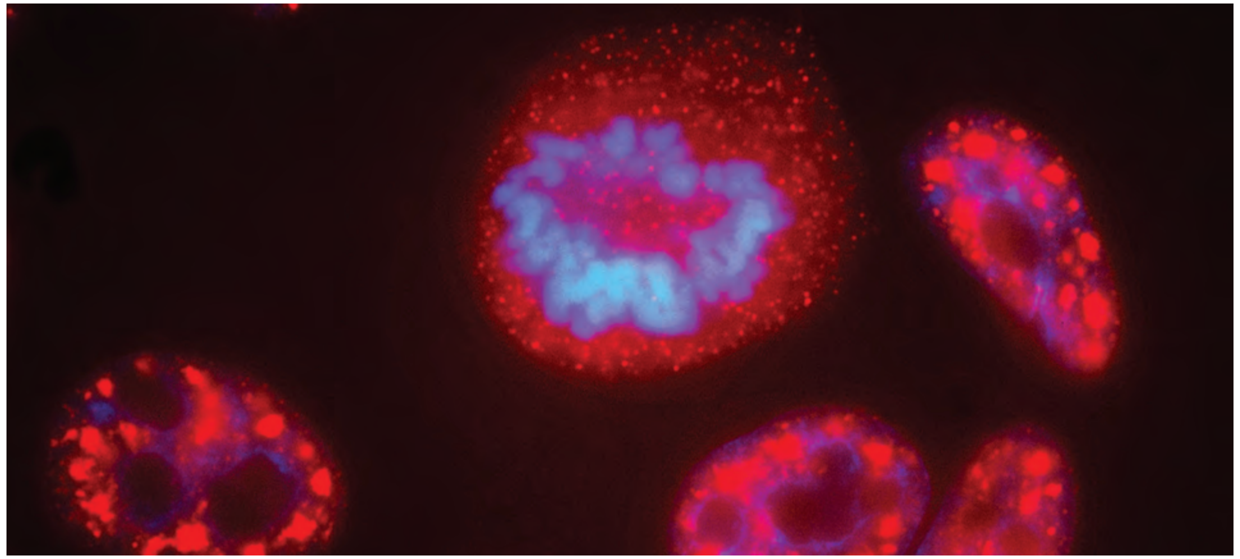
"You are all entrepreneurs," said Goldsmith, addressing Omenn-Darling Bioengineering Institute faculty, students, and staff. "You have all started something new. This is one of the first new institutes at Princeton in quite some time. And that gives you the opportunity to really forge something special here that will have impact well beyond what anyone can do on their own. That's what I find so exciting about this launch of the institute today."

The main areas of focus of the Omenn-Darling Bioengineering Institute are cellular engineering, device engineering, and computational bioengineering, as well as the ethical and public policy implications of such new ideas and technologies. An important aspect of the institute's work is to bolster innovation and entrepreneurship by collaborating with the region's biotech and pharmaceutical industries.

The Omenn-Darling Bioengineering Institute will be housed ultimately in the new environmental studies and engineering neighborhood on the Princeton University campus, scheduled to be completed in 2025.

The Venture Forward campaign supports the University's strategic framework, and its fundraising and engagement initiatives are aligned with the key focus areas of that plan: college access and affordability, financial aid, data science, bioengineering, the environment, American Studies, and other important areas of inquiry that characterize Princeton's commitment to the liberal arts.

–by Advancement Communications



Researchers bend DNA strands with light, revealing a new way to study the genome

Researchers have developed a tool that can bend DNA strands using light. The work represents a new way to probe the genome. Shown here, from an unrelated study, are chromosomes (blue) inside a human cell nucleus. Image by Steve Mabon and Tom Misteli, NCI Center for Cancer Research, National Cancer Institute, National Institutes of Health

With the flick of a light, researchers have found a way to rearrange life's basic tapestry, bending DNA strands back on themselves to reveal the material nature of the genome.

Scientists have long debated about the physics of chromosomes — structures at the deepest interior of a cell that are made of long DNA strands tightly coiled around millions of proteins. Do they behave more like a liquid, a solid, or something in between? Much progress in understanding and treating disease depends on the answer.

A Princeton team has now developed a way to probe chromosomes and quantify their mechanical properties: how much force is required to move parts of a chromosome around and how well it snaps back to its original position. The answer to the material question, according to their findings, is that in some ways the chromosome acts like an elastic material and in other ways it acts like a fluid. By leveraging that insight in exacting detail, the team was able to physically manipulate DNA in new and precisely controlled ways. They published their findings in the journal Cell.

"What's happening here is truly incredible," said Cliff Brangwynne, the June K. Wu '92 Professor of Chemical and Biological Engineering, director of Princeton's Omenn-Darling Bioengineering Institute and principal investigator of the study. "Basically we've turned droplets into little fingers that pluck on the genomic strings within living cells."

The key to the new method lies in the researchers' ability to generate tiny liquid-like droplets within a cell's nucleus. The droplets form like oil in water and grow larger when exposed to a specific wavelength of blue light. Because the droplets are initiated at a programmable protein — a modified version of the protein used in the gene-editing tool known as CRISPR — they can also attach the droplet to DNA in precise locations, targeting genes of interest. With their ability to control this process using light, the team found a way to grow two droplets stuck to different sequences, merge the two droplets together, and finally shrink the resulting droplet, pulling the genes together as the droplet recedes. The entire process takes about 10 minutes.

Physically repositioning DNA in this way represents a completely new direction for engineering cells to improve health and could lead to new treatments for disease, according to the researchers. For example, they showed that they could pull two distant genes toward each other until the genes touch. Established theory predicts this could lead to greater control over gene expression or gene regulation — life's most fundamental processes. **–by Wright Señeres**

Science has an AI problem. This group says they can fix it.

Artificial intelligence holds the potential to help doctors find early markers of disease and policymakers avoid decisions that lead to war. But a growing body of evidence has revealed deep flaws in how machine learning is used in science, a problem that has swept through dozens of fields and implicated thousands of erroneous papers.

Now, an interdisciplinary team of 19 researchers, led by Princeton computer scientists Arvind Narayanan and Sayash Kapoor, has published guidelines for the responsible use of machine learning in science.

"When we graduate from traditional statistical methods to machine learning methods, there are a vastly greater number of ways to shoot oneself in the foot," said Narayanan, director of Princeton's Center for Information Technology Policy and a professor of computer science. "If we don't have an intervention to improve our scientific standards and reporting standards when it comes to machine learning-based science, we risk not just one discipline but many different scientific disciplines rediscovering these crises one after another."

The authors say their work is an effort to stamp out this smoldering crisis of credibility that threatens to engulf nearly every corner of the research enterprise. A paper detailing their guidelines appeared on May 1, 2024, in the journal Science Advances.

Because machine learning has been adopted across virtually every scientific discipline, with no universal standards safeguarding the integrity of those methods, Narayanan said the current crisis, which he calls the reproducibility crisis, could become a far-reaching problem.

The good news is that a simple set of best practices can help resolve this crisis before it gets out of hand, according to the authors, who come from computer science, mathematics, social science, and health research.

"This is a systematic problem with systematic solutions," said Kapoor, a graduate student who works with Narayanan and who organized the effort to produce the new consensus-based checklist.

The checklist focuses on ensuring the integrity of research that uses machine learning. Science depends on the ability to independently reproduce results and validate claims. Otherwise, new work cannot be reliably built atop old work, and the entire enterprise collapses. While other researchers have developed checklists that apply to discipline-specific problems, notably in medicine, the new guidelines start with the underlying methods and apply them to any quantitative discipline.

"The scientific literature, especially in applied machine learning research, is full of avoidable errors," Narayanan said. "And we want to help people. We want to keep honest people honest."
–by Scott Lyon

Caterbot? Robotapillar? It crawls with ease through loops and bends.

Engineers at Princeton and North Carolina State University have combined ancient paper folding and modern materials science to create a soft robot that bends and twists through mazes with ease.

Soft robots can be challenging to guide because steering equipment often increases the robot's rigidity and cuts its flexibility. The new design overcomes those problems by building the steering system directly into the robot's body, said Tuo Zhao, a postdoctoral researcher at Princeton.

In an article published in the journal PNAS, the researchers describe how they created the robot out of modular, cylindrical segments. The segments, which can operate independently or join to form a longer unit, all contribute to the robot's ability to move and steer. The new system allows the flexible robot to crawl forward and backward, pick up cargo, and assemble into longer formations.

Zhao said the robot's ability to assemble and split up on the move allows the system to work as a single robot or a swarm.

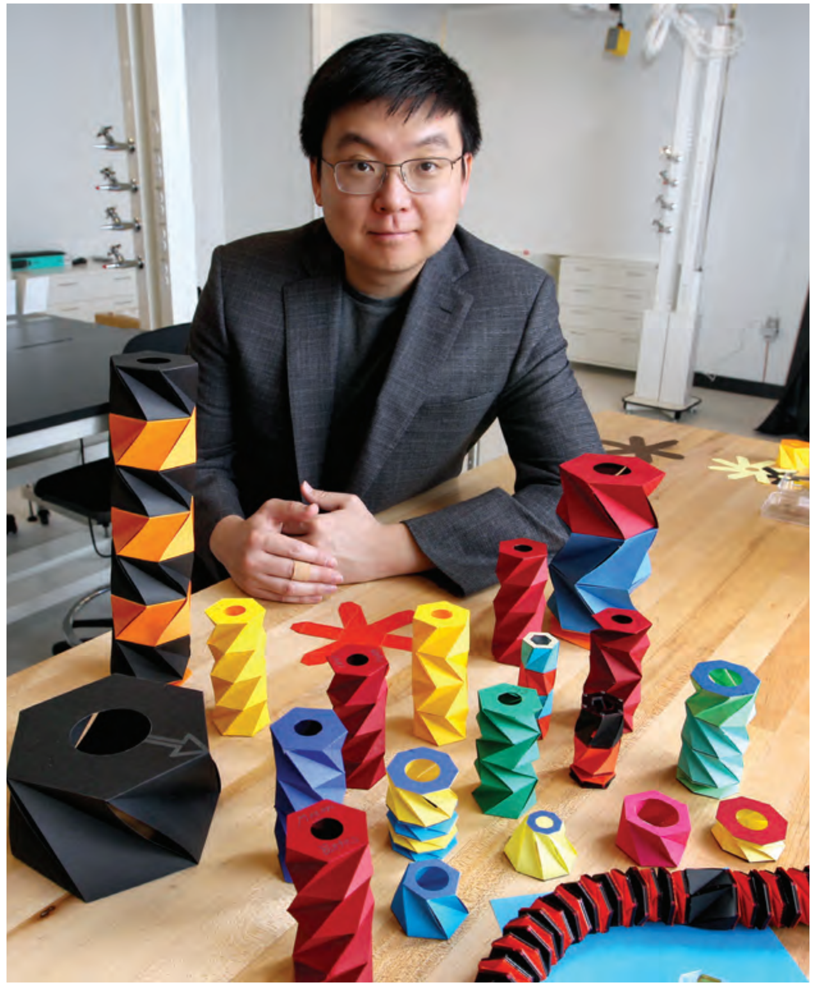
"Each segment can be an individual unit, and they can communicate with each other and assemble on command," he said. "They can separate easily, and we use magnets to connect them."

Zhao works in Glaucio Paulino's lab in the Department of Civil and Environmental Engineering and the Princeton Materials Institute. Paulino, the Margareta Engman Augustine Professor of Engineering, has created a body of research that applies origami to a wide array of engineering applications, from medical devices to aerospace and construction.

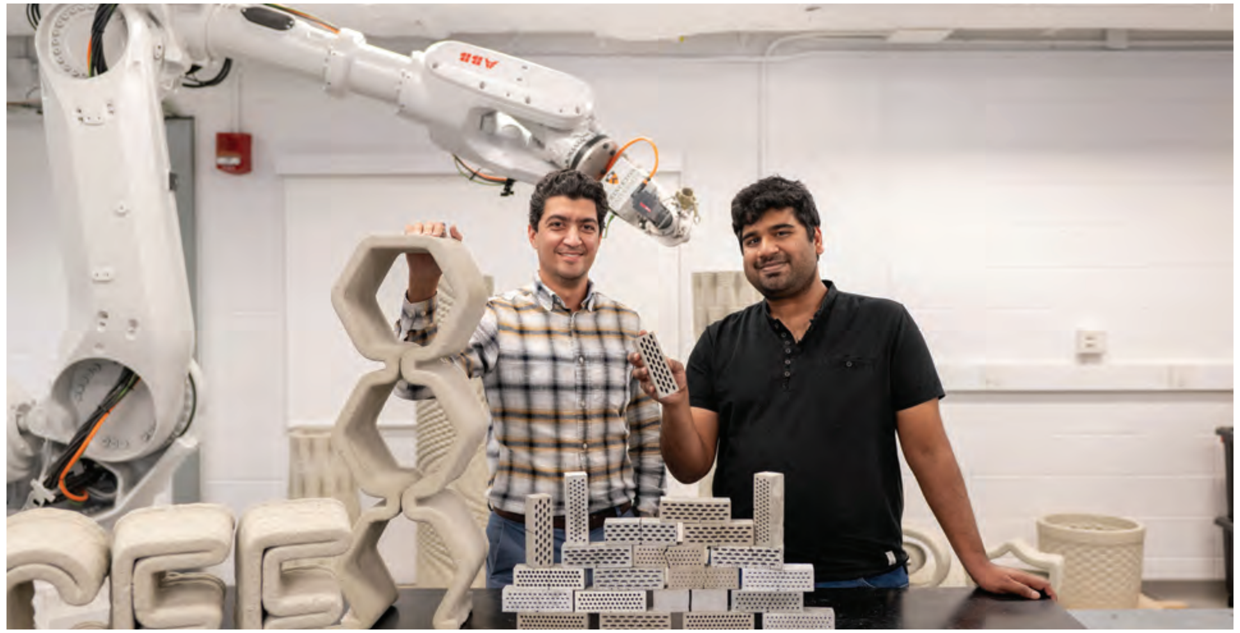
"We have created a bio-inspired plug-and-play soft modular origami robot enabled by electrothermal actuation with highly bendable and adaptable heaters," Paulino said. "This is a very promising technology with potential translation to robots that can grow, heal, and adapt on demand."

The researchers said that the current version of the robot has limited speed, and they are working to increase the locomotion in later generations.

Zhao said the researchers also plan to experiment with different shapes, patterns, and instabilities to improve both the speed and the steering. **–by John Sullivan**



Tuo Zhao, a postdoctoral researcher, with origami figures used for research in Professor Glaucio Paulino's laboratory. Photo by Frank Wojciechowski



Professor Reza Moini and graduate student Shashank Gupta take inspiration from biology to design better cement and related materials. Photo by Sameer A. Khan/ Fotobuddy

Tougher concrete, inspired by bone

Inspired by the architecture of human bone's tough outer layer, engineers at Princeton have developed a cement-based material that is 5.6 times more damage-resistant than standard versions. The bio-inspired design allows the material to resist cracking and avoid sudden failure, unlike conventional, brittle cement-based counterparts.

In an article in the journal Advanced Materials, the research team led by Reza Moini, an assistant professor of civil and environmental engineering, and Shashank Gupta, a Ph.D. candidate, demonstrated that cement paste deployed with a tube-like architecture could significantly increase resistance to crack propagation and improve the ability to deform without sudden failure.

"One of the challenges in engineering brittle construction materials is that they fail in an abrupt, catastrophic fashion," Gupta said.

In brittle construction materials used in building and civil infrastructure, strength ensures ability to sustain loads, while toughness supports resistance to cracking and spread of damage in the structure. The proposed technique tackles those problems by creating a material that is tougher than conventional counterparts while maintaining strength.

Moini said the key to the improvement lies in the purposeful design of internal architecture, by balancing the stresses at the crack front with the overall mechanical response.

"We use theoretical principles of fracture mechanics and statistical mechanics to improve materials' fundamental properties 'by design'," he said.

The team was inspired by human cortical bone, the dense outer shell of human femurs that provides strength and resists fracture. Cortical bone consists of elliptical tubular components known as osteons, embedded weakly in an organic matrix. This unique architecture deflects cracks around osteons. This prevents abrupt failure and increases overall resistance to crack propagation, Gupta said.

The team's bio-inspired design incorporates cylindrical and elliptical tubes within the cement paste that interact with propagating cracks.

"One expects the material to become less resistant to cracking when hollow tubes are incorporated," Moini said. "We learned that by taking advantage of the tube geometry, size, shape, and orientation, we can promote crack-tube interaction to enhance one property without sacrificing another." **–by the Office of Engineering Communications**

From left: Mihir Kshirsagar, clinical lead at the Center for Information Technology Policy; Prateek Mittal, a professor of electrical and computer engineering (ECE); Grace Cimaszewski, a graduate student in ECE; Henry Birge-Lee, a member of the Class of 2021 and a research software engineer in ECE; and Jennifer Rexford, Princeton's Provost and the Gordon Y.S. Wu Professor in Engineering. Photo by Sameer A. Khan/ Fotobuddy

Internet researchers reach beyond academia to close major security loophole

For years a potential disaster lurked in the internet's encryption system, threatening the security of organizations and individuals worldwide. Princeton engineers have now squelched that threat, working with industry leaders to transform their research into a universal security standard that was adopted by global organizations in August and made effective on Sept. 6, 2024.

The change centers on how web browsers and operating systems verify a website's identity when establishing a secure connection. They rely on third-party organizations known as certification authorities, who issue digital certificates of authenticity based on a website owner's ability to demonstrate legitimate control over the website domain, usually by embedding a random value that the certification authority has provided.

The Princeton team, led by professors Prateek Mittal and Jennifer Rexford '91, showed that bad actors could easily sidestep those hurdles to obtain a fraudulent certificate for a website they do not legitimately control. The scheme took less than a minute to pull off using a laptop. And it could target any website on the internet. Users had no way to spot the fraud since the certificates were real, even if their underlying facts had been forged. With a fraudulent certificate, criminals could attack users and route traffic to fake sites without anyone knowing.

That raised the specter of worst-case scenarios, according to Ryan Dickson and Chris Clements, cybersecurity experts at Google Chrome who helped usher in the new Princeton standard.

"Imagine somehow a bad actor getting between you and your news site," Dickson said. "And it fraudulently claims there's an imminent natural disaster and people must begin evacuating their area."

In the old system, the fake site would look every bit as legitimate as the real one. The bad actor could wreak havoc. "The harm to society could be catastrophic," he said.

Virtually all the internet's billions of daily interactions, from social media posts to bill payments to intergovernmental document transfers, were subject to this fraud.

By adopting the Princeton standard, certification authorities have agreed to verify each website from multiple vantage points rather than only one — a deceptively simple-sounding solution that has taken more than five years to refine for broad adoption.

Mittal said this work, although not typical of academics, was crucial in giving their research a chance to make a difference in real lives. It wasn't as simple as finding the problem and proposing a solution. It took a sustained effort, convincing powerful people again and again over many years. "We had to do the missionary work," he said.

–by Scott Lyon

Simple shift could make low Earth orbit satellites high capacity

Low-orbit satellites could soon offer millions of people worldwide access to high-speed communications, but the satellites' potential has been stymied by a technological limitation — their antenna arrays can only manage one user at a time.

The one-to-one ratio means that companies must launch either constellations of many satellites, or large individual satellites with many arrays, to provide wide coverage. Both options are expensive, technically complex, and could lead to overcrowded orbits. For example, SpaceX went the "constellation" route. Its network, StarLink, currently consists of over 6,000 satellites in low-Earth orbit, more than half of which were launched in the past few years. SpaceX aims to launch tens of thousands more in the coming years.

Now, researchers at Princeton Engineering and at National Yang Ming Chiao Tung University in Taiwan have invented a technique that enables low-orbit satellite antennas to manage signals for multiple users at once, drastically reducing needed hardware.

In a paper published in the IEEE Transactions on Signal Processing, the researchers describe a way to overcome the single-user limit. The strategy builds on a common technique to strengthen communications by positioning antenna arrays to direct a beam of radio waves precisely where it's needed. Each beam carries information, like texts or phone calls, in the form of signals. While antenna arrays on terrestrial platforms such as cell towers can manage many signals per beam, low-orbit satellites can only handle one.

The satellites' 20,000 mile-per-hour speed and constantly changing positions make it nearly impossible to handle multiple signals without jumbling them.

"For a cell tower to communicate with a car moving 60 miles per hour down the highway, compared to the rate that data is exchanged, the car doesn't move very much," said co-author H. Vincent Poor *77, the Michael Henry Strater University Professor of Electrical and Computer Engineering at Princeton. "But these satellites are moving very fast to stay up there, so the information about them is changing rapidly."

To deal with that limitation, the researchers developed a system to effectively split transmissions from a single antenna array into multiple beams without requiring additional hardware. This allows satellites to overcome the limit of a single user per antenna array.

The new technique can be incorporated into existing satellites that are already built, according to Poor. "But a key benefit is that you can design a simpler satellite," he said.

–by Alaina O'Regan

Experts show routes to recycling carbon dioxide and coal waste into useful products

A congressionally mandated study led by Professor Emily A. Carter has released a comprehensive roadmap for research and policies to enable large-scale recycling of carbon pollution into high-demand, useful products like fuels and construction materials.

The release follows a 2023 report by the same committee that found that a significant fraction of carbon emissions could be recycled but cautioned that accomplishing the task faced substantial challenges. The new report adds to the potential uses and details ways to approach those challenges through both research and policy.

The committee was established in 2021 and convened by the National Academies of Sciences, Engineering, and Medicine. In addition to Carter, it included 17 other experts from universities, nonprofit organizations, and industry.

Fossil fuel use and industrial processes emit carbon dioxide gas, which traps heat in the atmosphere, changing weather patterns and disrupting ecosystems. The new study identifies potential ways to reuse up to about 10% of carbon dioxide emissions. These uses include durable products such as concrete or carbon fiber, or short-lived products such as jet fuels or pharmaceuticals.

Reusing carbon dioxide or permanently storing it are key strategies for reaching net-zero emissions (when carbon dioxide no longer accumulates in the atmosphere), said Carter, Princeton's Gerhard R. Andlinger Professor in Energy and the Environment and senior strategic advisor and associate laboratory director at the Department of Energy's Princeton Plasma Physics Laboratory.

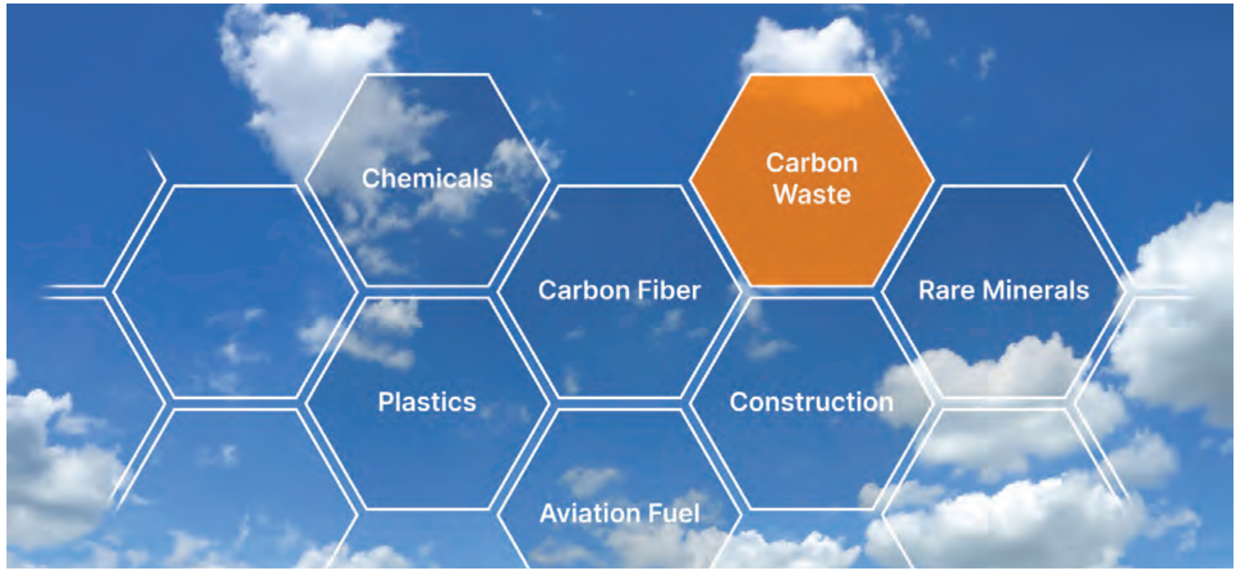
Carter said the goal cannot be to eliminate the use of carbon, because the element plays a critical role in day-to-day life, from food to medicines. "We are never going to decarbonize civilization completely, because we need carbon," said Carter, who also is a professor of mechanical and aerospace engineering. "The question is, how do we create a sustainable, circular carbon economy?"

Treating carbon as a waste product that can be reused could be an important part of the answer, she said.

The new report contains a detailed analysis of the potential markets for products made from waste carbon. In addition to construction materials and fuels emphasized in the first report, the new report identifies potential uses such as carbon fiber materials that could replace rebar in construction or replace titanium in high-tech applications. The report also discusses economic assessments of these technologies, including capital and operational costs.

Overall, Carter said, reusing carbon not only results in useful products, but helps pay for the considerable expense of implementing carbon capture and sequestration technologies, which are part of most strategies for reducing emissions. "If you make money on a useful product, it's a way of offsetting the cost of sequestration," she said.

–by Steven Schultz



Empowering climate solutions

New technologies to transform our energy systems and adapt to a changing planet

Over the past century we've seen remarkable growth and change in the systems that power our transportation, heating and cooling, and electricity. We've also seen the sobering consequences of these technologies: air and water pollution, climate change that fuels extreme weather, and the depletion of natural resources. These crises have led a growing number of governments, companies, and institutions to commit to reaching net-zero carbon emissions in the coming decades. This monumental transformation requires deep, sustained work by engineers from many disciplines — and partnerships with industry and government to bring their solutions to fruition.

Princeton Engineering is at the forefront of both developing climate and energy solutions and collaborating across many sectors to test and scale new technologies. The stories featured here represent some of our efforts to analyze decarbonization pathways across the globe, apply cutting-edge computing to guide the integration of renewables, and turn waste products into useful sources of clean energy. Please follow us at **engineering.princeton.edu** or on social media for all the latest.

Stabilizing fusion reactions is a learning process — for AI systems and the engineers who design them

Controlling the superheated plasma that makes up the whirling core of a fusion reactor is simple. You just have to predict the future.

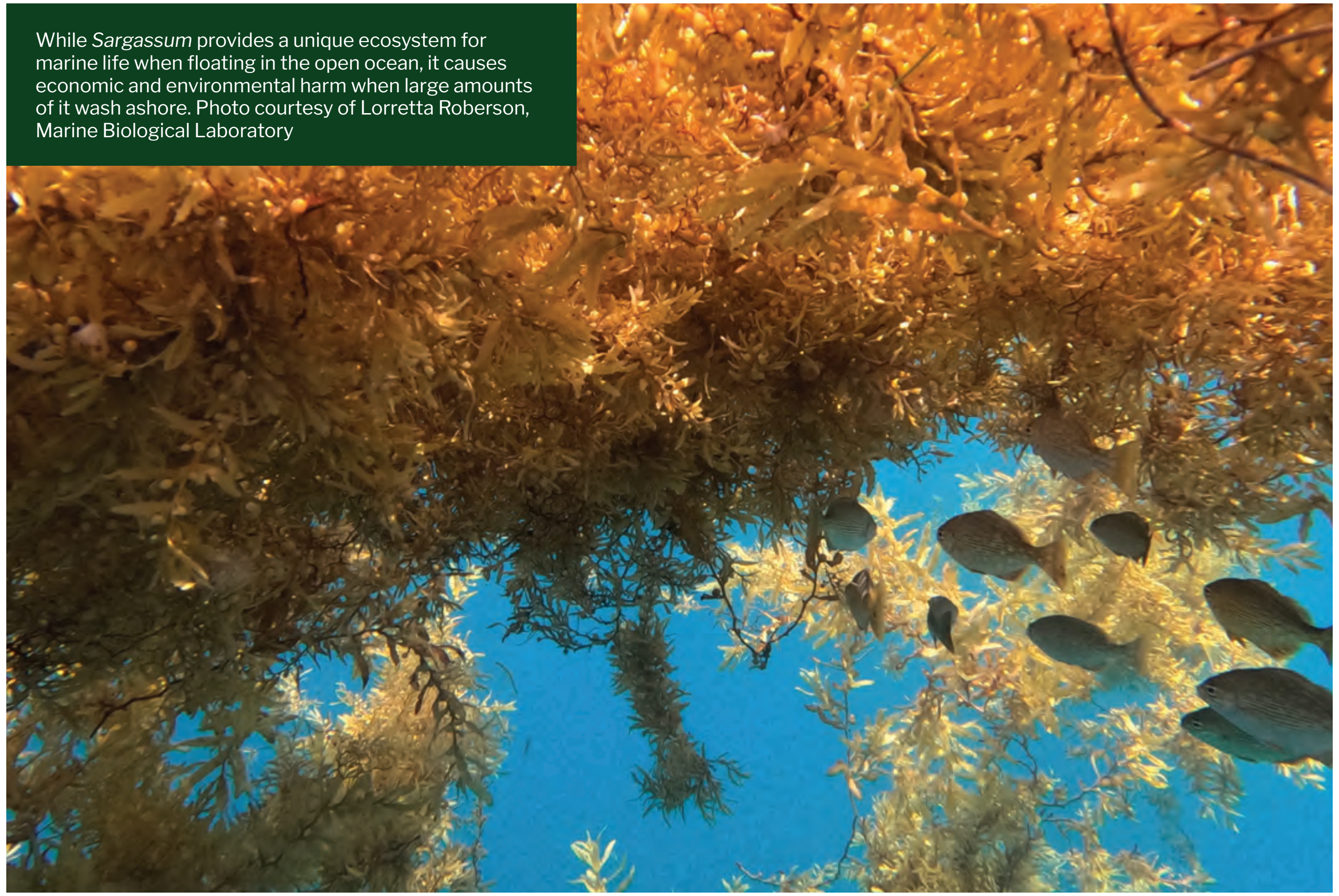
Working with his research team at Princeton University and the Princeton Plasma Physics Lab, Egemen Kolemen *08 is using artificial intelligence to do just that. IIn a recent effort, Kolemen, an associate professor of mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment, developed techniques that allow engineers to anticipate, and correct for, instabilities in plasma that can shut down a fusion reaction.

In experiments at the DIII-D National Fusion Facility in San Diego, the researchers showed that their model, trained on data from previous tests, could forecast certain plasma instabilities up to 300 milliseconds in the future. That's roughly the time it takes for a human to blink, but it was enough for an AI controller to change parameters and correct for the problem.

The research team is now working to improve the control system that handles the instabilities. Kolemen said they are also working to expand their control algorithm to handle many different types of problems at once. He described it as a learning process in which the AI is learning to better handle the plasma, and the researchers are learning to deploy the AI.

–by Alaina O'Regan

Egemen Kolemen. Photo by David Kelly Crow



While *Sargassum* provides a unique ecosystem for marine life when floating in the open ocean, it causes economic and environmental harm when large amounts of it wash ashore. Photo courtesy of Lorretta Roberson, Marine Biological Laboratory

From troublesome seaweed to sustainable feedstock

Since 2011, enormous seaweed blooms have spread across the Atlantic Ocean, spanning 5,000 miles from West Africa to the Gulf of Mexico.

While supporting a unique ecosystem for a host of marine life when floating in the open ocean, *Sargassum* seaweed has proven to be an economic and environmental disaster when large mats of it wash ashore and decay. In 2018 alone, attempts to clean it up from beaches across the Caribbean totaled around $120 million.

Now, a Princeton-led team of researchers from eight institutions and an industry partner are transforming this seaweed from burden to boon. Harnessing the tools of bioengineering, they are developing processes to convert *Sargassum* into valuable products including fuels, chemicals, and fertilizers. The researchers believe their biorefinery process could ultimately support a new type of sustainable economic growth across the Gulf of Mexico and Caribbean Sea, in which *Sargassum* is reimagined from a disaster to an opportunity.

"At an oil refinery, you have one input — petroleum — and convert it into dozens of products like gasoline, petrochemicals, and plastics," said lead investigator José Avalos, associate professor of chemical and biological engineering and the Omenn-Darling Bioengineering Institute. "Here, we're developing similar processes, but we're using a seaweed as a renewable and sustainable feedstock." **–by Colton Poore**

Christos Maravelias. Photo by Sameer A. Khan/Fotobuddy

Where complexity reigns, Maravelias reins it in

Christos Maravelias' trick is to turn ideas into equations. Often detailed and complex, those equations in turn optimize industrial systems.

Since arriving at Princeton in 2020, Maravelias has helped turn municipal wastewater into clean fuels, optimize a pharmaceutical supply chain, and speed the energy transition in trucking.

Deploying important innovations at scale "is never going to require just one component or technology. It's going to require a system in which that component is only one part," said Maravelias, the Anderson Family Professor in Energy and the Environment and chair of the Department of Chemical and Biological Engineering. While researchers often focus on scientific questions concerning a single component, he said the bottlenecks that slow innovation often appear in other parts of the process.

That's where Maravelias steps in — optimizing tradeoffs, minimizing waste, and reducing environmental impacts.

Lately, he has been working toward decarbonizing energy-intensive parts of the economy. He is collaborating with industrial giant Siemens to study how food and pharmaceutical production can be electrified. And his collaborations with NEC Labs and Korea's Posco aim to electrify aspects of steel production, which accounts for around 8% of human-generated carbon emissions annually.

"What we have seen time and time again is the importance of systems thinking," Maravelias said. "How studying the entire system, in addition to its components, helps us identify the major technological and economic drivers of new technologies and, ultimately, guide future research." **–by Scott Lyon**

Guiding energy transitions across the globe

After making an impact on U.S. policy, a group of energy systems researchers is going global to help countries chart their own pathways to ending the buildup of greenhouse gases in the atmosphere.
–by Colton Poore

In December 2020, a Princeton-led group of researchers released the Net-Zero America report. The uniquely comprehensive analysis described five distinct pathways for the United States to shift its economy away from climate-changing emissions using existing technologies.

The report has been widely influential in public policy and industry decision-making. Net-Zero America project leaders, including Jesse Jenkins, assistant professor of mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment, conducted over 300 briefings to communicate their findings to industry, academia, government entities, and non-governmental organizations. The work was covered extensively in the media, including a cover story in The Economist.

Now, Jenkins and his Net-Zero America co-leaders at the Andlinger Center, senior research scientist Chris Greig and senior research engineer Eric Larson, are expanding their efforts across the world.
First stop: Australia.

Experts at The University of Queensland, the University of Melbourne, and the management consultancy Nous Group worked with the Princeton team to show how Australia could decarbonize its economy. They went further by analyzing pathways to shift Australia from its status as one of the world's largest exporters of coal and liquified natural gas.

The effort, spearheaded at Princeton by Greig, was directly inspired by the U.S. project and also has been recognized by Australian policymakers, non-governmental organizations, and research bodies.

Net Zero Australia was the first of several projects now underway to help countries chart their own pathways to decarbonization. The researchers said their vision is to create a network of local partners to develop net-zero studies in a range of countries that are either currently or anticipated to become major contributors to global greenhouse gas emissions.

"The effort is not about us at Princeton delivering these studies on behalf of other countries. Rather, the studies are being locally anchored and led," said Greig, the Theodora D. '78 & William H. Walton III '74 Senior Research Scientist at the Andlinger Center. "Our job is to provide guidance where needed and to support them with the tools and resources to help local experts lead their own countries to a net-zero future."

Greig has helped launch a Net-Zero India effort in partnership with researchers at the Indian Institute of Technology Delhi, and the non-governmental organization Prayas (Energy Group). The work will model how India, currently the world's third largest carbon emitter, can meet its ambitious climate targets by transitioning away from fossil fuels while ensuring energy security for its growing population.

Larson, working with collaborators at Tsinghua University, has helped launch a Net-Zero China study, which included a week-long visit to Princeton this summer from six members of the Tsinghua team. China is currently the world's largest carbon emitter.

Larson is also leading Princeton's engagement on a Net-Zero Poland study led by a colleague at Poland's Silesian University of Technology. Poland is Europe's most coal-dependent nation. And together with João Biehl, director of Princeton's Brazil LAB and the Susan Dod Brown Professor of Anthropology, Larson is helping launch a Net-Zero Brazil study. Brazil is the largest carbon emitter in Latin America, with most of its emissions associated with land-use activities.

Other countries for which the researchers aim to launch Net-Zero projects include South Korea, Indonesia, Pakistan, South Africa, and Mexico.

As the initiative expands, researchers in Jenkins' group are developing open-source software for modeling energy-system transitions that will be available to researchers in any country. The software, developed in collaboration with researchers at the Massachusetts Institute of Technology and New York University, will provide a foundation for the global network of researchers they hope to unite, helping local researchers build capacity to execute impactful country-level net-zero studies.

"The idea is to build a global consortium of energy transition researchers from some of the best universities in the world to develop common methods, share lessons learned, and collaborate on globally relevant decarbonization efforts," Jenkins said.

Jesse Jenkins leads a team of energy executives and leaders through a game challenging players to ramp up energy production by 2050 without increasing net carbon emissions. Photo by Frank Wojciechowski

Eric Larson, who is spearheading Princeton's involvement with the Net-Zero China and Net-Zero Brazil projects. Photo by Sameer A. Khan/Fotobuddy

Chris Greig leads a group of energy executives and leaders through a modeling exercise during the Young Global Leaders program on Princeton's campus. Photo by Frank Wojciechowski

Understanding Africa's electric grid is key to growing it

Of the 733 million people who lack access to electricity worldwide, 600 million live in sub-Saharan Africa, according to data from the World Bank. The region's current electrification pace must triple to bring energy access to this population by 2030.

Among the barriers to expanding and improving the power grid is spotty information about existing networks, particularly the mid- and low-voltage lines that bring power to end users.

Jürgen Hackl, an assistant professor of civil and environmental engineering, is using network science and statistical methods to infer the region's grid structure from existing data. Crucially, his team's models quantify their own uncertainty and can be updated as more data becomes available.

"To invest a lot of money in this kind of system, you want to know what's already there," said Hackl. With network models, "we can test different hypotheses on how the network might change or how we could change the network in order to fulfill certain needs."

Hackl's group plans to validate their models using data from better-mapped electricity networks. Then, they will create tools to help prioritize investments for policymakers at the World Bank and the engineering firm WSP. Hackl has a formal collaboration with WSP through the Andlinger Center for Energy and the Environment's Fund for Energy Research with Corporate Partners. **–by Molly Sharlach**

Jürgen Hackl. Photo by David Kelly Crow

These projects are supported in part by the Fund for Energy Research With Corporate Partners, established by the University in 2022 and administered by the Andlinger Center for Energy and the Environment.

Hurricane Maria ravaged the town of Vega Alta in Puerto Rico. Photo by alejandrophotography/iStock

Predictive models could prevent post-hurricane power failures

For many coastal regions, avoiding hurricanes is impossible. But avoiding catastrophic power failures needn't be.

Princeton researchers Ning Lin *10 and Luo Xu are working with power companies and governments to understand and prevent cascading power outages that frequently follow severe coastal storms. In one effort, the researchers are consulting with Puerto Rico's energy operator, LUMA, to strengthen the island's power grid.

Puerto Rico has been repeatedly storm-battered this decade, and during 2022's Hurricane Fiona, LUMA collected high-resolution records of outage times for the entire island, showing when different transmission and distribution nodes failed. The researchers used the data to create models, evaluating the failures and pointing to preventative upgrades.

Lin, a professor of civil and environmental engineering, is an expert on simulating hurricanes under future climate scenarios. Her team's techniques can project location-specific probabilities of hazards such as wind, rain, and storm surge. The project's co-principal investigator, electrical and computer engineering professor H. Vincent Poor *77, brings deep knowledge of network science to the study of energy systems.

Xu, a postdoctoral researcher, is combining hazard projections with new power grid models, aiming to predict which parts of the grid will be most vulnerable and inform planning by LUMA and energy regulators.

The researchers are also advising Puerto Rico on integrating renewable energy into the grid. The island has committed to using 100% renewable energy by 2050. But moving from a fossil fuel-based system to a renewable one requires careful planning and new energy storage components.

"We are moving towards net-zero to mitigate climate change," said Xu. "But we cannot reverse climate change immediately. Integrating more renewables makes the grid more sensitive to climate [hazards]. We call this superimposed risk."

Lin believes that the methods her team is developing in Puerto Rico could be adapted to serve other coastal regions. As a co-principal investigator for the Megalopolitan Coastal Transformation Hub, a National Science Foundation-funded consortium, she hopes to apply lessons from Puerto Rico to grid resilience in New Jersey, Philadelphia, and New York City.
–by Molly Sharlach

First chess, now power grids? AI helps harden energy systems.

As the growth of renewable energy and rising threats from climate change increase the number and severity of power outages, artificial intelligence technology could help grid operators avoid blackouts.

Princeton researchers are exploring AI techniques that treat energy grid operation like a game that's played against the environment — the better the grid stays up in response to fluxes or weather hazards, the greater the win.

"The nature of this game is very different than the kinds of things that have been successful before," such as AI algorithms that play chess or Go, said computer science professor Ryan Adams. "The number of things that's possible to do is enormous." In addition, actions taken on a power grid have what researchers call continuous values. Rather than placing a game piece or flipping a switch, the actions involve tweaking output levels and distribution patterns.

Adams and his team are working with Siemens, an infrastructure technology company, developing solutions to modernize the energy grid, including renewables integration and autonomous systems.

Tackling real-world issues can move AI and computer science forward. Adams said that power grids are fertile ground for addressing problems that are relatively unexplored in AI research. **–by Molly Sharlach**

Ryan Adams. Photo by Tori Rupp/Fotobuddy

Impact close to home

While Princeton faculty members are making waves with their work across the globe, they are also leading the way to a more sustainable campus, using Princeton as a living laboratory for research and innovation. **– by Colton Poore**

Fume hood stickers are part of an integrated behavioral science approach to reduce the energy consumption of Princeton's lab spaces. Photo by Bumper DeJesus

Focusing on fume hoods

On each of the 16 fume hoods in Professor Tom Muir's lab in the Frick Chemistry Building, a sticker of a tiger stands guard behind the words: "CLOSE THE SASH."

Why? A single hood can consume more energy than the average U.S. home. The stickers are part of an integrated behavioral science approach for cutting laboratories' energy consumption across Princeton's campus. Comprising only 13% of Princeton's physical footprint, labs are responsible for almost 50% of the campus's energy use. Fume hoods, which are ventilated enclosures designed to protect people working with chemicals from hazardous fumes, are a large component of a lab's energy consumption, because the conditioned air used in a fume hood is exhausted to the outdoors and cannot be recirculated.

The team, advised by Elke Weber, the Gerhard R. Andlinger Professor in Energy and the Environment and professor of psychology and public affairs, has demonstrated a 24% reduction in energy use from fume hoods by harnessing tools from behavior science that encourage users to close them when not in use. These tools include stickers reminding users to shut the fume hood, a dashboard alerting lab managers when a fume hood has been left open for too long, and a monthly progress report.

"Behavioral science helps us call attention to and correct some of our bad habits, which could be behaviors that people might not even register as problematic until they're made aware of the consequences," said Weber.

Breaking ground on geo-exchange

When Princeton announced its decision to install a geo-exchange system to help meet its commitment to net-zero campus emissions by 2046, Forrest Meggers saw an opportunity to collect valuable data.

Meggers, an associate professor of architecture and the Andlinger Center for Energy and the Environment who researches ways to develop more efficient heating and cooling systems, helped with prototyping for the system. His contributions included setting up the sensing system for an over 1,800-foot-deep test borehole designed to find the ideal number and depth for the wells that will ultimately comprise the geo-exchange system.

The final system, with over 2,000 wells, will operate as a high-efficiency thermal "piggy bank." During the summer, excess heat removed from buildings will be stored underground using the geo-exchange bores. That stored heat will be used to warm campus buildings during the winter.

Meggers was particularly interested in leveraging the deep test borehole to inform research in his lab. "The ground gets warmer as you continue to drill," said Meggers, who also served on Princeton's Infrastructure Master Plan committee. "With such a deep test borehole, I could take measurements and develop models to understand how the resulting thermal gradient increased the system's efficiency."

While the majority of the installed geo-exchange boreholes are much shallower than the test bore — extending between 600 and 850 feet below ground, depending on their location on campus — Meggers said his experiments provided data that will help his research team develop better heat exchange technologies.

Forrest Meggers presents research on energy-efficient heating and cooling and describes energy-saving measures in place at Princeton during an academia-industry retreat on the built environment. Photo by Adena Stevens

Image courtesy of Princeton University Broadcast Center

Drone-assisted laser scanners pinpoint gas leaks from the air

Gas leaks can be hard to spot. Methane escapes undetected from fracking sites and contributes to atmospheric warming. Toxic fumes spew from improperly disposed waste. Natural disasters upset critical infrastructure, creating invisible hazards to residents and rescue workers.

Now, a Princeton team has developed a comprehensive, agile way to locate and identify gas leaks using drones, advanced lasers, and mathematical models of how gases disperse in the atmosphere.

While existing monitoring systems are typically ground-based and tuned to one or a few chemicals at a time, the new technology can detect dozens of chemicals simultaneously, creating a 3D map of all the gas plumes in an area.

"We can really fingerprint where the sources are," said Mark Zondlo, professor of civil and environmental engineering. That fingerprinting gives monitors more effective intervention tools and deeper insight into root causes.

Led by Gerard Wysocki, professor of electrical and computer engineering, the team includes Zondlo; Elie Bou-Zeid, professor of civil and environmental engineering; and Jaime Fernández Fisac, assistant professor of electrical and computer engineering. They've recently partnered with ThorLabs, an optical equipment company, to commercialize this technology under the name ChemScanAir.

"ChemScanAir is going to be the complete package that can be deployed very quickly after disasters," Bou-Zeid said, "so that we can minimize the leakage of air pollutants and hazardous chemicals in the environment." **–by Scott Lyon**

A Nebraska neighborhood during 2011 flooding along the Missouri River. Photo by Diana Fredlund, U.S. Army Corps of Engineers

Helping engineers design for waterways on a changing planet

For much of history, the past guided builders' designs. In a stable environment, this usually worked. Roman aqueducts carried water for centuries, and China's Grand Canal still helps transport river traffic. But in a changing climate, the past may prove insufficient.

Gabriele Villarini, a professor of civil and environmental engineering and the High Meadows Environmental Institute, is developing techniques to help design infrastructure that accounts for challenges posed by a changing climate. His work concentrates on hydrology, particularly river systems.

In recent work, Villarini's team collaborated with colleagues at the U.S. Army Corps of Engineers and the Department of Defense to examine how changing water levels in the Mississippi River have impacted shipping. In another project, Villarini's research group predicted that climate change will drive noticeable changes in flood peaks across the continental United States, especially for higher greenhouse gas emissions scenarios. In an article in Nature Communications, they projected that changing temperatures and precipitation levels will increase flooding in the Northeast and Southeast, while flooding will decrease in the Southwest and the Northern Great Plains.

"As an engineer, you look at historical data, generally assuming the future will be comparable to the past," Villarini said. "But what if the future is different?"
–by John Sullivan

Princeton startup recycles rare minerals from lithium batteries

Bruce Koel compares recycling lithium-ion batteries to transforming a stale loaf of rye back into oven-ready bread dough.

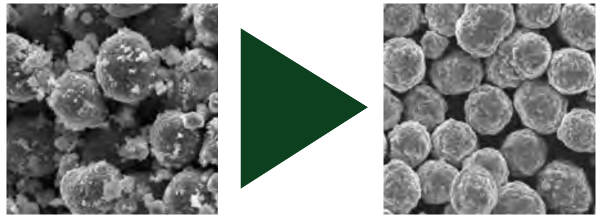
The transformation strips impurities from the battery's key section using low-temperature plasma, a reactive cloud of charged particles. Koel, now a professor emeritus of chemical and biological engineering, and his research team discovered that these plasmas could clean up materials for various chemical engineering processes.

The new method for direct battery recycling, developed at a startup company, applies plasma to a battery's cathode, the positively charged part of the battery containing valuable materials like lithium, cobalt, and nickel. With contaminants removed and a little more processing, the cathode material is ready for reuse.

Conventional methods involve shredding used batteries and using acids or high temperatures to separate them into component atoms. These processes are energy-intensive and require reassembling the cathode material.

Koel co-founded Princeton NuEnergy in 2019 with Yiguang Ju, professor of mechanical and aerospace engineering, and postdoctoral researchers Xiaofang Yang and Chao Yan. Yan is now CEO and Yang is CTO.

The company received funding from Princeton's Intellectual Property Accelerator Fund, the Department of Energy, and private investors. A pilot plant in Texas is operating at a scale of 500 tons per year and a demonstration plant now under construction in South Carolina is expected to operate at a scale of 10,000 tons per year of recycled cathode material.
–by Molly Sharlach



A new method for direct battery recycling uses low-temperature plasma to remove contaminants from aged lithium nickel cobalt manganese cathode materials (left), commonly used in electric vehicle batteries, and transform them directly into active cathode materials (right). Images copyright Princeton NuEnergy

(Left) Anu Ramaswami with Dhanasree Durairaj, a local Chennai intern with Princeton University, and Amir, an auto-rickshaw driver. (Right) Princeton undergraduate interns Chaeyoung Lee and Seungho Lee work with graduate student Neha Agarwal to attach sensors to a car in Chennai. Photos courtesy of the researchers

Measuring the human impacts of extreme heat to guide cities' climate action plans

Last May, Neha Agarwal returned to her home city of Delhi, India, to initiate a Princeton study measuring human exposure to extreme heat. Stepping out of the airport "felt like walking into a furnace," said Agarwal, a Ph.D. student in civil and environmental engineering.

When Delhi hit an all-time high temperature of 120.4°F (49.1°C) on May 29, Agarwal was distributing pendants to track individuals' heat stress over a 24-hour period. She also asked residents what was helping them endure the heat.

"One participant said that when they wash clothes and they have some gray water, instead of just draining it out, they splash it onto their roof. It immediately evaporates" into Delhi's dry air, "but at least for a brief moment, they have some experience of cooling," said Agarwal.

Agarwal is a member of Princeton's Urban Nexus Lab, led by Anu Ramaswami, Sanjay Swami '87 Professor of India Studies and a professor of civil and environmental engineering and the High Meadows Environmental Institute, as well as director of Princeton's M.S. Chadha Center for Global India. Ramaswami designed the study to focus on measuring human exposure to extreme heat stress in India's cities, with potential to extend learning to other cities of the Global South.

Ramaswami's lab aims to improve cities' equity and environmental sustainability in tandem, taking a holistic approach to solutions in energy, buildings, transportation, and other sectors. With extreme heat becoming more frequent, the variability in exposure to heat stress across socioeconomic groups and neighborhoods is a missing piece of this complex puzzle.

In Delhi, the team gave wearable pendant heat sensors to a cross-section of residents with diverse dwelling types, occupations, and commuting patterns. The pendants use temperature and humidity measurements to calculate the heat index.

Earlier in the summer, Associate Professional Specialist Ajay Nagpure initiated a parallel study in Chennai. There, daytime temperatures hovered around 98.7°F (37°C), which sounds bearable until you factor in the air's 80% humidity, which can make it feel about 50°F warmer.

In addition to the wearable pendants and other air temperature sensors to measure variations across neighborhoods, the team brought with them a novel cube sensor designed by Forrest Meggers, associate professor of architecture and the Andlinger Center for Energy and the Environment, to measure the heat radiated by surfaces, a key component of thermal comfort that's not captured by air temperature.

Other Princeton collaborators include professor Elie Bou-Zeid, an expert in urban microclimates who will apply models to predict the effects of different interventions; and assistant professor Jyotirmoy Mandal, whose group creates optical materials that can cool buildings and neighborhoods by reflecting sunlight and radiating heat to the sky.

Heat is among the challenges that Ramaswami's group is addressing through a new partnership with the Chennai Metropolitan Development Authority. Similar to collaborations Ramaswami has forged with U.S. cities, her group plans to work with policymakers in Chennai to model pathways to decarbonization that offer co-benefits to health, climate resilience, and quality of life. The work in India is supported by the M.S. Chadha Center for Global India.

–by Molly Sharlach

How water innovation could be key to a circular economy

It did not take long for the business world to tune in after Z. Jason Ren and team published a 2023 paper on how to capture lithium, the essential element of batteries, from briny water with great efficiency.

Ren, a professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment, leads a group that focuses on making more efficient use of water, particularly by recovering valuable resources and slashing greenhouse gas emissions from impaired water sources such as salty brine and wastewater.

When the group hit on a simple technology that would vastly lower the energy consumption and land use required for harvesting lithium, Ren's postdoctoral researcher Sean Zheng left Princeton to co-found a company, PureLi, to bring the idea to market. The company soon won support from the Grantham Foundation and venture capital firm SOSV as part of the firm's HAX startup accelerator in Newark. It is now setting up two pilot projects to extract lithium in Chile. The researchers' system can shrink by 90% an extraction process that typically requires square miles of evaporation ponds.

For Ren, the lithium project is one example of the urgency he feels around using fundamental science to reveal where inefficient management of waste streams is harming the environment — and developing solutions that move toward a "circular economy."

"At its root, my lab asks, 'How do we maintain a sustainable operation of our society?'," Ren said.

In a different project, Ren is collaborating with New Jersey Resources, a company that provides natural gas utility and clean energy services, to develop ways to extract hydrogen, a clean-burning fuel, and oxygen from municipal wastewater effluent. New Jersey Resources is working on novel approaches to clean hydrogen development to decarbonize its energy sources. The same process would allow the water resource recovery utility to use the oxygen to greatly lower the energy needed to process municipal wastewater.

"At wastewater treatment plants, their waste is our gain, and our waste — oxygen — is their gain," said Chris Chen, business development manager for NJ Resources. "This is the type of circular ecosystem we are looking for, and that's why this is a great project to do with Jason." **–by Steven Schultz**

The Princeton-PureLi team works with partners in the salt flats of the Atacama desert in Chile to improve lithium production from brine. Photo courtesy of Z. Jason Ren

FACULTY NEWS





Rodney Priestley, Robert Prud'homme, Catherine Peters, Aleksandra Korolova, and Ben Raphael

Recent faculty awards, promotions, and honors

Andlinger Center for Energy and the Environment

Iain McCulloch
Director, Andlinger Center for Energy and the Environment

Elke Weber
Frontiers of Knowledge Award, BBVA Foundation

Chemical and Biological Engineering

Jonathan Conway
E. Lawrence Keyes, Jr./Emerson Electric Co. Faculty Advancement Award
New Investigator, Joint Genome Institute

Jerelle Joseph
Maximizing Investigators' Research Award, National Institute of General Medical Sciences

Christos Maravelias
Sustainable Engineering Forum Research Award, AIChE

Athanassios Panagiotopoulos
Alpha Chi Sigma Award, AIChE

Rodney Priestley
Fellow, American Physical Society
INNOVATE100 honoree, Innovate New Jersey

Robert Prud'homme
Member, National Academy of Engineering

Michele Sarazen
CAREER Award, National Science Foundation

Civil and Environmental Engineering

Sigrid Adriaenssens
Francqui Chair, Ghent University
Grand Gold Award, Greater Bay Area Flower Show, Shenzhen, China
University Innovation Award, European Cultural Centre

Elie Bou-Zeid
Distinguished Scientific/Technological Accomplishment Award, American Meteorological Society

Reza Moini
Howard B. Wentz Jr. Junior Faculty Award

Catherine Peters
Award for Outstanding Contribution to Environmental Engineering & Science Education, AEESP

Z. Jason Ren
INNOVATE100 honoree, Innovate New Jersey
Walter J. Weber, Jr. Frontier in Research Award, AEESP

Computer Science

Kyle Jamieson
Distinguished Member, Association of Computing Machinery

Brian Kernighan *69
Science & Technology Medal, R&D Council of New Jersey

Aleksandra Korolova
Sloan Fellowship, Alfred P. Sloan Foundation

Pravesh Kothari
Presburger Award, European Association for Theoretical Computer Science

Lydia Liu '17
Amazon Research Award

Margaret Martonosi
Frances E. Allen Award for Outstanding Mentoring, Association of Computing Machinery

Ravi Netravali
Rising Star Award, SIGCOMM

Yuri Pritykin *14
E. Lawrence Keyes, Jr./Emerson Electric Co. Faculty Advancement Award

Ben Raphael
Fellow, Association of Computing Machinery

Jennifer Rexford '91
Alexander Graham Bell Medal, IEEE

Huacheng Yu
Howard B. Wentz Jr. Junior Faculty Award
CAREER Award, National Science Foundation

Electrical and Computer Engineering

Jaime Fernández Fisac
CAREER Award, National Science Foundation

Tian-Ming Fu
Trailblazer R21 Award, National Institute of Biomedical Imaging and Bioengineering

Yasaman Ghasempour
E. Lawrence Keyes, Jr./Emerson Electric Co. Faculty Advancement Award
Young Investigator, Air Force Office of Scientific Research

Andrea Goldsmith
Asad M. Madni Outstanding Technical Achievement & Excellence Award, IEEE-Eta Kappa Nu
James H. Mulligan Jr. Education Medal, IEEE
Technical Activities Board Hall of Honor, IEEE
Honorary Doctorate, University of Malaga
Honorary Doctorate, University of Tel Aviv
INNOVATE100 honoree, Innovate New Jersey
National Inventors Hall of Fame
Wireless Hall of Fame

Andrew Houck '00
Anthony H.P. Lee '79 P11 P14 Professor of Electrical and Computer Engineering

Stephen Lyon
William R. and Jane G. Schowalter Research Fund Award

Prateek Mittal
Grace Murray Hopper Award, Association of Computing Machinery

H. Vincent Poor *77
Corresponding Member, Australian Academy of Science
Honorary Fellowship, Indian Academy of Sciences
Member, American Academy of Sciences and Letters

Naveen Verma
Edison Patent Award, R&D Council of New Jersey

Mengdi Wang
Donald P. Eckman Award, American Automatic Control Council

Saien Xie
Packard Fellowship for Science and Engineering, David and Lucile Packard Foundation

Mechanical and Aerospace Engineering

Craig Arnold
INNOVATE100 honoree, Innovate New Jersey

Emily A. Carter
Foreign Member, Royal Society
Marsha I. Lester Award for Exemplary Impact in Physical Chemistry, American Chemical Society
William H. Nicols Medal, American Chemical Society

Kelsey Hatzell
Camille Dreyfus Teacher-Scholar Award

Jesse Jenkins
TIME100 Next list

Yiguang Ju
Fellow, American Institute of Aeronautics and Astronautics

Egemen Kolemen *08
Technical Accomplishment Award, American Nuclear Society

Naomi Leonard '85
Richard E. Bellman Control Heritage Award, American Automatic Control Council

Howard Stone
Neil A. Omenn '68 University Professor of Mechanical and Aerospace Engineering

Aimy Wissa
Howard B. Wentz Jr. Junior Faculty Award

Operations Research and Financial Engineering

Amir Ali Ahmadi
Egon Balas Prize, INFORMS Optimization Society

Jianqing Fan
Foreign Member, Royal Flemish Academy of Belgium

Boris Hanin
Sloan Fellowship, Alfred P. Sloan Foundation

Mete Soner
Chair, Operations Research and Financial Engineering

Bartolomeo Stellato
Beale — Orchard-Hays Prize, Mathematical Optimization Society
Howard B. Wentz Jr. Junior Faculty Award
Vice Chair for Computational Optimization and Software, INFORMS Optimization Society




Andrew Houck, H. Vincent Poor, Emily A. Carter, and Boris Hanin

Photos by Denise Applewhite David Kelly Crow, and Sameer A. Khan/Fotobuddy. Korolova photo courtesy of Aleksandra Korolova

Engineering faculty recognized for excellence in teaching, service, and mentorship





Photos by Sameer A. Khan/Fotobuddy, David Kelly Crow, and Denise Applewhite

Five Princeton Engineering faculty members were honored this year for outstanding teaching, service, and mentorship.

Brian Kernighan *69, the William O. Baker *39 Professor in Computer Science, was the recipient of the SEAS Faculty Distinguished Service Award.

In nominating Kernighan for the award, Szymon Rusinkiewicz, chair of the computer science department, wrote that "in addition to his legendary contributions to computing," Kernighan has "served the department, the school, the University, and the field in a dizzying array of service roles" since joining Princeton in 2000.

Claire Gmachl, the Eugene Higgins Professor of Electrical and Computer Engineering, received the SEAS Excellence in Mentoring Award. She is currently associate chair of electrical and computer engineering and has been the head of Whitman College since 2019.

"Claire is the embodiment of patient, dedicated, thoughtful, and generous mentoring," wrote Alexis Andres, who worked with Gmachl at Whitman College and is now the dean of Yeh College. "Many Princeton University B.S.E. students owe their strong starts to her."

Clancy W. Rowley '95, the Sin-I Cheng Professor in Engineering Science and a professor of mechanical and aerospace engineering, was one of four recipients of the University-wide President's Award for Distinguished Teaching.

Colleagues and students describe Rowley as a gifted lecturer who makes complicated topics not only accessible but also inspiring to students from across departments. "Professor Rowley's lectures consistently achieved an unparalleled balance of clarity and mathematical rigor, making even the most technical and abstract concepts accessible for his students," a graduate student said. "His course notes rival traditional textbooks in quality and are a testament to his commitment to accessible and high-quality education."

Maria Garlock, the Daniel Tsui Professor of Civil and Environmental Engineering, received the engineering school's annual Distinguished Teaching Award. Presenting the award at the school's May 27 Class Day ceremony, Vice Dean Antoine Kahn *78 said that Garlock has had a transformative impact on engineering education.

"Professor Garlock has not only been a great course developer, a teacher, a mentor, but also an extraordinary innovator in teaching and a role model who has pushed the boundaries of modern engineering to the next level," said Kahn.

Andrés Monroy-Hernández, an assistant professor of computer science, was one of four recipients of the 2024 Graduate Mentoring Awards from the McGraw Center for Teaching and Learning.

Students found Monroy-Hernández to be approachable and warm, and they were grateful for the invaluable guidance he provided as they made their way through the academic world. "Those who know Andrés will agree he has an amazing ring of positive energy," said one student. "I really enjoyed working with him even when research was hard."

Another student observed, "Andrés' mentorship extends beyond academic and professional growth; he is our friend." The student added that Monroy-Hernández "is a role model whose influence has been pivotal in my development as a researcher and individual."

Class Day marks achievement, determination, and optimism

The Class of 2024 entered college at the height of the COVID-19 pandemic and were leaving amid protests on campuses across the country, but through these challenges graduates showed "courage, determination, and optimism," Dean Andrea Goldsmith said at the Class Day ceremony on Monday, May 27.

"You found new ways to support each other, to work, to study, and to socialize utilizing technology as well as the very human skills that make up the fabric of our society and our Princeton community," said Goldsmith, the Arthur LeGrand Doty Professor of Electrical and Computer Engineering.

"I hope that going forward you will continue to engage as scholars and citizens of the world in bringing about positive change to benefit humanity," Goldsmith said. "We look forward to seeing the positive impact you all will have as engineers and as leaders in the years ahead. Your hard work, your dedication and perseverance are the attributes that led you to Princeton and to be so successful here, and they will be the foundation of your future."

The Princeton Engineering Class of 2024 included 376 students receiving engineering degrees and 58 receiving bachelor of arts degrees in computer science, for a total of 434 members.

Award winners at the 2024 Princeton Engineering Class Day, as presented by Associate Dean for Undergraduate Affairs Peter Bogucki, included:

J. Rich Steers Award
Varun Deb
Electrical and Computer Engineering
Anne Grinder
Civil and Environmental Engineering

Jeffrey O. Kephart '80 Prize in Engineering Physics
Yiming (Cady) Feng
Electrical and Computer Engineering
David Shustin
Computer Science

Tau Beta Pi Prize
Brendan Kehoe
Electrical and Computer Engineering
Owen Travis
Computer Science

Joseph Clifton Elgin Prize
Paige Silverstein
Civil and Environmental Engineering
Yenet Tafesse
Computer Science

George J. Mueller Award
Emily (Leilani) Bender
Civil and Environmental Engineering
Sarah Fry
Mechanical and Aerospace Engineering

Calvin Dodd MacCracken Senior Thesis/Project Award
Holly Cheng
Molecular Biology
Marina Mancoridis
Computer Science

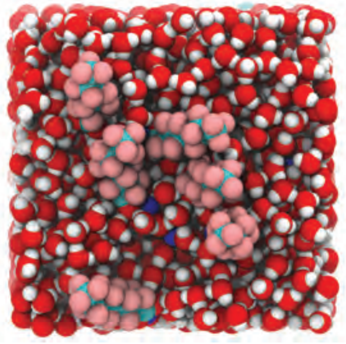
Melissa Woo
Operations Research and Financial Engineering

Lore von Jaskowsky Memorial Prize
Yiming (Cady) Feng
Electrical and Computer Engineering
Devdigvijay Singh
Mechanical and Aerospace Engineering

James Hayes-Edgar Palmer Prize in Engineering
Amélie Lemay
Civil and Environmental Engineering
Reha Mathur
Chemical and Biological Engineering

Photo by Frank Wojciechowski

Can 'forever' chemicals become less so? This senior thesis works toward smarter cleanup of PFAS.



Lemay investigated how seven types of PFAS molecules behave at the interface between air and water. In this visualization, the hydrophobic tails of PFOS molecules (pink and aqua) extend from a layer of water molecules (red and white). Image by Amélie Lemay

The class of chemicals known as PFAS — used in firefighting foams, some nonstick cookware, and many other products — can resist heat and repel water. Their chemical bonds are hard to break, and they persist in water sources for decades.

Exposure to them has been associated with cancers, "impacts to the liver and heart, and immune and developmental damage to infants and children," according to the Environmental Protection Agency, which recently set national limits for PFAS in drinking water.

For her thesis research, Amélie Lemay crafted computer simulations that could one day help lead the way to removing PFAS pollution from the environment.

Lemay, a civil and environmental engineering major, used simulations to investigate how seven types of molecules behave above bodies of water, where the water meets the air. She modeled their tendencies to mix with water or stick to the water-air boundary, and probed how mixtures of PFAS molecules interact — mimicking the messy reality of contaminated water.

Detailed knowledge of this chemistry could be key to understanding how remediation methods will work in settings like water treatment plants. Over the next few years, utilities across the United States will need to find effective ways to remove PFAS (per- and polyfluoroalkyl substances) from drinking water to comply with the EPA limits.

"Most of our drinking water treatment plants are not set up to deal with these compounds," said Lemay. "This type of research can eventually lead to better ways to be able to take PFAS out of water."

Lemay, of Wynnewood, Pennsylvania, came to Princeton with aspirations of using engineering to address environmental challenges. But using computer simulations to understand pollution was not part of her plan.

The summer after her first year, in 2021, Lemay secured internship support from Princeton's High Meadows Environmental Institute to conduct field work with associate professor Ian Bourg on how rocks weather in the Princeton area and in the French Alps — research with implications for soil nutrients and atmospheric CO_2 forecasting.

But COVID-19 travel restrictions were still in place that summer, so Bourg worked remotely with Lemay and several other students to set up simulations exploring the behavior of pollutants ranging from PFAS to anti-inflammatory drugs to insecticides.

"When I first started with Professor Bourg, he had to walk me through step by step how to create a file" simulating a single chemical compound, said Lemay, who earned certificates in statistics and machine learning and sustainable energy.

Over time, she learned to add more complexity, accounting for variables like salinity and surface tension. The work became "like second nature."

The summer project was a new direction in the lab's research. Bourg, an associate professor of civil and environmental engineering and the High Meadows Environmental Institute, said he was learning along with the students. He quickly realized that he could rely on Lemay, who was "thinking like a grad student since the very beginning, in terms of being super conscientious and questioning the way we do things," said Bourg.

For her senior thesis with Bourg, Lemay developed complex simulations of how multiple PFAS molecules move and interact at the interface of water and air. Her results revealed that the contaminants' movements are not limited only by physical space but also by complex charge interactions among neighboring PFAS molecules.

The simulations are a powerful way to understand how pollutants move in the environment, potentially helping to explain how rain interacts with contaminants, and why sea spray and lake spray aerosols are an important source of PFAS exposure in coastal communities. Lemay hopes this understanding can inform strategies to clean up PFAS pollution.

She is now a Ph.D. student at the Massachusetts Institute of Technology. She's interested in using computational methods to design chemicals for programmed degradation, to prevent problems with environmental contamination in the future.

"I think Princeton's focus on undergraduate research really sets this institution apart," said Lemay. "I'm grateful to have had the chance to work with multiple mentors who have shown me … how to design solutions and search for knowledge, and then share that with the greater community." **–by Molly Sharlach**

For her senior thesis, Amélie Lemay worked with Ian Bourg, an associate professor of civil and environmental engineering and the High Meadows Environmental Institute. She developed simulations of how PFAS molecules, a critical class of environmental contaminants, move and interact at the interface of water and air. Photo by Sameer A. Khan/Fotobuddy

GRADUATE NEWS

Graduate students advance research on sustainable energy and artificial intelligence

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Photo courtesy of José de Jesús Moñtano López

José de Jesús Montaño López
Ph.D. 2024
Chemical and Biological Engineering
Adviser: Adviser: José Avalos, Associate Professor of Chemical and Biological Engineering and the Omenn-Darling Bioengineering Institute

Montaño López is engineering yeast — the same yeast used for millennia to bake bread and ferment wine and beer — to produce isobutanol, a biofuel with the potential to replace both gasoline and jet fuel and help curb global climate change.

"Compared to bioethanol, isobutanol has higher energy density, it is less corrosive, it can be compatible with current infrastructure for cars, and can be upgraded to jet fuel," said Montaño López. "And we can produce it through microbes!"

With painstaking work, Montaño López generated a library of 5,000 genetically modified yeast strains, cataloged by their ability to produce isobutanol.

His adviser José Avalos praised Montaño López for his persistence and outside-of-the-box thinking. "Not just any student could do this kind of work," said Avalos, noting that Montaño López had to transform 5,000 strains, repeating the experiment more than 5,000 times — because you have to do them more than once — and then analyze all the results. "I think he's very bold in taking new approaches to old problems without knowing what he will find at the end. That takes a lot of courage."

Montaño López was named one of four winners of the Porter Ogden Jacobus Fellowship, Princeton University's top honor for graduate students.

Photo courtesy of Allison Chen

Allison Chen
Ph.D. Candidate
Computer Science
Adviser: Olga Russakovsky, Associate Professor of Computer Science

Chen is interested in better understanding artificial intelligence, and understanding nonexperts' beliefs and attitudes toward AI.

She entered graduate school in 2022 with research experience in computer vision, specifically depth perception and medical imaging, but had an interest in psychology and cognitive science as well. In Professor Tom Griffiths' lab, Chen worked on a project to examine what visual understanding capabilities large language models (LLMs) can gain from text alone and what aspects of the models enable this performance.

The second vein of Chen's research has stemmed from a realization that there is a great need for better education on the rapidly changing area of AI to empower people to use the technology safely and appropriately. She's researching questions that can guide the creation of informal educational materials around AI, such as games or museum exhibits. Chen is looking into how the rhetoric and discourse around LLMs affect individuals' anthropomorphic beliefs. For example, do advertisements or news articles about AI social companions make us more prone to see LLMs as capable of feeling?

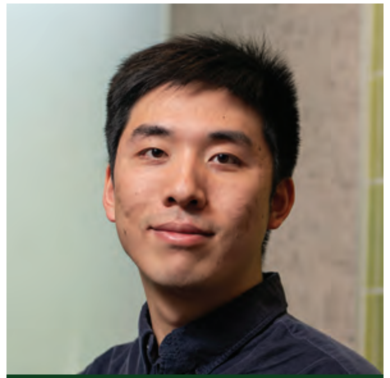


Photo by Adena Stevens

Jinyue (Jerry) Jiang
Ph.D. Candidate
Civil and Environmental Engineering
Adviser: Z. Jason Ren, Professor of Civil and Environmental Engineering and the Andlinger Center for Energy and the Environment

At the beginning of his graduate career, Jiang helped develop technologies for cutting carbon emissions from the water and wastewater treatment sectors. As he entered his fifth year, he shifted his focus to the role water itself will play in the overall decarbonization of society.

"Water and energy are strongly intertwined, and the relationship between them goes both ways," said Jiang. "Many of the steps for extracting and treating water are surprisingly energy-intensive. On the other hand, many energy technologies require quite a large amount of water, both as a feedstock and for cooling purposes."

Jiang is investigating the costs, opportunities, and feasibility of using treated wastewater as a water source for the emerging hydrogen economy.

Producing clean-burning hydrogen production requires abundant water and electricity from renewable sources such as solar energy. Yet many seemingly ideal locations for such a process, such as California, with its large solar generation capacity, are already water-stressed.

Most hydrogen production uses the public water supply, Jiang said. "If we could instead integrate these technologies to use treated wastewater effluent, it could be an efficient and widely available way to deploy clean energy without significantly worsening water shortages."

Jiang is a recipient of the Maeder Graduate Fellowship, which is supported by the Paul A. Maeder '75 Fund for Innovation in Energy and the Environment.

Graduate students honored for excellence in teaching

In May 2024, the Graduate School presented 10 graduate students with its annual Teaching Awards in recognition of their outstanding abilities as instructors.

Honorees in engineering were Katherine Sniezek and Katie VanderKam. **–by Jennifer Altmann**

Photo by Matthew Graesser

Photo by Emma Schmaltz

Katherine Sniezek, a Ph.D. student in chemical and biological engineering, served as an assistant in instruction for the courses "Chemical Engineering Laboratory" and "Mass, Momentum, Energy Transport."

"Katherine's desire for students to learn not just the answer, but the fundamental understanding behind the answer, was on full display from Day 1," said Michele Sarazen, an assistant professor in chemical and biological engineering.

One student, who has had Sniezek as a preceptor and thesis adviser, observed that she "is always willing to allocate as much time as necessary for me to truly understand the material, and her thorough understanding of chemistry and biology allows her to adapt to a variety of teaching styles that best facilitate my learning experiences or whomever she is helping."

Katie VanderKam, a Ph.D. student in mechanical and aerospace engineering, served as a preceptor for the courses "Energy Conversion and the Environment: Transportation Applications" and "Thermodynamics."

"Approaching teaching as an opportunity to unleash the inner potential of all of the students, she would push the students to go one step further, unlocking self-discovery rather than simply telling the students the answers," said Michael E. Mueller, the associate chair and professor in the Department of Mechanical and Aerospace Engineering.

Students remarked that VanderKam made an extra effort to provide guidance when students were wrestling with complex material. "Katie was able to always give direct and concise yet still understandable answers to our questions," one student said. "I also think Katie did a great job of relating the material to real world examples."

Alumni Honors for Research and Innovation

Norman Augustine '57 *59 H07 received a Lifetime Achievement Award from the Air & Space Forces Association. A distinguished aerospace leader, Augustine served as assistant director of defense research and engineering, assistant secretary of the Army, undersecretary and acting secretary of the army. In the private sector, he led Martin Marietta and Lockheed Martin as CEO. Augustine has been pivotal in shaping U.S. space policy, chairing the "Advisory Committee on the Future of the U.S. Space Program" and serving on key advisory boards. In the nonprofit sector, he chaired the American Red Cross, National Academy of Engineering, and Association of the Unites States Army. He received B.S.E. and M.S.E. degrees in aeronautical engineering from Princeton, and an honorary Doctor of Laws degree in 2007.

Francis J. Doyle III '85, a professor of engineering and Brown University's provost, was elected a member of the American Academy of Arts and Sciences, one of the nation's most prestigious honor societies. Doyle applies systems engineering principles to the analysis of regulatory mechanisms in biological systems. His work includes the design of drug-delivery devices for diabetes; modeling, analysis, and control of gene regulatory networks underlying circadian rhythms; and computational analysis for developing diagnostics or post-traumatic stress disorder. Doyle holds a B.S.E. in chemical engineering from Princeton, a certificate of post-graduate studies from Cambridge University, and a Ph.D. in chemical engineering from the California Institute of Technology.

Cato Laurencin '80 was inducted into the Plastics Hall of Fame. The university professor and CEO of The Cato T. Laurencin Institute for Regenerative Engineering at the University of Connecticut, Laurencin was recognized for his work in pioneering the field of regenerative engineering and utilizing polymeric materials in medical devices, biologics, and pharmaceuticals. He earned a B.S.E in chemical engineering from Princeton, his medical degree from Harvard Medical School, and his Ph.D. in biochemical engineering/biotechnology from the Massachusetts Institute of Technology. He is the first engineer-scientist-surgeon to be elected to the National Academy of Sciences, the National Academy of Engineering, the National Academy of Medicine, and the National Academy of Inventors.

Li Li *05, the Barry and Shirley Isett Professor of Civil and Environmental Engineering in the Penn State College of Engineering, was honored with the American Geophysical Union's Joanne Simpson Medal. Her research focuses on questions at the intersections of hydrology, biogeochemistry, ecology, and environmental engineering. She earned master's and bachelor's degrees in environmental chemistry from Nanjing University, China, and a Ph.D. in environmental engineering and water resources from Princeton. Before joining Penn State in 2009, she worked at the Lawrence Berkeley National Laboratory.

Sridhar Vembu *94, the co-founder and CEO of Zoho Corporation, was named to the International Business Times' (IBT) Top 20 CEOs List for 2024. In 1996, Vembu and co-founder Tony Thomas started AdventNet Inc., which later evolved into Zoho Corporation. Their goal was to develop high-quality, affordable software solutions that catered to diverse business needs. IBT cited Zoho Corporation's comprehensive suite of applications, commitment to affordability, and global presence Vembu earned a degree bachelor's from the Indian Institute of Technology Madras and a Ph.D. from Princeton, both in electrical engineering.

A paper written by **Brent Waters** *04, director of the Cryptography & Information Security Lab at NTT Research, has been honored by with a Test-of-Time Award by the International Association for Cryptologic Research. The paper, delivered at Crypto 2009, presented a new way of proving adaptive security for identity-based encryption, which was later expanded to cover more complex cryptographic systems. This is Waters' third Test-of-Time Award from the IACR, and sixth total. Waters, who is also a professor of computer science at the University of Texas at Austin, received a B.S. from the University of California-Los Angeles and a Ph.D. from Princeton, both in computer science.

Photos courtesy of the subjects. Photo of Li Li by Kevin Sliman

Alumni Leadership in Academia and Industry

Robert Batten *11 has been appointed CEO of The Princeton Review and its affiliate company, Tutor.com, which helps institutions and organizations deliver personalized homework help at scale. He comes to The Princeton Review from Cengage, where he led the launch of Cengage Unlimited and scaled the ed2go business. Prior to that, he drove digital innovation for technology and telecommunications companies during his tenure at the Boston Consulting Group. Batten holds a bachelor's degree in chemical engineering from the Massachusetts Institute of Technology and a Ph.D. in chemical engineering from Princeton.

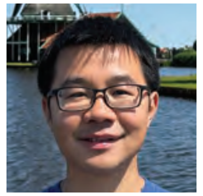
Ann Chen '89 was named a term member of Princeton University's Board of Trustees. She was a partner at Bain & Company, where she worked for 22 years. Since retiring, she serves as an independent adviser to family foundations and nonprofit organizations. Chen also sits on the boards of Common Sense Media and the Corporation of Yaddo. Previously, she served on the Dean's Leadership Council and Dean's Advisory Group at the Harvard Graduate School of Education, as well as on the Harvard Business School Alumni Board. After receiving her B.S.E. in computer science from Princeton, Chen earned an M.B.A. from Harvard Business School.

Kenneth Chen Wei-on '87 was named vice president for administration at The Chinese University of Hong Kong (CUHK), responsible for administering the infrastructure development of the university in line with its strategic vision. Chen worked in investment banking and management consulting before joining The Hong Kong Jockey Club in various senior management positions. He was undersecretary for education of the Hong Kong Government from 2008 to 2012, and secretary general of the legislative council secretariat from 2012 to 2024. He received a B.S.E. in electrical engineering from Princeton, an M.S. from Harvard University, and an M.B.A. from The Wharton School of the University of Pennsylvania.

Edith Elkind *05 joined Northwestern Engineering's Department of Computer Science as a Ginni Rometty Professor of Computer Science. Elkind's research has significantly advanced the fields of computational social choice and multi-agent systems with applications in artificial intelligence. Prior to joining Northwestern, she was a professor of computing science at the University of Oxford. She earned an M.Sc. in mathematics from Moscow State University and a Ph.D. in computer science from Princeton.

Susan Ipri-Brown '93 is the 143rd president of the American Society of Mechanical Engineers (ASME). Ipri-Brown is a Fellow of ASME, has served on the ASME Board of Governors, and has been an active member of the society for 34 years, including her years as a student member. She is a strategic partnership specialist at the National Institute of Standards and Technology (NIST) Office of Advanced Manufacturing (OAM). Prior to joining OAM, she served as the associate dean for educational outreach, as founding director of the ExploreHope Academic Outreach Office, and as an associate professor of engineering instruction at Hope College in Holland, Michigan. She also served as associate director of STEM Education Partnerships at Northwestern University. Ipri-Brown received a B.S.E. in mechanical and aerospace engineering from Princeton and an M.E. in mechanical engineering from the Massachusetts Institute of Technology.

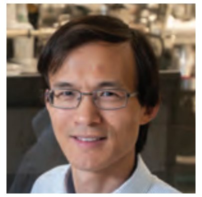
James Lee '96 was named CFO of Target. Lee most recently served as PepsiCo's deputy CFO. Before that, he held several senior positions at the beverage giant, including senior vice president of corporate finance, as well as chief strategy and transformation officer. He joined PepsiCo over 25 years ago. He received a B.S.E. in civil engineering from Princeton and an M.B.A. from Columbia Business School.



Dan Li *13, an associate professor of earth and environment at Boston University, joined BU's Initiative on Cities (IOC) as the Urban-H Associate Director of Heat. In this capacity, he will spearhead the development of innovative solutions to urban heat challenges. Li received his B.E. in hydraulic engineering from Tsinghua University and his Ph.D. in civil and environmental engineering from Princeton. He currently oversees the Environmental Fluid Mechanics Group, which analyzes interactions between the lower atmosphere and the Earth's surface, utilizing research tools to address environmental challenges, including climate change and urbanization.

Yanbing Li *98 was named the chief product officer of Datadog, a monitoring and security platform for cloud applications. Li has more than 25 years of product, technology, and engineering experience, having led global engineering, operations, and infrastructure teams at Aurora, Google, and VMware. Most recently, Li was senior vice president of engineering at Aurora, where she led all software development efforts. She holds a Ph.D. in electrical engineering from Princeton, a master's degree from Cornell University, and a bachelor's degree from Tsinghua University.

Qiangfei Xia *07, professor of electrical and computer engineering at the University of Massachusetts Amherst, was appointed to the Dev and Linda Gupta Professorship for a five-year term. Established in 2000, the professorship supports Department of Electrical and Computer Engineering faculty members who are pursuing new areas of inquiry. A UMass Amherst ECE faculty member since 2010, Xia leads the Nanodevices and Integrated Systems Laboratory and is an internationally renowned researcher in the field of emerging computing hardware, specifically memristor devices and their application in machine intelligence. Xia holds B.E. and M.S. degrees from Shanghai Jiao Tong University and received his Ph.D. in electrical engineering from Princeton.



Photos courtesy of the subjects. Photo of Qiangfei Xia by Ben Barnhart, bbimages