Fall 2024

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Engineering Innovation @LehighU

AMPLIFYING IMPACT

Lehigh's interdisciplinary research culture sparks collaboration and incubates innovation

See page 10

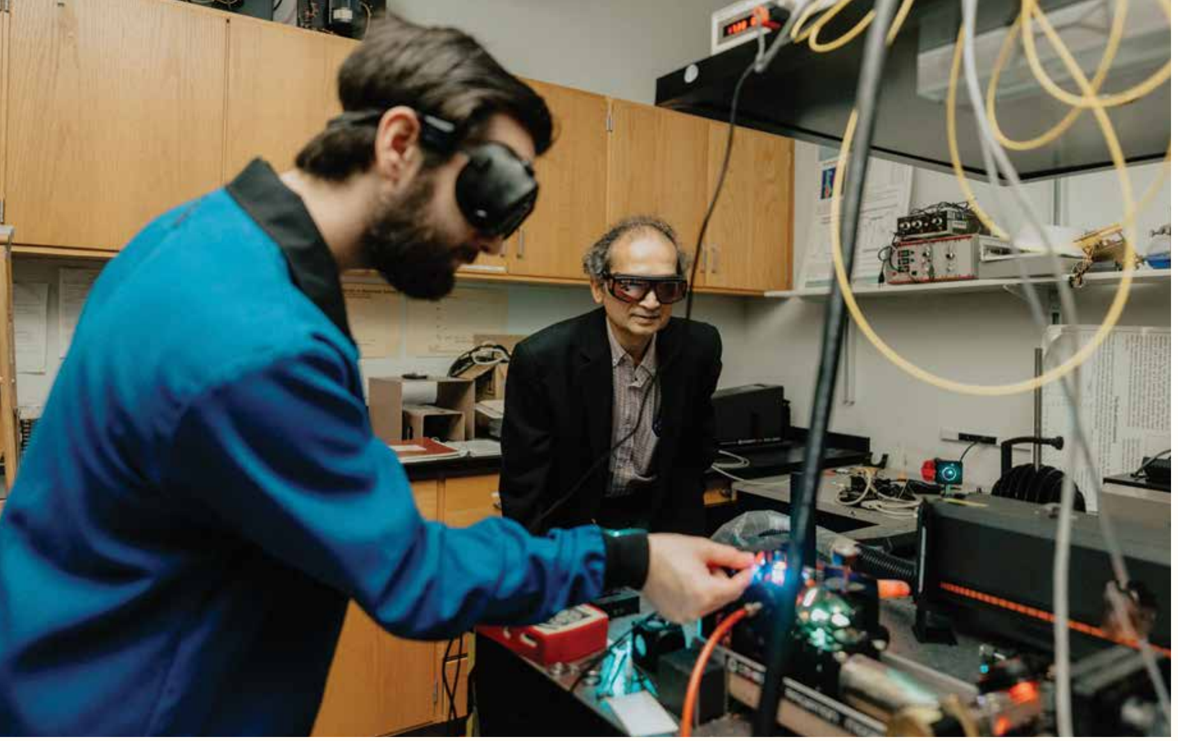
/ Shaping a greener chemical industry

See page 16

/ FYRE: A first-year student experience like no other

See page 22

LEHIGH UNIVERSITY | P.C. Rossin College of Engineering and Applied Science



Anthony Tsekrekas, a PhD student in Lehigh's P3 Program, and Prof. Himanshu Jain work with the dye laser featured on this issue's cover. The laser's tunability allows them to explore how materials interact with various wavelengths of light under different conditions.

Features

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LEHIGH UNIVERSITY

Incubating innovation

Welcome to the Fall 2024 issue of *Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

This issue of *Resolve* celebrates some of the many accomplishments of Lehigh's three Interdisciplinary Research Institutes (IRIs). These "incubators of innovation" encourage our faculty to explore new research vistas through cross-disciplinary collaboration, while positioning Lehigh toward greater societal impact.

Since their inception in 2018, the Institutes for Functional Materials and Devices (I-FMD); Data, Intelligent Systems, and Computation (I-DISC); and Cyber Physical Infrastructure and Energy (I-CPIE) have grown to include more than 50 research teams, 150-plus faculty members from all five colleges, numerous graduate students, and diverse external partners in industry, government, and academia.

Our cover article (page 10) explains how initiatives rooted in the IRIs have become central to the launch of Lehigh's recently announced University Research Centers (URCs). The goal of these centers, a key initiative emerging from Lehigh's institutional strategy, *Inspiring the Future Makers*, is to aim for Lehigh to be "first, best, or only" by supporting faculty, students, and partners to drive innovation, secure funding, and produce impactful research in specific areas of existing strength and future promise.

The first wave of the URCs was announced earlier this year. The teams mobilized by this new designation are tackling interdisciplinary challenges within topics such as community and infrastructure resilience, equitable and reliable electrification, and the intersection of technological development and public health. These teams were seeded within the IRIs and grew in strength and focus to become initiatives worthy of institutional-level support.

These URC initiatives, along with other projects featured in this issue of *Resolve*, are a testimony to the power of the collaborative, interdisciplinary culture that the Lehigh faculty has built and nurtured.

THESE RESEARCH INITIATIVES TESTIFY TO THE COLLABORATIVE, INTERDISCIPLINARY CULTURE BUILT BY THE LEHIGH FACULTY.

For example, "Reaction Time" (page 16) delves into an array of multifaceted efforts to bring sustainability to the chemical industry. Rossin College researchers are tackling challenges—from supercharging catalytic converters to optimizing agricultural fertilizer to fine-tuning the manufacturing of building materials—that could play a key role in the U.S. government's net-zero strategy.

And in "Good Nanomedicine" (page 14), we explore the work of bioengineering professor and department chair Anand Ramamurthi. His team is combating aortic aneurysms by developing nonsurgical regenerative therapies that have the potential to slow, reverse, or perhaps even stop aneurysm growth soon after detection.

Incubating innovation in the educational experiences of our students, while retaining the rigor of a classic Lehigh education, has been another main area of focus for our college over the past few years. "Catching FYRE" (page 22) introduces our initiative to re-envision the way that first-year engineers encounter and explore our field.

The First-Year Rossin Experience, or FYRE, will incorporate the principles of Lehigh User-Designed Inquiry (LUDI) into the academic journey of our incoming class each fall. This initiative, developed with support and guidance from William Guadelli, the university's senior vice provost for educational innovation and assessment, will enable our students to create personalized academic programs and will encourage them to pursue unique interdisciplinary learning experiences based on their individual passions.

In our Q&A (page 8), we catch up with Lehigh chemical engineering alumnus Stephen S. Tang '85G '88 PhD '22P, a renowned business leader and entrepreneur with extensive experience in healthcare, biotechnology, and innovation leadership.

To close, we shine the spotlight on this issue's Rising Star, A. Emrah Bayrak, an assistant professor of mechanical engineering and mechanics (page 24). His work in developing best practices for integrating artificial intelligence into complex engineering design projects led to a successful bid for a 2024 NSF CAREER Award, which recognizes outstanding early-career faculty research and education.

I hope you enjoy this edition of *Resolve*; thank you as always for your interest in Lehigh Engineering!

Stephen P. DeWeerth, *Professor and Dean*
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THIS PAGE: RYAN HULVAT; OPPOSITE PAGE: SHOTBYASGAR

A perfect storm

Study looks at risks to communities when flooding and cyber attacks combine

Society is now in an era in which climate change and cyber insecurity are regular threats to life and property. In tandem, the two have the potential to be especially deadly.

"There's evidence that climate change increases the risk of flooding, and the losses due to those floods are growing every year," says Y.C. Ethan Yang, an associate professor of civil and environmental engineering. "Scientists have started thinking about compound issues that exacerbate flooding, like when a hurricane is followed by heavy rainfall."

"WE WANTED TO KNOW IN WHAT FLOODING SCENARIO A HACKER COULD CAUSE THE MOST HARM." —Y.C. Ethan Yang

The team, which included Chung-Yi Lin '23 PhD (now a postdoc at Virginia Tech) and Lehigh civil and environmental engineering faculty member Farrah Moazeni, were interested in studying what happens when a natural disaster and a man-made disaster, like a cyber attack, happen simultaneously. They wanted to understand how vulnerable a smart stormwater system could be to a hacker when that system was also dealing with storm-induced flooding.

"The idea of the smart city is great, but it opens the door to hackers," says Yang. "We wanted to know in what flooding scenario a hacker could cause the most harm."

The team used historical data from the stormwater management system in Bethlehem Township, Pennsylvania, to build a hydrological model to simulate flooding. They also developed an attack model that mimicked how a hacker might interfere with the system, for instance, by opening or closing gates that control water levels in retention ponds.

They combined the data with the models to run simulations under various climate change impact scenarios to evaluate the conditions in which a hacker might have the greatest impact on a stormwater system, thereby increasing a community's flood risk.

"The most vulnerable condition is during low- to mid-level flooding events," says Yang. "The system should be able to handle those events. But if someone intentionally opens a gate at the wrong time, it will overwhelm the system and cause a flood downstream. We were able to quantify and show through visualizations this additional flooding risk caused by a cyber attack."

The results have already prompted two additional projects: One will explore how to prevent such interference, and the second will examine the cascading effects within a flooded community, specifically how different groups of people are affected.

Yang hopes the mathematical framework he and his team developed for this project will be adopted by other communities across the country and around the world.

"We developed a procedure that allows any municipality to identify the vulnerabilities within their stormwater systems," he says. "If you have the data, the method is universal."

INTERNATIONAL PARTNERSHIP FOCUSES ON FLOOD RISK

An interdisciplinary team led by Professor Y. C. Ethan Yang has been awarded a $1 million grant by the National Science Foundation and the Japan Science and Technology Agency to fund research focusing on flood-prone areas in the United States and Japan. The project aims to enhance flood risk management through human-centered data analysis.

The project will study the Kuma River in Japan (pictured) and the Passaic River in New Jersey, employing a catastrophe modeling approach to predict flood impacts and recovery. This research builds upon work within Lehigh's Catastrophe Modeling Center (see page 12).

One novel aspect of the study involves gathering human-centered data via surveys to understand how communities, particularly minoritized ones, prepare for and respond to floods. The research seeks to build resilience and mitigate the impact of natural disasters worldwide and will help build international cooperation in addressing increasingly severe climate-related hazards.

TOP: BILANOL/ADOBE STOCK; BOTTOM: GEOSPATIAL INFORMATION AUTHORITY OF JAPAN (CC BY 4.0)

What's next in semiconductors

For decades, silicon has been the go-to semiconductor for use in electronics because of its abundance, availability at a very high crystal quality, and ability to be what scientists call "doped," or having its electrical properties controlled through the introduction of impurities.

"Silicon works but it's not ideal," says Siddha Pimputkar, an associate professor of materials science and engineering. "We're researching new synthesis pathways to make materials that have superior properties for the conversion of electricity at higher power."

In more recent times, a new class of semiconductors has been developed that enables better performance for a variety of applications, including use at higher temperatures, handling higher frequencies, and switching larger voltages. The two leading "wide-band gap" (WBG) materials are gallium nitride (GaN) and silicon carbide (SiC).

"The challenge now is, can we do even better than GaN and SiC?" says Pimputkar, whose research in this space is funded by a $1.1 million grant from the U.S. Army DEVCOM Research Laboratory. "Now we're talking about materials that used to be considered insulators, but if we can control the electron concentrations in them, we can consider them ultra-wide bandgap semiconductors."

Diamond is considered by many to be the leading UWBG material for applications because of an advantageous combination of material properties. It has the potential to perform well in high-voltage and high-frequency applications, and recent advances have made it possible to grow single-crystal synthetic diamonds in laboratory settings. However, there are challenges to using diamond as a semiconductor material, including difficulties in doping the material for some applications.

Pimputkar believes that a different material, cubic boron nitride (c-BN), holds the greatest potential for power electronic applications. The compound's atoms are arranged in a structure similar to that of diamond, and the material has a wider bandgap of 6.4 eV compared with 5.5 eV for diamond. But c-BN comes with challenges of its own—namely, growing it at crystal sizes needed to produce "wafers," the thin slices of semiconductors on which microelectronics are built.

Currently, the process for growing bulk, single-crystal c-BN is similar to that of synthesizing diamonds, requiring high pressures and high temperatures while yielding crystals that are only millimeters in size.

"For electronics, you need crystals of centimeters or inches to create wafers," Pimputkar says. "I want to find a way to grow c-BN using a process that actually scales to an industrial level."

The path there is two-pronged. One goal is to grow c-BN using a new process that requires less pressure. The other is to grow it large enough to make a device enabling the measurement of the saturation velocity of electrons in c-BN, something that has been done so far only using computational methods.

"Based on figures of merit, c-BN is the best," he says. "Now, can we make a c-BN device that can substantiate the promised properties of the material? No one has been successful in doing that yet."

Pimputkar theorizes that the process of growing c-BN at lower pressures can be enabled by beginning with a seed crystal of c-BN and depositing more boron nitride onto its surface using a new synthesis pathway and appropriate catalysts. He believes that this method can produce the desired cubic crystal structure and not just the more readily grown hexagonal structure.

"While hexagonal boron nitride (h-BN) is a fantastic material in its own right, we are learning how to coax out the cubic version," he says.

Pimputkar's laboratory (pictured) has established expertise in researching nitride growth processes under a previous grant from the National Science Foundation's Faculty Early Career Development (CAREER) program. His research group has been investigating the c-BN growth question for approximately two years of the initial three-year U.S. Army grant, which could be extended up to two additional years.

Early results are promising, Pimputkar says. Experiments have demonstrated the growth of h-BN, which is similar to and complements graphene, the two-dimensional "supermaterial" that netted its investigators a Nobel Prize in 2010.

"We're at a phase where we are trying to understand what it takes to grow c-BN instead of h-BN," he says. "We're aiming for a proof of concept followed by demonstration of cm-scale crystals we can give people to further test it for its future potential. It's high-risk, high-reward."

TOP: SHOTBYASGAR; BOTTOM: REMIGIUSZ/ADOBE STOCK

RECOVERING RESOURCES FROM UTILITY WASTE

The waste created by power generation utility companies could be a potential source of metals and minerals that are key components of modern electronics, batteries, vehicles, and the clean-energy industry as a whole.

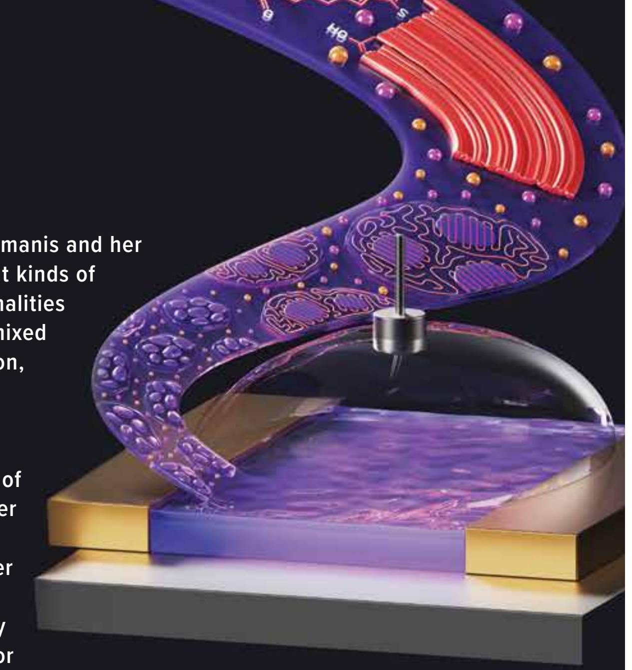
Zheng Yao, principal research scientist within Lehigh's Energy Research Center (ERC), and a multidisciplinary team of researchers received a $2.5 million grant from the Department of Energy to identify rare earth elements (REEs) and elements of interest (EOIs) in wastewater and solid waste streams and to develop the technology that could extract those elements.

"Energy production creates liquid waste in the form of wastewater, or leachate, and solid waste in the form of ash," says Yao, the project's lead researcher. "The volume of landfill leachate is approximately 10 billion gallons per year, and the volume of ash is 190 to 240 billion gallons per year. Developing a means of mineral recovery to reduce the cost of waste treatment while recovering valuable constituents is of great importance."

According to Yao, there is only one large-scale mine in the United States that extracts REEs that are essential to the batteries that power devices like cell phones and electric vehicles, which are vital to growing the clean-energy economy. Tapping into the vast waste streams generated by utility companies could bolster our national reserves of such materials and reduce our dependence on foreign suppliers.

The goal is to demonstrate the effectiveness of the technology and to ultimately scale it up to be available commercially.

"Utility companies could use it to mitigate waste and contamination, and the U.S. would have another domestic feedstock for battery manufacturing," says Yao. "This is an opportunity to solve real-world problems."



EXPANDING POSSIBILITIES IN SENSOR TECHNOLOGY

Sensors enable us to monitor changes in systems of all kinds. The materials at the heart of those sensors, of course, ultimately determine their end-use application. Devices made of silicon, for example, enable ultrafast processing in computers and phones, but they aren't pliable enough for use in physiological monitoring. They also require a lot of energy to produce.

Elsa Reichmanis, Carl Robert Anderson Chair in the Department of Chemical and Biomolecular Engineering, recently received a grant from the NSF for her proposal to identify new materials platforms that could form the basis of effective sensors for applications in areas like physiological, environmental, and Internet of Things monitoring, while increasing the energy efficiency of fabrication processes.

"We'll be creating the polymers that could be the building blocks of future sensors," says Reichmanis. "The systems we're looking at have the ability to interact with ions and transport ionic charges, and in the right environment, conduct electronic charges."

Having the ionic charge within the organized polymer network can essentially "dope" the charge of the polymer so that it becomes a semiconductor.

"And then as a semiconductor with very low applied voltages," she says, "there will be charge transport, which can then lead to an electronic signal readout that can tell you what's happening."

The network will also be functionalized to interact with various chemical species, she says. Taken together, functionalized material that can act as a semiconductor could be used in a range of applications.

Specifically, Reichmanis and her team will explore what kinds of polymers and functionalities will support organic mixed ion electron conduction, where both ions and electrons are transported. That ability to support the transport of both allows for a better signal-to-noise ratio, which enables the user to determine if something is, indeed, really there. It also allows for devices to operate at low voltage—an important characteristic when considering their use on or in the human body.

"We'll be researching the chemistries involved, but then simultaneously, from a modeling simulation perspective, how are these ions actually interacting with the polymers and their functionalities on a more fundamental level? What is the interaction between ion transport and electron transport?"

Ultimately, she says, the goal is to broaden the choice of building block materials, expand the functionalities that support mixed conduction, and come to a better understanding of what mixed conduction is really about.

Digging deeper into stability challenges of nuclear fusion

Mayonnaise continues to help researchers better understand the physics behind nuclear fusion.

"We're still working on the same problem, which is the structural integrity of fusion capsules used in inertial confinement fusion, and Hellmann's Real Mayonnaise is still helping us in the search for solutions," says Arindam Banerjee, the Paul B. Reinhold Professor of Mechanical Engineering and Mechanics and chair of the MEM department.

Inertial confinement fusion is a process that initiates nuclear fusion reactions by rapidly compressing and heating capsules filled with fuel, in this case, isotopes of hydrogen. When subjected to extreme temperatures and pressure, these capsules melt and form plasma, the charged state of matter that can generate energy. "One of the main problems associated with this process is that the plasma state forms these hydrodynamic instabilities, which can reduce the energy yield," says Banerjee.

In their first paper on the topic back in 2019, Banerjee and his team examined that problem, known as Rayleigh-Taylor instability. The condition occurs between materials of different densities when the density and pressure gradients are in opposite directions, creating an unstable stratification. "We use mayonnaise because it behaves like a solid, but it flows when subjected to a pressure gradient," he says. Using the condiment also negates the need for high temperatures and high-pressure conditions.

In their latest paper, published in *Physical Review E*, the team looked at the material properties, the perturbation geometry (amplitude and wavelength), and the acceleration rate of the materials that undergo Rayleigh-Taylor instability.

"We investigated the transition criteria between the phases of Rayleigh-Taylor instability and examined how that affected the perturbation growth in the following phases," says Aren Boyaci '24 PhD, the first author of the study. "We found the conditions under which the elastic recovery was possible, and how it could be maximized to delay or completely suppress the instability. The experimental data we present are also the first recovery measurements in the literature."

There is, however, the looming question of how the team's data fit into what happens in actual fusion capsules, the property values of which are orders of magnitude different from the soft solids used in their laboratory experiments.

"In this paper, we have non-dimensionalized our data with the hope that the behavior we are predicting transcends these few orders of magnitude," says Banerjee. "We're trying to enhance the predictability of what would happen with those molten, high-temperature, high-pressure plasma capsules with these analog experiments of using mayonnaise in a rotating wheel."

Ultimately, Banerjee and his team are part of a global effort to turn the promise of fusion energy into reality.

"We're another cog in this giant wheel of researchers," he says. "We're all working toward making inertial fusion cheaper and attainable."

TOP: ILLUSTRATION BY ELLA MARUSHCHENKO; BOTTOM: KANSAKOI/ADOBE STOCK

Timber-based wall system takes on tall task of earthquake resilience

A building's resilience is measured by its ability to operate safely during—and after—extreme events. It may remain standing after an earthquake, but if damage is severe enough to make it uninhabitable, the building is not a resilient structure.

Traditionally, the materials used to promote resiliency under maximal loading caused by events like earthquakes have been steel and concrete—both of which have significant carbon footprints. According to the consulting firm McKinsey & Company, producing a ton of steel emits 1.85 tons of carbon dioxide into the atmosphere, while cement production accounts for a whopping 7 percent of global CO_2 emissions.

> "THE CONSTRUCTION INDUSTRY IS TRYING TO REDUCE ITS CARBON IMPACT."
> —Alia Amer '23 PhD

"The construction industry is trying to reduce its carbon impact," says Alia Amer '23 PhD, a postdoctoral researcher at the Lehigh University National Hazards Engineering Research Infrastructure (NHERI) Real-Time Cyber-Physical Structural Systems Testing Laboratory. "And so the focus has shifted to timber, which historically didn't give us the appropriate strength and stiffness for use in tall buildings located in seismic regions. But there are now engineered wood products that do provide those properties, and they can be made from trees that don't need to grow very large. Our job is to better understand how this material behaves under earthquake loading conditions, so industry feels confident using it for these structures."

Amer—supervised by Richard Sause, the Joseph T. Stuart Professor of Structural Engineering, and James M. Ricles, the Bruce G. Johnston Professor of Structural Engineering and director of Lehigh's Real-Time Multi-directional Earthquake Simulation Facility—succeeded in designing and testing a large-scale timber subassembly constructed with cross-laminated timber (CLT) rocking and glue-laminated (glulam) timber components that are able to survive an earthquake without suffering damage. The effort is part of the NHERI TallWood project, funded by the National Science Foundation.

"There were no design guidelines," says Ricles. "Dr. Amer had to do everything from the ground up when it came to figuring out how to build a shear wall made of timber and all the connections—meaning the beams, columns, and brackets—so it could withstand an earthquake of very high magnitude. And she proved that it could work."

The team published their work, and their findings were also incorporated into a 10-story mass timber structure (pictured) that was tested last year on a giant outdoor shake table at the University of California, San Diego. Researchers simulated magnitude 6.7 and 7.7 earthquakes and found very little damage to the structure.

The ultimate goal of the NHERI TallWood project is to develop design and construction guidelines for the rocking-wall system that can then be incorporated into building codes. Once the method is codified, timber could become a viable, greener alternative for tall buildings.

"The system can survive just about any damage," says Ricles. "Traditionally, engineers designed systems to survive an earthquake that led to damage but avoided collapse. But if the building is condemned because of damage, it's essentially the same result. We wanted to design something that could continue to function—and do it with timber. And that's exactly what we did."

UNIVERSITY OF CALIFORNIA SAN DIEGO/DAVID BALLOT

NEW ATLSS LEADERSHIP

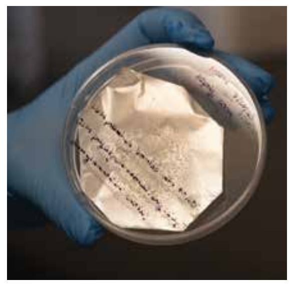
Professor James M. Ricles (left) has been appointed director of Lehigh's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center, succeeding Professor Richard Sause after more than 20 years of leadership. Professor Muhannad T. Suleiman, who specializes in geotechnical engineering, is the new deputy director.

Exploring enzyme-polymer interactions

Whitney Blocher McTigue's research could inform the development of specialized degradable bandages

Imagine you are deep in the backcountry on a hiking trip, and you fall and rip a deep gash in your lower leg. You are a two-day walk away from proper treatment. After you stop the bleeding, your concern becomes keeping the wound clean.

Now, imagine you had just the thing in your first aid kit—a spray-on bandage embedded with a mild painkiller and a disinfectant. A bandage meant to deliver relief, and degrade within 48 hours, giving you time to make it to the hospital.



Solid polymer complexes are airbrushed onto a substrate, demonstrating a key step toward developing next-gen wound coverings.

That's one reality that Whitney Blocher McTigue, an assistant professor of chemical and biomolecular engineering, is working toward. She recently received a grant from the National Science Foundation to study the dynamics of how enzymes interact with polymer complexes and cause them to degrade.

"The inspiration for this research came from burn patients," says Blocher McTigue. "People who suffer second- or third-degree burns are at high risk of infection, and so their wounds need to be cleaned regularly. However, when you remove traditional bandages, you actually remove a lot of the nascent healing that's taken place. So every time you remove a bandage, you actually reduce and prolong the healing process."

The ultimate goal, she says, is to develop a degradable bandage. But first, she and her research team must better understand how the polymer complexes break apart. Polymer complexes comprise both negatively and positively charged peptides in either a liquid or solid state. The novelty of her lab's approach, she says, is how they are using enzymes to degrade the complexes.

"I like to think of enzymes like Pac-Man because they like to chew things up," she says. "And they can do that faster or slower depending on the concentration of the enzyme."

Once Blocher McTigue and her team better understand how the complexes and enzymes interact, they will be able to more effectively tune the structure of the complex itself—perhaps making it more positive or more negative—and the amount of enzyme required, based on the goal of the application. Essentially, they will be able to dictate how and when the degradation takes place.

For instance, a burn patient might require a bandage that breaks down, say, every four hours, in time for the next round of wound care. Or, medical providers might require a bandage that degrades in response to a specific stimulus—like a saline wash. Her team is also looking into how the technique could be used in drug delivery. Those sprayable bandages could be embedded with an analgesic, for instance, or a complex encapsulated with drugs or nutrients could be swallowed and timed to release its payload as it enters the small intestine.

"Or if you're out in the field, or you're a member of the military, and you experience some sort of physical trauma, a spray-on bandage could take the place of trying to pack a wound," she says. "It would keep the wound relatively clean until you made it to the operating room where doctors could use saline to degrade the covering and then get to work."

The potential applications are vast and exciting. But before the researchers can get to what Blocher McTigue calls "the really fun science," they need to understand the dynamics of the interplay between polymer complex and enzyme.

"This grant is going to allow us to look at how we can fiddle with those dynamics and make them do exactly what we want them to do," she says. "But I am very big into direct applications of research. Everyone in my lab is looking forward to how we can take this really cool fundamental science and, eventually, drop it into everyday use."

Blocher McTigue explains her research on the Rossin Connection podcast.

CHRISTA NEU

TOP: ADOBEDESIGNER/ADOBE STOCK; BOTTOM: LEHIGH ATHLETICS/HOLLY FASCHING '26

Balancing act

Team tackles the challenges of floating wind turbines

Our nation's greatest potential for abundant wind energy lies offshore. Locating wind turbines off both coasts, where wind speeds are the highest, could unlock high energy yields, akin to the offshore wind production in the North Sea near northern Europe.

But constructing wind turbine platforms in water deeper than about 60 meters presents problems. Turbines in shallow waters, like those in the North Sea, can be mounted on fixed-bottom platforms that are held to the seafloor by a rigid structure such as a monopile or foundation.

The offshore turbines operating in the United States are fixed-bottom turbines located in the relatively shallow waters over the continental shelf near New England. But deeper water, like that along the Northeast and the West Coast, which represents two-thirds of the country's offshore wind resources, renders this type of mount impractical. Engineers are therefore turning to floating offshore platforms and attempting to create economical, innovative floating structures that can harvest wind energy while also capturing energy from wave action.

> TWO-THIRDS OF U.S. OFFSHORE WIND POTENTIAL LIES IN WATERS TOO DEEP FOR CONVENTIONAL FOUNDATIONS.
>
> —Dept. of Energy

Floating platforms, which originated with oil and gas drilling, are held in place by mooring lines anchored to the ocean floor in various designs and configurations. But unlike oil and gas platforms, these structures need to carry the taller, unbalanced load of a wind turbine. That presents an additional set of problems—issues that Muhannad Suleiman, a professor of civil and environmental engineering, and his team are working to solve.

The interdisciplinary team of Suleiman, deputy director of Lehigh's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center; James M. Ricles, the Bruce G. Johnson Professor of Structural Engineering and ATLSS director; Richard Sause, the Joseph T. Stuart Professor of Structural Engineering; and Keith Moored, an associate professor of mechanical engineering and mechanics, recently received a $1 million National Science Foundation Research Advanced by Interdisciplinary Science and Engineering Clean Energy Technology award for their three-year project.

The project has four goals. The first is finding new ways to reduce the platform's motions. Limiting these motions improves the resilience of the structure. The second aim is to evaluate the effects of platform motion reductions on mooring line fatigue response. The third goal involves investigating bio-inspired concepts for energy generation and foundation design to determine potential increased power output and improve platform stability. The fourth goal involves real-time hybrid simulations. The data from the previous research tasks will be used to simulate their combined interactions under extreme loading conditions, allowing the team to address the technical challenges and interactions involved in floating offshore wind energy production.

The wind, water, and mechanical loads on the turbine, platform, and mooring lines will be analyzed and combined via computer modeling with experimental results on the soil and the foundation to produce "the response of the whole floating offshore wind turbine system, which helps us understand the interaction between different parts, or subsystems," Suleiman says.

This is important, he says, because typically these subsystems are treated separately. Bringing all the parts together not only mimics the real interactions of these subsystems, but also allows researchers to better understand their operation and maximize their energy output.

The team will use facilities at ATLSS and Suleiman's soil-foundation-structure interaction facility, as well as Lehigh's real-time hybrid simulation facility.

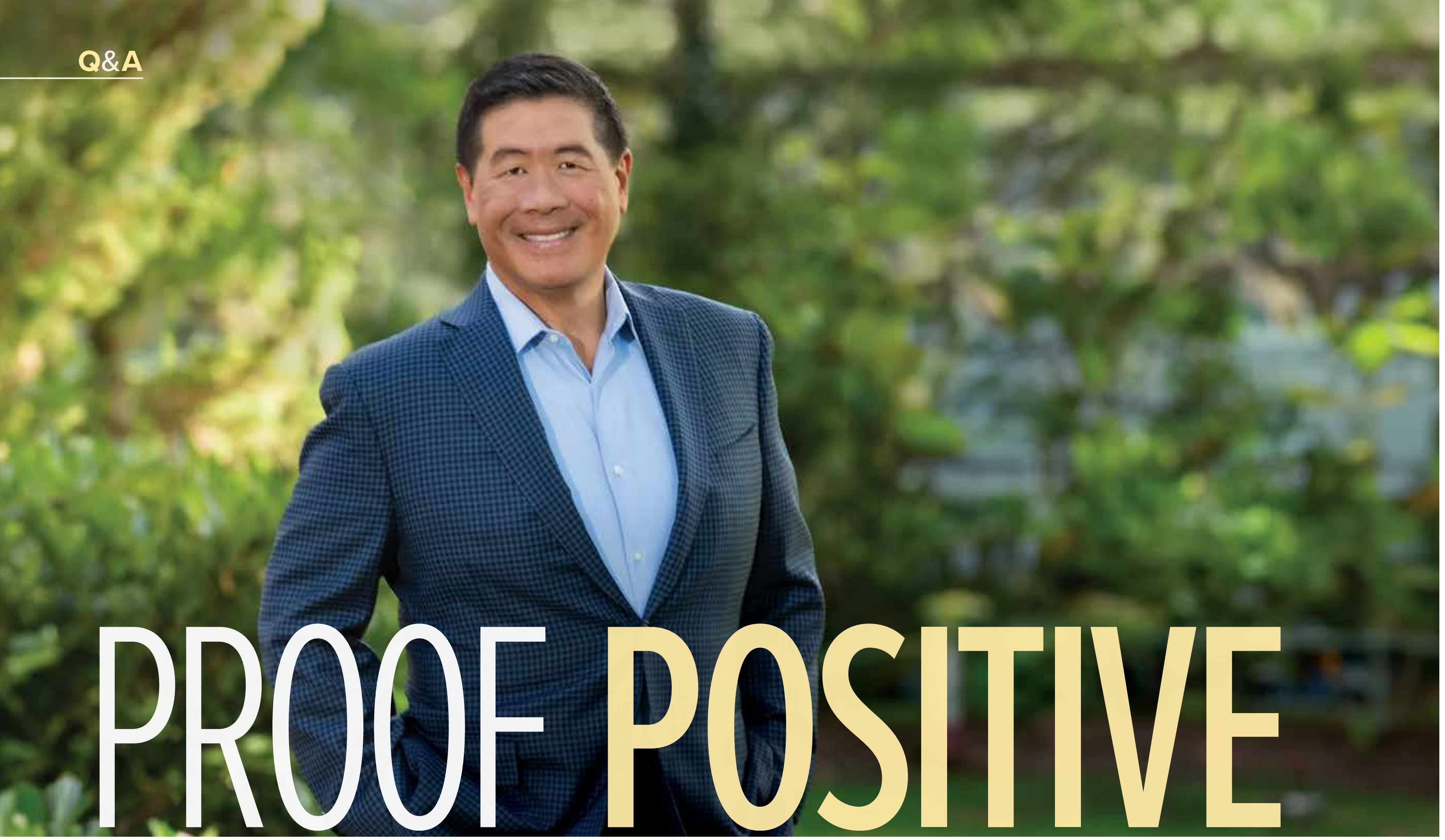
WEARABLE TECH HITS THE SOCCER FIELD

Dhruv Seshadri, an assistant professor of bioengineering, and his lab are partnering with wearable technology company Beyond Pulse in a collaboration with Lehigh University Athletics. The initiative focuses on validating wearable technology for data collection in athletes and refining predictive models to enhance their health and performance.

The first project involves integrating Beyond Pulse's wearable technology into the Lehigh Women's Soccer program. By tracking biometric data—such as heart rate, distance covered, and intensity of activity—during training and games, the collaborators aim to develop customized training programs, manage workloads effectively, and boost the overall well-being and performance of the student-athletes.

The industry-academic collaboration also has broader implications, says Seshadri.

"The models generated from this study are being translated to address unmet clinical needs in medicine where objective data from wearable technology can complement subjective clinical decision-making protocols to improve patient-reported outcome measures."



PROOF POSITIVE

CEO and entrepreneur Steve Tang on shaping future leaders with vision and empathy

Over more than three decades as a business leader and biotech innovator, Stephen S. Tang ’85G ’88 PhD ’22P has made his mark. After transforming Philadelphia’s entrepreneurial landscape as president and CEO of the University City Science Center, the chemical engineering alum went on to play a pivotal role at OraSure Technologies. The company, which is based in Bethlehem and has Lehigh roots, pioneered groundbreaking advancements in rapid diagnostics well before COVID test kits became household items. “My time at OraSure underscored the importance of trustworthy and compassionate leadership before and during the COVID-19 pandemic,” says Tang, who reflects on his experiences in his recently published book, *A Test for Our Time: Crisis Leadership in the Next Normal*. “I’m proud that the company played a pivotal role in developing easy-to-use, at-home COVID test kits that helped to slow the spread of the virus and bring the pandemic to an end.” Tang is currently the principal at Tangent2Cogent and board chairman of NowDiagnostics. He also serves as a Lehigh Trustee and gave the keynote address at the 2024 Graduate Commencement and Doctoral Hooding Ceremony, in which he emphasized to graduates the importance of “leaving a legacy of kindness, compassion, empathy, and service to higher causes.”

Q: Your Commencement message mentioned your family’s strong academic background and how you followed a similar path. How would you characterize the value of graduate engineering education for students aiming to make a real-world impact?

A: Even though I’m a third-generation PhD, grad school surprised me with its intensity and rigor. More importantly, I discovered that learning extends far beyond textbooks and labs. Collaborating with diverse minds and cultures taught me the value of multidisciplinary approaches to solving complex problems. Building resilience and perseverance amidst challenges were crucial lessons, strengthening my ability to adapt and innovate in the real world.

Graduate engineering education is invaluable for students aiming to make a high impact. Advanced technical skills aside, it cultivates critical thinking, teamwork, and creativity—essential traits for solving society’s pressing challenges. Lehigh’s unique environment inspires the development of ground-breaking solutions, allowing graduates to drive meaningful change and contribute to a better future.

Lehigh’s real-world value lies in deep specialized knowledge and broad personal growth. It equips individuals with confidence, curiosity, and adaptability to navigate an ever-evolving landscape. Graduate engineering education empowers students to make a profound difference in the world by fostering collaboration and resilience and cultivating thought leadership.

COURTESY OF STEPHEN S. TANG

Watch a video recognizing Tang as a recipient of Lehigh’s Outstanding Entrepreneur Award.

Q: How do you define an “entrepreneurial mindset” and how has your experience as an entrepreneur influenced your leadership style? What benefits do you see in enhancing entrepreneurial training and practice across Lehigh’s campus?

A: An entrepreneurial mindset embodies creativity, resilience, and a passion for turning ideas into impactful solutions. It thrives on embracing challenges and relentlessly pursuing opportunities.

My entrepreneurial journey profoundly shaped my leadership style. Over 30-plus years, I cultivated adaptability, strategic thinking, and a bias for action—crucial traits in today’s rapidly evolving world. By fostering an innovative and agile culture, I’ve empowered teams to embrace calculated risks, learn from failures, and achieve remarkable outcomes.

As a Lehigh Trustee, I envision advancing entrepreneurial training and practice as a catalyst for *Inspiring the Future Makers*. Infusing this mindset across disciplines nurtures a versatile talent pool adept at tackling complex global issues. It fuels interdisciplinary collaboration, cultivates problem-solving skills, and ignites the desire to drive positive change.

Entrepreneurship programs complement Lehigh’s mission by equipping students with the tools, resources, and confidence to turn ideas into realities. By cultivating an entrepreneurial spirit, Lehigh graduates will be well-prepared to tackle the world’s most pressing challenges and excel as innovative leaders.

Q: You’ve called OraSure one of the great success stories of a start-up company spinning out of a university. What key elements contributed to that success?

A: OraSure Technologies’ success as a university spin-off can be attributed to key elements, including a strong intellectual property portfolio, strategic partnerships, and a relentless focus on delivering innovative diagnostic solutions. By translating cutting-edge research into impactful products, OraSure exemplifies the potential of academia-industry collaboration.

Universities like Lehigh can foster similar success stories in a number of ways. Enhancing technology transfer infrastructure streamlines the process of commercializing research. Promoting interdisciplinary collaboration encourages researchers to address real-world challenges together. Fostering industry partnerships leverages external expertise and resources to accelerate innovation. And supporting entrepreneurship education equips students with the skills to transform ideas into viable businesses.

By prioritizing these elements, universities can create ecosystems where research thrives and transformational ideas become life-changing solutions that benefit society.

Q: How would you describe the impact of advancements in point-of-care and over-the-counter diagnostics and sample collection technologies over your career? What do you see as the next frontier?

LEFT AND RIGHT: COURTESY OF STEPHEN S. TANG; CENTER: JOHN KISH IV

A: Over my career, point-of-care and OTC diagnostics advancements have revolutionized healthcare, enabling rapid, accessible, and accurate testing outside traditional settings. These innovations have empowered individuals, improved patient outcomes, and reduced healthcare burdens. I’m fortunate to have participated in the launch of at-home tests for HIV, COVID-19, and syphilis. To date, those are the only FDA-cleared at-home tests for infectious diseases.

The next frontier lies in integrating diagnostics with digital health, artificial intelligence, and telemedicine. This convergence will enable real-time monitoring, personalized care, and predictive analytics. The key trends I see include wearable devices for continuous monitoring and early disease detection; digital biomarkers from body secretions and excretions that leverage artificial intelligence to analyze data and identify health patterns; and at-home diagnostics seamlessly integrated with virtual care platforms.

I'm particularly excited about the potential of AI-powered diagnostics to unlock new levels of accuracy and precision. By combining these advancements, we can create a future where healthcare is truly personalized, proactive, and accessible to all.

Q: In your book, you discuss steering OraSure through the pandemic. What is one lesson from this period that is particularly relevant for engineers?

A: In navigating OraSure through the pandemic, I learned the importance of adaptability and embracing uncertainty. Engineers often seek clear-cut solutions and rely on past experiences to guide their decisions. However, during unprecedented times, we must be willing to challenge assumptions, pivot strategies, and take calculated risks.

One particularly relevant lesson for engineers at any career stage is the value of fostering a culture of resilience and innovation. By encouraging diverse perspectives, open communication, and a growth mindset, we can build teams that thrive amidst chaos and transform challenges into opportunities.

As we forge ahead in an ever-evolving landscape, engineers’ ability to embrace change and adapt will be critical for driving breakthrough solutions, navigating unexpected obstacles, and creating lasting impacts in our organizations and the world at large.

INCUBATORS *of* INNOVATION

Lehigh's Interdisciplinary Research Institutes provide fertile ground for nurturing impactful team science

In taking on the world's greatest challenges, there's strength, as the saying goes, in numbers.

Since their founding in 2018, Lehigh's three Interdisciplinary Research Institutes (IRIs) have grown to encompass more than 50 active research teams, over 150 faculty from across all five of Lehigh's colleges, countless graduate students, and a wide variety of external partners in industry, government, and academia.

The Institutes for Functional Materials and Devices (I-FMD); Data, Intelligent Systems, and Computation (I-DISC); and Cyber Physical Infrastructure and Energy (I-CPIE) were designed to catalyze crucial research in areas in which the university could take a leading position and make lasting societal contributions, says Steve DeWeerth, dean of the Rossin College.

"The IRIs were created to be research center incubators through the support of ideas, teams, and proposals," says DeWeerth, who oversaw their planning and launch not long after joining Lehigh in 2016, having previously served as associate dean for research and innovation at the Georgia Tech College of Engineering. "By fostering a culture of interdisciplinary teaming through faculty engagement in shared experiences such as workshops and seminars, the IRIs create an environment where communities of scholars convene and coalesce around grand challenges. The goal for the IRIs has always been to incubate innovative ideas, enabling them to grow and gather the academic strength necessary to compete for and win extramural funding opportunities."

The IRIs have indeed been a crucial part of efforts to develop successful interdisciplinary team-based proposals.

> "By fostering a culture of interdisciplinary teaming, the IRIs create an environment where communities of scholars convene and coalesce around grand challenges."
>
> —Steve DeWeerth

TOP AND RIGHT INSET: SHOTBYASGAR; LEFT INSET: ILLUSTRATION BY DANTE TERZIGNI

In 2021, the U.S. Department of Energy awarded the Atlantic Marine Energy Center (AMEC), a partnership between Lehigh and three other East Coast universities, $9.7 million to focus on research and development in sustainable renewable ocean energy. More recently, AMEC received an additional $12 million from the Department of Energy as an investment into the National Marine Energy Centers under the Bipartisan Infrastructure Law. This funding further increases the scope of AMEC's work and draws 10 Lehigh faculty into the center's efforts.

And in December, the National Science Foundation granted Lehigh a four-year, $6 million award through its Accelerating Research Translation (ART) program to "increase the scale and pace of advancing academic research into solutions that benefit and serve the public." The 16-member Lehigh team represents all five Lehigh colleges.

Each of these successful initiatives trace their roots back to the IRIs.

Turning ideas into thriving research centers

The IRIs' success as innovation incubators is reflected in new university commitments to supporting impactful research. As part of its institutional strategy, *Inspiring the Future Makers*, Lehigh is launching University Research Centers, or URCs, consisting of focused teams in selected high-impact research fields. Through this investment, Lehigh seeks to propel these teams to compete successfully for external large-scale funding.

"The idea for the University Research Centers is to identify something that we are fairly good at already, in which, with the right investment, we can become world leaders," says Anand Jagota, Lehigh's vice provost for research. The ultimate vision, says Jagota, who is also professor and founding chair of the Department of Bioengineering, "is to identify a societal problem and build a team including Lehigh and other partners to solve that problem."

The first wave of the URCs was announced earlier this year, with strong ties to the IRIs.

> Catastrophe Modeling attempts to predict the likelihood of events such as natural disasters, pandemics, financial crises, and political unrest, as well as their associated risks, including infrastructure damage and financial losses.

Building resilient communities

The Center for Catastrophe Modeling and Resilience, which is affiliated with I-DISC and led by Paolo Bocchini, a professor of civil and environmental engineering, is Lehigh's inaugural University Research Center. It brings together a team of faculty from across disciplines, leveraging a wealth of experience and expertise in their respective fields, who attempt to predict catastrophes, assess their associated risks, and plan for them.

"Of the proposals that came in, one was unanimously seen as very strong, with great promise and mature enough to take off as a University Research Center," Jagota says.

Bocchini had been running a version of the center well before the IRIs were established, but with funding from the university and I-DISC's support, he and his team were able to formalize their work.

"We at Lehigh created an area of strength in community and infrastructure resilience," says Bocchini. "We started about 15 years ago to work on this. We have reached critical mass, and I think we've established ourselves as relevant players in the field."

Specifically, Catastrophe Modeling, or CatModeling, attempts to predict the likelihood of potentially catastrophic events, such as natural disasters, pandemics, financial crises, and political unrest, as well as their associated risks, including financial losses and damage to buildings and other infrastructure.

CatModeling is particularly important for insurance companies that often cover the costs of disasters. The speed with which insurers can make payments can impact the long-term recovery of a region. Despite the importance of CatModeling, the field has not previously been explored systematically in academia.

While the private sector has moved research forward in CatModeling, it can benefit from stronger collaborations with the fundamental and interdisciplinary research done in academia, Bocchini says. The Center for Catastrophe Modeling and Resilience envisions a thriving University Research Center that expands the role of academia in CatModeling and interacts with major stakeholders in industry and government and researchers at other universities to address the most relevant problems in the field.

Bocchini's background is in probabilistic modeling applied to civil engineering. Since his early research years, Bocchini has applied probabilistic modeling to natural disasters.

"I saw students get immediately excited when I pitched this type of application, because we are dealing with the biggest threats to our society," Bocchini says. He and his colleagues realized such models could be applied to other events as well. They began trying to predict epidemics before the COVID pandemic hit.

"These are measures of threats our society faces, and in some cases they are existential," Bocchini says. "Trying to do something about it, for me as an engineer, is very fascinating. I'm not trying to cure diseases, but I think this is the best approximation of trying to help our society defend against its threats."

LEFT AND RIGHT: BOON A - AI STOCK/ADOBE STOCK

Sustainable energy for all

The team behind another promising University Research Center proposal, titled ACES—Advancing Community Electrification Solutions—was given a 12-month development grant from the university to further refine its vision.

"We will use that time to identify the gaps in our vision and figure out how to fill them," says Shalinee Kishore, Iacocca Chair Professor of Electrical and Computer Engineering and director of the Institute for Cyber Physical Infrastructure and Energy. "And we will leverage our established successes. The ACES group is coming out of I-CPIE, and we've done a lot of interdisciplinary work across a range of team grants on resilient infrastructure, sustainable energy, and data-driven solutions. We have a very strong network of partners across fields like engineering, data science, economics, environmental policy, and population health, and we'll be working with our colleagues in all of these disciplines to make the case for ACES as a University Research Center."

Making that case involves addressing what Kishore calls legacy issues in infrastructure and energy systems—those of emissions and omissions.

"These systems often emit greenhouse gasses and other toxic substances while their benefits are not uniformly realized, meaning there's a differential impact across communities," she says. "Moving forward, we'd like to change both of those legacy characteristics."

A primary way to reduce emissions across areas such as transportation, heavy industry, light manufacturing, agriculture, and the water system is through electrification. But shared reliance on the power grid introduces new challenges.

"In the past, water systems and transportation systems may not have necessarily interacted with each other except perhaps in the case of waterway transportation or during disasters like flooding," says Kishore, "but when they're both drawing energy from the grid, they become far more interdependent. We need to understand how to deliver reliable, sustainable power to all these infrastructures while ensuring their smooth operation, both during threatening natural or man-made events, and day to day. To that end, we'll be focused specifically on water, transportation, and building infrastructure systems, and how they interface with the grid as they become electrified."

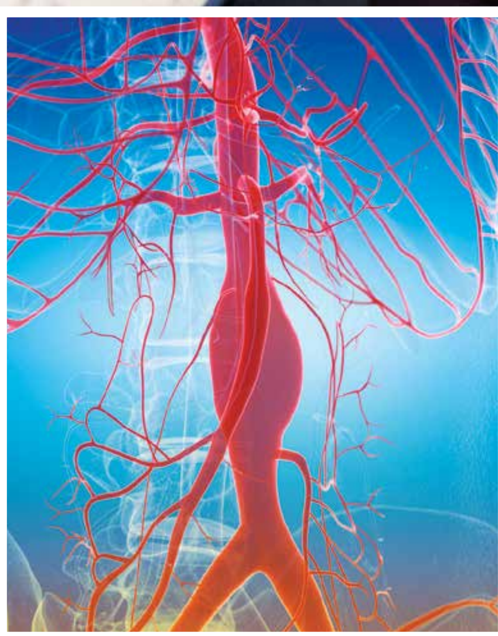
Addressing omissions, she says, requires an understanding that engineering solutions alone will not solve the problem of inequity. All solutions must involve and engage individuals and the wider community, and be considered within the cultural, economic, and environmental realities of a given area and its inhabitants.

"We are going to try very hard to make sure our projects will have a strong connection to stakeholders, and what they're looking for in these solutions," she says. "In other words, we don't tell you how to do things. You tell us what to do, and we figure out the solution based on that."

Over the coming months, the ACES team will use the development grant to further hone its focus across three major areas: conceiving of decarbonized and decentralized technologies and policies that enable their widespread adoption and equitable benefits distribution; coordinating real-time data to ensure interdependent systems operate efficiently; and building resilience through disruption-tolerant solutions that will enable the system to withstand natural and man-made events.

"ACES would represent a significant step toward positioning Lehigh as a leader in energy transitions and electrification, potentially setting a national standard in this field," says DeWeerth. "This team as well as the Center for Catastrophe Modeling and Resilience are both testaments to the power of the interdisciplinary culture that the Lehigh faculty has built and nurtured. That culture now permeates everything we do."

EXPLORE CATASTROPHE MODELING AND RESILIENCE AT LEHIGH The center supports academic research in catastrophe modeling and resilience analysis, advances research on specific topics such as fair insurance practices and ethical considerations, fosters collaborations between private and public sectors, and serves as a hub for connecting research teams in the field. Visit **engineering.lehigh.edu/catastrophe-modeling** to learn more, or scan the code for videos from faculty and students of the program.



Ramamurthi is a Fellow of the American Heart Association and an expert in tissue engineering, tissue repair, and biomimetic regeneration.

GOOD NANO-MEDICINE

Bioengineering researcher Anand Ramamurthi leads a team developing minimally invasive techniques that could transform the treatment of aortic aneurysms

LEFT: SEBASTIAN KAULITZKI/ADOBE STOCK; TOP: DOUGLAS BENEDICT/ACADEMIC IMAGE; RIGHT: RAMAMURTHI LAB FOR MATRIX ENGINEERING

Aortic aneurysms are bulges in the aorta, the largest blood vessel that carries oxygen-rich blood from the heart to the rest of the body. Smoking, high blood pressure, diabetes, or injury can all increase the risk of aneurysms, which tend to occur more often in Caucasian male smokers over the age of 65.

"The soft tissues that make up blood vessels act essentially like rubber bands, and it's the elastic fibers within these tissues that allow them to stretch and snap back," says Professor Anand Ramamurthi, chair of the Department of Bioengineering. "These fibers are produced primarily before and just after birth. After that, they don't regenerate or undergo natural repair after injury. So when they become injured or diseased, the tissue weakens and causes an aneurysm, which can grow over time. After about seven to 10 years, it typically reaches the rupture stage."

During that period, there is no treatment. Patients are screened regularly via imaging to monitor the rate of the aneurysm's growth. Once it's deemed big enough to potentially rupture (rupture of aneurysms is often fatal), surgery is the only option. But it's a risky one for elderly patients.

Ramamurthi and his team are working on minimally invasive ways to regenerate and repair these elastic fibers using polymeric or biological nanocapsules, called nanoparticles, that are designed to release novel regenerative therapeutics. Their innovative techniques could enable treatment soon after an aneurysm is detected and potentially slow, reverse, or even stop its growth. Findings in a paper published earlier this year in the *Journal of Biomedical Materials Research* build on their earlier work and represent a step toward a future where surgery is no longer the best, and only, treatment option.

"In previous research, we've identified drugs and gene-silencing agents that can actually coax adult diseased vascular cells to produce new elastic fibers and inhibit the enzymes that break down existing fibers," he says. "We've also been working on how to deliver these therapeutics efficiently only at the site of tissue repair."

The team has also developed a nanoparticle design called active-targeting that incorporates small protein fragments, or peptides, on the nanoparticle's surface. "These peptides recognize components that are unique to the aneurysm tissue. So when the nanoparticles are injected into the bloodstream, they stick only to the aneurysm wall, where they slowly degrade and release the drug.

For this paper, he says, the researchers "investigated how the nanoparticles actually penetrate the blood vessel wall to deliver the drug to the affected tissue."

All blood vessels are lined with a protective barrier made of endothelial cells, which can become "leaky" as inflammation from tissue damage or disease breaks down the endothelium and creates gaps between the cells. These gaps allow white blood cells to move in and start the tissue repair process, and they also serve as the entry point for nanoparticles that accelerate healing.

"We wanted to know how the shape and the aspect ratio of these nanoparticles affect their ability to cross that endothelial cell barrier," says Ramamurthi.

It was a critical question to answer because not all nanoparticles are created alike, and if they can't penetrate the barrier, they can't repair the tissue.

Ramamurthi and his team developed a novel cell culture model in which they simulated disease and then examined mechanisms of transport: specifically, how nanoparticles of different kinds interacted with endothelial cells and moved through them. Did they enter through gaps among the endothelial cells (a process called extravasation) or through the cells themselves (known as translocation)?

> "THESE FINDINGS WILL HELP GUIDE US IN DESIGNING NANOPARTICLES FOR EFFICIENT DELIVERY TO THE ANEURYSM WALL."
>
> —Anand Ramamurthi

"Let's say a nanoparticle goes through an endothelial cell. Some of it might stay within that cell and not come out the other side, which means you lose that particle, and it's no longer useful to the healing process. The goal is transportation with minimal retention."

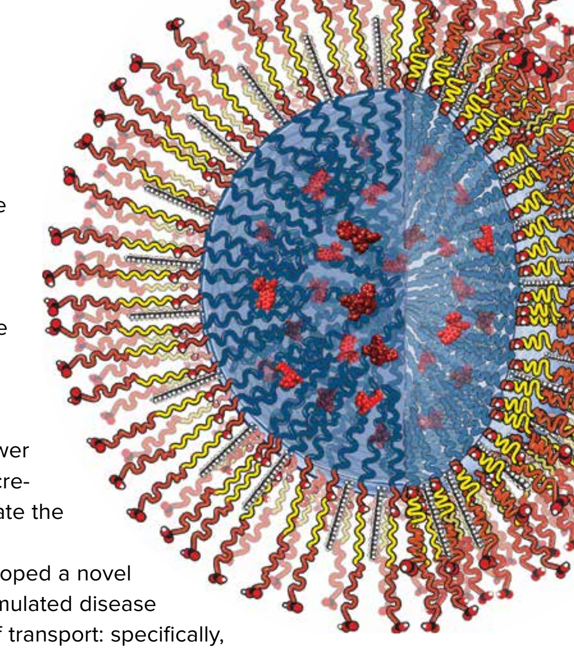
The team found that rod-shaped particles, as opposed to spherical particles, with a high aspect ratio (i.e., long and skinny versus short and stubby) were selectively taken up by diseased endothelial cells. "And they showed very little uptake into healthy endothelial cells compared with the spheres, which is good because we don't want them interacting with healthy vessel walls," he says.

They also found that particles reached the tissue primarily by extravasation (or via the cell gaps). "The longer and skinnier they were, the less likely they were to remain within the endothelial cell layer, which means they're getting through to the affected tissue for more effective therapy."

The team will now integrate these findings with their work on active-targeting—incorporating components on the surface of nanoparticles that recognize proteins expressed by diseased cells—in animal models.

The ultimate goal is to develop a nonsurgical regenerative therapy capable of slowing aneurysm growth. For example, increasing the current growth-to-rupture stage from seven years to 15 years. An even more ambitious outcome, says Ramamurthi, would be to revert that growth.

"Regression of aneurysm growth would be the preferred long-term outcome," he says. "That's a long way off, but we're excited because these findings will help guide us on how to design our nanoparticles for more efficient delivery to the aneurysm wall. It's an opportunity to get closer to that reality." *—Christine Fennessy*



The team is designing biodegradable nanoparticles that release drugs to help rebuild elastic tissue.

Take a video tour of the Ramamurthi Lab for Matrix Engineering.

LEFT: VALERII EVLAKHOV/ADOBE STOCK (CLOCK); SUPAKITMOD/ADOBE STOCK (PLANT); RIGHT: RAWIWAN/ADOBE STOCK

BY CHRISTINE FENNESSY

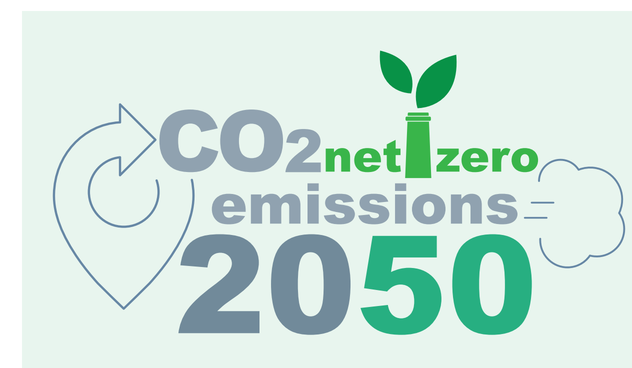
REACTION TIME

Research teams reimagine materials, processes, and the chemical industry as a whole to respond to pressing sustainability challenges

In 2021, the United States government outlined its strategy to achieve net-zero emissions by 2050 to mitigate the effects of climate change. The strategy acknowledged that to reach this goal—and, at the same time, create jobs, improve public health, and stimulate growth—would require action across every sector of the economy.

The wide-ranging chemical industry, for one, is among the heavyweights.

"We're all working toward solving this climate crisis," says Srinivas Rangarajan, an associate professor of chemical and biomolecular engineering. "Globally, the chemical industry itself emits 1.9 gigatons of CO_2 every year. As chemical engineers, we want to replace fossil fuels as a feedstock and as an energy source."



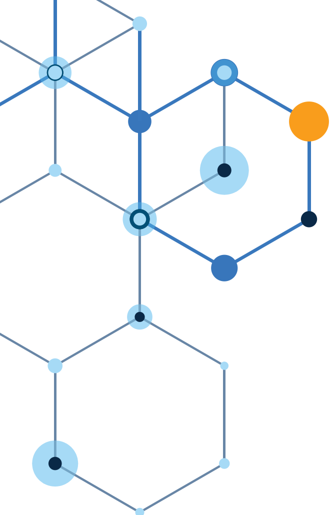
Chemical refineries of the future, says Rangarajan, will rely on alternative carbon and hydrogen feedstocks—waste plastics, waste biomass, CO_2 captured directly from the air or water—to make the products we need. And those plants will be powered by variable renewable energy sources. It will require a fundamental rewriting of the script and a reexamination of how chemical engineering is taught.

"We have to basically reimagine how we make chemicals," he says.

Such rethinking is in full force across a dizzying array of projects within the Rossin College. There are initiatives focused on using electricity to drive chemical reactions. Fundamental explorations into the chemistry required to split water and make hydrogen. Investigations on how that hydrogen could eventually be stored and transported. There's research into how new and more benign chemistries and materials can be used to make current molecules, and new methods using machine learning are being developed to control and optimize chemical processes in manufacturing.

The list is seemingly endless, so what follows is just a sample of ongoing work in this arena. And although these projects may be spearheaded by chemical engineers, they are, by necessity, informed by the full range of engineering disciplines.

"Our work is extremely cross-disciplinary," says Rangarajan. "It cuts across multiple length scales, from understanding how materials are synthesized to how reactions occur on an atomistic scale, to how it all comes together in a reactor and in a process plant, and how that plant interacts with the environment and systems around it. It's a scope that goes all the way from atoms up to the world as a whole. It touches upon topics ranging from chemistry to materials science to process control, economics, and the life cycle of materials. We're constantly thinking about these connections and how they relate to the bigger picture when it comes to sustainability."



The quest for kinder catalysts

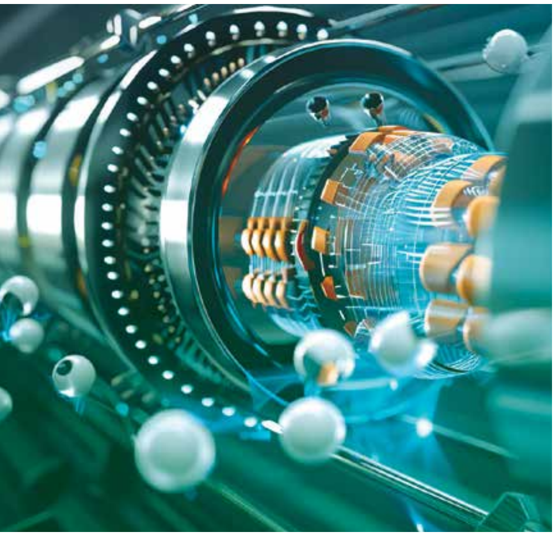
When power plants burn fossil fuels at high temperatures, nitrogen and oxygen molecules break apart and then recombine to form a class of compounds called nitrogen oxides, or NOx. These gases are major pollutants and contribute to—among other things—acid rain and global warming.

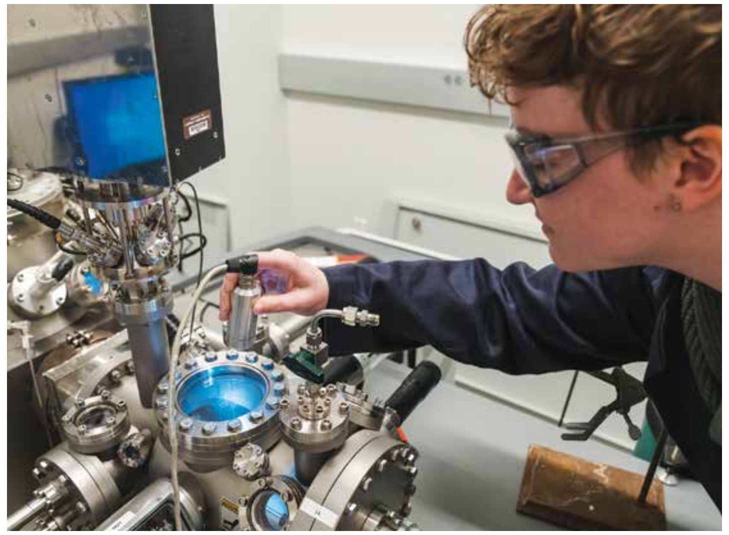
One way to curb such emissions is with a catalytic converter, similar to what's used in a vehicle.

"The catalytic converter injects ammonia into the plant's emissions stream, and the hydrogen in the ammonia reacts with the oxygen in the NOx, and the products are nitrogen and water molecules, which are nontoxic and have no environmental impact," says Israel E. Wachs, the G. Whitney Snyder Professor of Chemical and Biomolecular Engineering and director of Lehigh's *Operando* Molecular Spectroscopy and Catalysis Research Lab.

The process that can convert pollution into benign byproducts is called selective catalytic reduction, or SCR. Until now, it has been unclear how this reaction actually occurs, and contradictions have long existed between reaction models within the literature. Wachs and his team used a novel, cutting-edge technology called modulation excitation spectroscopy, or MES, to finally identify the correct pathway. Their results were recently published in *Nature Communications*.

Wachs and his students use MES to identify the pathway within catalytic converters (illustration, left) that can convert pollution into benign byproducts.





LEFT: LUCIJA/ADOBE STOCK; RIGHT: SHOTBYASGAR

"Having the hard data that shows the correct reaction mechanism means that we now have the potential to positively impact thousands of catalytic reactions." —Israel E. Wachs

"Very few people have this capability at the moment," says Wachs, referring to MES. "It allowed us to monitor weak signals that were not detectable in the past, and revealed the details of how the reaction proceeded."

The finding is significant because having the right reaction model can indicate how to modify or redesign the catalytic converter for greater efficiency.

Wachs points out that the methodology is general enough so that it can be applied across a range of catalytic reactions, including those emitting NOx from automobiles, ships, tractors, and even riding lawn mowers.

"The products that catalysts manufacture represent 20 to 30 percent of the American economy," says Wachs. "They're used to make fuel, chemicals, fertilizers, and even pharmaceuticals. Having the hard data that shows the correct reaction mechanism means that we now have the potential to positively impact thousands of catalytic reactions."

MES will next be used in a collaboration between Wachs and Rangarajan that was recently funded by the National Science Foundation. The project will use MES to determine how certain promising catalysts can convert biomass or CO_2-derived alcohols, such as methanol and ethanol, into acrolein. Acrolein is an important ingredient for making acrylic acid and acrylate polymers, chemicals used in a range of products from adhesives to paints and plastics.

"The chemistry on this catalyst is quite complicated and the structure of the catalyst during the reaction is different from when it's synthesized," says Rangarajan. "MES provides unique insights into the dynamics of these structural changes and, in addition, allows us to more accurately calculate how fast reactions occur, meaning the kinetics of these reactions, and if there are short-lived intermediates that are otherwise missed in traditional approaches."

However, he says, analyzing MES data to get information about reaction speeds and intermediate steps has never been done before. So the team will employ data science and machine learning techniques to process and extract the information.

The team includes Raimun Horn at the Technical University of Hamburg in Germany, who will use a reaction setup called the Compact Profile Reactor (CPR) that will explore how the catalyst and the composition of reactants and products change as they move through the reactor.

"The goal is to find alternate routes to current chemical products and polymer feedstocks from greener, renewable carbon sources," says Rangarajan. "Currently, acrylic acid is made from hydrocarbons derived from crude oil. Our quest for greener chemistries produced using benign catalysts is important to move to a more sustainable future for manufacturing."

TOP: RYAN HULVAT/MERIS; COVER ILLUSTRATION: NICOLLE R. FULLER/SAYOSTUDIO; BOTTOM: IPOPBA/ADOBE STOCK

A potential power shift

Thermocatalysis is a process that accelerates chemical reactions by combining thermal energy and a catalyst, which lowers the activation energy required, making reactions more efficient and often feasible at lower temperatures. It's widely used in petroleum refining, chemical manufacturing, polymer production, the pharmaceutical industry, and environmental applications like catalytic converters. The thermal energy powering these reactions, however, is often generated by burning fossil fuels.

Electrocatalysis, by contrast, can use energy sourced from renewable technologies such as solar, wind, and hydropower. It can also often operate at lower temperatures and pressures, which can enhance safety and reduce operational costs. But despite these advantages, its widespread adoption has been limited, in part, because of concerns about the longevity and reliability of electrocatalytic systems.

"The goal is to eventually transition industry to electrocatalysis, but to do that, we're using electrochemical approaches to better understand thermocatalysis," says Bohyeon Kim, a PhD candidate in the Department of Chemical and Biomolecular Engineering (ChBE).

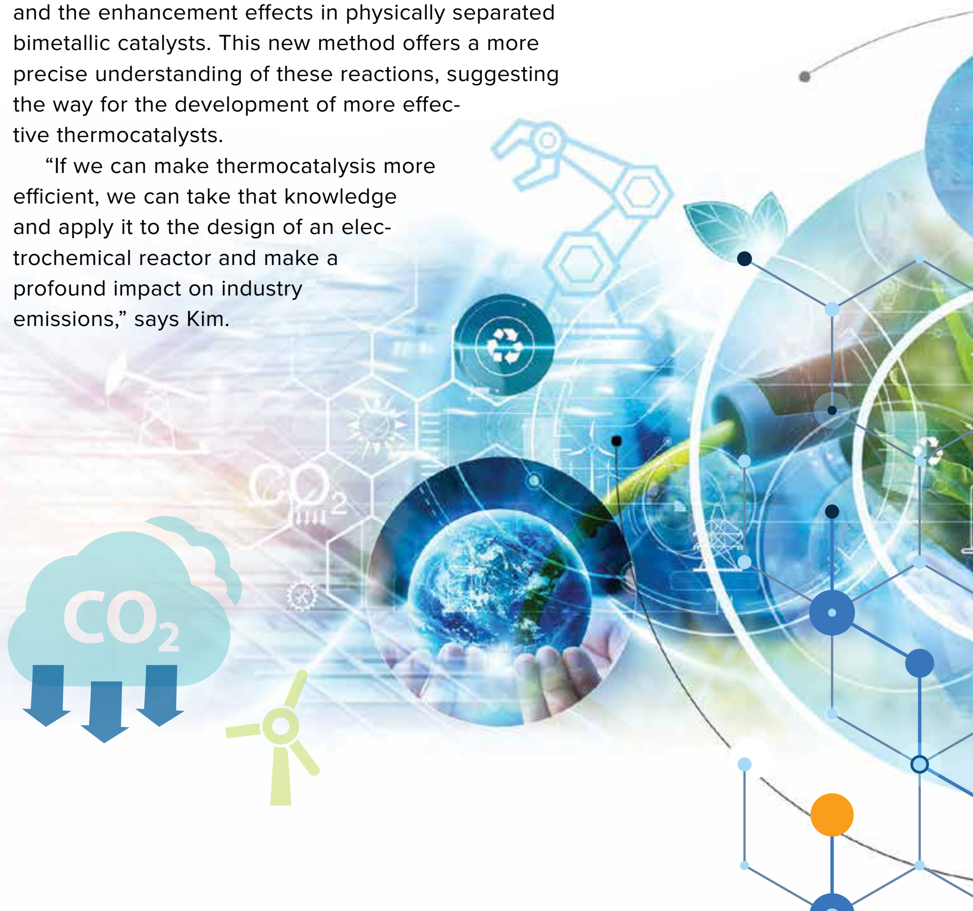
By understanding the electrochemical aspects of thermochemical systems, thermocatalytic activity can be significantly enhanced through innovative catalyst design. However, current electrochemical techniques often fail to accurately reflect catalytic trends, especially when the adsorption of one reactant is a limiting factor.

Kim, who is part of a team led by Steven McIntosh, Zisman Family Professor of Chemical and Biomolecular Engineering and chair of the ChBE department, is the lead author of a recent paper in the expanding field of using electrochemical approaches to interpret thermocatalytic reactions.

Working in McIntosh's lab collaboratively with researchers from Cardiff University in the United Kingdom, Kim proposed a novel electrochemical approach that more accurately captures thermocatalytic reactions and the enhancement effects in physically separated bimetallic catalysts. This new method offers a more precise understanding of these reactions, suggesting the way for the development of more effective thermocatalysts.

"If we can make thermocatalysis more efficient, we can take that knowledge and apply it to the design of an electrochemical reactor and make a profound impact on industry emissions," says Kim.

PhD candidate Bohyeon Kim was also co-lead author of a paper on bimetallic catalysts that was highlighted on the cover of *ACS Catalysis* in 2023.



Data-driven manufacturing

Addressing sustainability challenges is sometimes less a matter of creating or tweaking chemistries or materials, and more one of optimizing and accurately controlling the operation of a process.

"In the old world, if you wanted to assess the changes made to a manufacturing process, you conducted laboratory experiments," says Mayuresh Kothare, the R. L. McCann Professor of Chemical and Biomolecular Engineering and the Rossin College's associate dean for research. "Eventually, you move the process from lab scale to manufacturing scale. But in today's world, with data and machine learning, we can develop models that take the place of those experiments—effectively conducting digital experiments.

"We'd like to be able to give an engineer working on the system a model that can say something like, 'A 10 percent change in X variable will give you a six percent change in the output.'" —Mayuresh Kothare

When iterated with data from physical experiments to recursively refine the digital model, we end up with a loop that is referred to as the 'digital twin.'"

Kothare and Rangarajan are co-leading a Lehigh team that is working with Owens Corning, a leading building materials manufacturer, in building better models to evaluate the effect of changes to their insulation manufacturing process—changes that could make their process more efficient and accelerate progress toward the company's sustainability goals.

The project was initiated in collaboration with Lehigh chemical engineering alumnus Dr. Jim Beilstein '90, vice president for global operations and supply chain at Owens Corning, a member of the Rossin College Dean's Advisory Council, and chair of the chemical engineering advisory council at Lehigh. The project team includes Sulman Haque, technical program manager at Owens Corning; Lehigh graduate student Siddharth Prabhu; and an extended team of Owens Corning engineers who meet on a weekly basis to chart out research steps.

"In full-scale industrial processes, it is often difficult to measure in real time the effect of process changes on the quality of product," says Kothare. "Manufacturers usually resort to offline testing to see if products meet specifications. If the product doesn't meet stringent requirements, it becomes unsellable to their customers. In an ideal world, manufacturers would have a measurement that shows right away that something is wrong so they can correct the process immediately. The challenge for us has been to create a model and intervention strategy that catches quality problems rapidly enough to ensure that product stays within spec."

The team is testing a range of new modeling paradigms, specifically physics-informed and interpretable machine learning models. Machine learning is often referred to as a black box of sorts; it provides an output, but no sense of how it arrived at that output.

"So we're blending interpretable machine learning models with a physics-based set of equations that describe the insulation manufacturing process," says Kothare. "And then we try to develop a functional relationship for that unknown portion of the model from data-driven techniques. We'd like to be able to give an engineer working on the system a model that can say something like, 'A 10 percent change in X variable will give you a six percent change in the output.'"

Ultimately, the team's goal is twofold—to develop software that allows users to change parameters and see how that affects plant performance, and to use that same tool to identify the operating conditions that minimize energy use.

"With the help of Lehigh and the extended Owens Corning team, we are creating new capabilities that drive a deeper understanding of our process, helping us move toward our performance and sustainability goals, and further strengthening the industry-academia partnership," say Beilstein and Haque.

SUMMIT ART CREATIONS/ADOBE STOCK

LEFT: MRALLEN/STOCK.ADOBE.COM; RIGHT: S. LEITENBERGER/STOCK.ADOBE.COM

A focus on fertilizer efficiency

The most commonly used fertilizers around the world contain nitrogen. In 2021, global consumption of nitrogenous fertilizers was more than 195 million metric tons, up from 46 million in 1965, according to Statista.

Nitrogen is an essential nutrient for plants: It enables the growth of robust stalks, flowers, and foliage. However, it's a difficult nutrient to process. In its free form, nitrogen is inert, and to make it available to plants, it must be chemically processed.

"About five percent of the total global production of natural gas and between one and two percent of global electricity production is used to make nitrogenous fertilizers," says Jonas Baltrusaitis, an associate professor of chemical and biomolecular engineering. "It's a very, very energy intensive process, and it's also critical to sustain a growing population."

It takes a huge amount of energy to make nitrogenous fertilizer, and once applied, much of it becomes nonpoint source pollution.

"We believe we can revolutionize how these fertilizers are made, how they're handled, and what their impact is—globally—on food production, the environment, and the economy." —Jonas Baltrusaitis

The problem, he says, is that once it's put into the ground, nitrogenous fertilizer becomes reactive and unstable and only a small portion of it is absorbed by the plants. The rest becomes what's known as nonpoint source pollution.

"We put all this energy into making fertilizer, just to have half the nitrogen evaporate into the air where it volatizes as ammonia and nitrogen oxides, both of which are greenhouse gases that contribute to particulate matter pollution," says Baltrusaitis. "The rest of the nitrogen becomes nitrate, which is water soluble and pollutes waterways. So nitrogen is a necessary but problematic nutrient."

To solve such problems, Baltrusaitis and his team have developed a chemical process where they co-crystallize urea—one of the most commonly used nitrogen fertilizers. They combine urea, which has low stability in the natural environment and easily hydrolyzes, with various widely available and highly stable minerals (like gypsum), and in the process, create a third material that is far more stable than the parent urea.

"We end up with a material that contains properties of both parent compounds," he says. "It has nitrogen, but the minerals provide stability so it decomposes more slowly and becomes less soluble and reactive with water. The fertilizer can then stay in the soil for a longer period of time, which increases its availability for the plants."

The researchers have scaled the method to the level required by industry, and Lehigh has patented both the process and the materials developed in Baltrusaitis's lab. The next steps are testing the material in the field to assess the life-cycle impacts of co-crystallization, and working with industry to commercialize the process.

The impact of that commercialization could be huge.

"We believe we can revolutionize how these fertilizers are made, how they're handled, and what their impact is—globally—on food production, the environment, and the economy," says Baltrusaitis. "We're talking about transforming an industry that hasn't changed much in 100 years, making it more sustainable, more efficient, and more economical. The potential for that level of societal impact is extremely exciting, and a huge motivator for us."

Formula for a greener future

Trying to solve the myriad issues required to hit net-zero emissions is a daunting endeavor, to put it mildly. But it's also a unique opportunity to prepare the next generation of engineers for a differently powered world.

"These are extremely challenging problems, and they're completely different from what we've long been taught in chemical engineering," says Rangarajan. "When I was an undergraduate, we would learn about crude-oil-driven petrochemical production. But now we're talking about how to use electricity or waste carbon to drive chemical reactions. We're talking about developing new chemistries, new catalysts, new materials, and new algorithms. These projects require us to conceptualize the chemical industry of the future, and that's going to help us better develop the workforce of the future."

CATCHING FYRE

Incorporating principles of User-Designed Inquiry into the new FIRST-YEAR ROSSIN EXPERIENCE will transform how the college educates future generations of engineers

Generally speaking, universities have long relied on the "sage on a stage" approach to education. Students sit and listen; professors stand and speak. Homework, tests, and grades monitor progress, determine competency, and chart trajectories. It's a process that can leave some students feeling left out, and left behind.

"IT'S A COMPLETE REVAMPING OF WHAT WE'VE TRADITIONALLY DONE. IT'S THE MANIFESTATION OF PEDAGOGICAL INNOVATION." —Bill Gaudelli

"The traditional curriculum has assumed a singular, typical user, but we know that 'average student' doesn't exist," says Bill Gaudelli, Lehigh's senior vice provost for educational innovation and assessment. "I think we're losing a lot of talent across higher education by the rigidity in which we're engaging education."

As part of Lehigh's institutional strategy, *Inspiring the Future Makers*, Gaudelli is leading a university-wide effort to incorporate User-Designed Inquiry (UDI), an innovative, evidence-based educational approach designed to improve undergraduate student outcomes.

"Lehigh UDI is an attempt to shift the gravity of the work of education away from the faculty and toward the students," he says. "It takes into account a multiplicity of users with different backgrounds, experiences, interests, values, capacities, and directions, and it invites students to use the things that make them unique to drive their educational journey."

In essence, he says, it's a student-centered approach that gives those students a sense of agency and ownership over what they're studying, why they're studying it, and how they'll ultimately use what they're learning. Fully realized, UDI would represent a titanic shift. Hands-on learning experiences would integrate the learning of fundamentals into the context of complex issues. Competency-based assessment across a range of knowledge and skill sets would provide a more effective measure of students' academic progress. Digital portfolios would augment transcripts, allowing students to provide a much richer summary of their college careers.

While the goal is to implement UDI across all five colleges at Lehigh, the engineering college is already using it as a framework to reenvision its First-Year Rossin Experience, or FYRE.

A key advantage of FYRE, according to Rossin College Dean Steve DeWeerth, is that students would no longer learn subjects in silos. Rather, they would learn fundamental principles of chemistry, physics, calculus, engineering, and computing, while simultaneously understanding how those subjects relate to each other and how they can be applied to real-world engineering problems.

"That integration is key because it gives students a richer, deeper understanding of how problems are actually solved," says DeWeerth.

So what would FYRE look like from the first-year student's perspective? The vision is just taking shape, but a faculty task force, convened by DeWeerth, is developing the first-year experience around three primary components.

The first is a series of six project-based practica that would take the place of traditional courses. Each five-week practicum would focus on an engineering grand challenge, such as sustainable energy. An interdisciplinary team of faculty members—one that could include professors from outside the Rossin College—would present the problem in all its complexities and guide the students through a multi-faceted approach to addressing it. Students would work in small, faculty-directed teams to conduct their own research to enhance both their individual and the group's understanding of the issue. The development of the practica over the five weeks would culminate in the design of a prototype or the analysis of a complex data set.

Each of the practicum sessions would require students to develop new knowledge and skills, such as the chemistry behind how drugs can diffuse through a membrane, how to use a 3D printer, how to conduct laboratory experiments, or how to analyze complex data.

Mastering these core competencies represents the second component of the team's vision. Students would develop specific competencies through a combination of independent learning and guidance from faculty members and peer mentors. Competencies would then be assessed on an individual basis. If students fall short, they would receive the assistance they need to master the skill.

"With FYRE, students will also be able to move at their own pace until they learn what they need for each practicum," says DeWeerth. "For us, assessing students beyond traditional tests and quizzes will be critical, and something that we'll be learning from Bill and his team."

CLOCKWISE FROM TOP LEFT: HOLLY FASCHING '26 (2); CHRISTA NEU (2); HOLLY FASCHING '26

First-year students would complete six project-based practica to gain hands-on experience in addressing real-world problems.

With each of the six practica tackling an interdisciplinary problem, students would have multiple chances to explore specific engineering disciplines.

"Students will learn why certain problems are interesting to chemical engineers or environmental engineers," DeWeerth says. "By the end of the year, they'll have worked on six projects and been exposed to every department in a variety of ways. We expect that they'll notice a pattern in the ones they've particularly enjoyed, and that exposure will help them decide which discipline they want to pursue starting in their second year."

The third component would be a cocurricular one, in which students pick an experience that spans their first year. They might choose, for example, to conduct research in a faculty member's lab, join one of the college's competition teams, or take part in a Creative Inquiry project. Students across different projects would then be connected to each other, and these groups would be able to share individual challenges and problems. The goal would be to expose them to the full breadth of perspectives and opportunities across the university.

"The hope is that after they've completed the six projects and mastered the competencies, that these cocurricular projects will be something they'll want to continue through their undergraduate experience," says DeWeerth.

And at the end of their first year, students would not have a series of grades, but a set of mastered competencies and a digital portfolio that summarizes their accomplishments.

"When you get to the end of a class," says Gaudelli, "you should have more to say about it than, 'I got an A.' These performance dossiers would outline what a student accomplished, how that product or analysis is used in the real world, and most importantly, why it matters to society. Students will be able to articulate what they learned, and crucially, how it informs where they want to go next."

Implementing Lehigh UDI and using it to help transform the first-year engineering curriculum into FYRE will be no small task. Because, as Gaudelli says, it's not a matter of simply tweaking a few things.

"It's a complete revamping of what we've traditionally done, and how we've done it," he says. "It's the manifestation of pedagogical innovation."

"WE HAVE THE OPPORTUNITY TO HELP STUDENTS DEVELOP A SENSE OF BELONGING IN THE FIELD OF ENGINEERING, WHILE UPHOLDING THE RIGOR OF A CLASSIC LEHIGH EDUCATION." —Steve DeWeerth

For DeWeerth, the excitement lies in both the challenge and the potential.

"We have the opportunity to rethink how students learn what it means to be an engineer, and help them develop a sense of belonging in the field of engineering, while upholding the rigor of a classic Lehigh education," he says. "This will be tremendously rewarding work for our students—and for our faculty."

Hear why faculty from across the university are energized by the possibilities of Lehigh UDI.

The NSF CAREER award provides Bayrak with nearly $560,000 in support for a five-year period.

Dream team

Mechanical engineering researcher earns NSF CAREER award to develop best practices for human-AI collaboration in engineering design

As artificial intelligence (AI) is inevitably woven into the workplace, teams of humans will increasingly collaborate with robots on complex design problems, such as those in the automotive and aerospace industries.

"Right now, design is mainly done by humans, and it's based on their expertise and intuitive decision-making, which is learned over time," says A. Emrah Bayrak, an assistant professor of mechanical engineering and mechanics who joined the Rossin College faculty earlier this year. "Usually, you're not creating something totally new. You take something that works already, understand how it works, and make incremental changes. But introducing AI could make the process a lot faster—and potentially more innovative."

However, best practices for integrating AI in a way that both maximizes productivity and the job satisfaction of the human worker remain unclear. Bayrak recently won support from the National Science Foundation's Faculty Early Career Development (CAREER) program for his proposal to allocate portions of complex design problems to human and AI teams based on their capabilities and preferences.

Bayrak will explore the problem of dividing a complex task between human designers and artificial intelligence from both a computational and experimental perspective. For the former, he will use models that predict how a rational human being would explore the design of, say, the powertrain in an electric vehicle (EV).

"We know that decision-making is a sequential process," he says. "People will make a decision, look at the outcome, and revise their next decision accordingly. In order to maximize the range of an EV, when humans consider the design of the powertrain, they must make decisions about gear ratios, motor size, and battery size. These are all variables that we can feed into a model to predict what the next decision should be if the human is a rational person."

AI, in contrast, makes decisions based on training data. Feed it data on good decisions regarding gears, motors, and batteries, and it can then estimate possible vehicle designs that will yield an acceptable range. Artificial intelligence could also use that knowledge to think about what the next design decision should be.

> "THIS WORK COULD POTENTIALLY SHAPE HOW ORGANIZATIONS ARE STRUCTURED."
> —A. Emrah Bayrak

Bayrak's model will also contain different human archetypes. For example, a person who trusts AI completely versus one who does not, and those who hover somewhere in the middle. The model will combine the mathematical variables that represent decision-making with the full range of archetypes to determine strategies for the division of labor between humans and AI. Bayrak will then test those findings experimentally. Participants will be asked to work together with AI to virtually approach the design of a vehicle.

OPEN STUDIO/ADOBE STOCK

"We give them a design problem and tell the people which decisions they're responsible for making and which are the responsibility of the AI," says Bayrak. "They work together, and the goal is to collect the data and see if the computational results reflect what happens in the experimental findings. In other words, do designers act as predicted by the models or do those designers who don't fully trust AI end up satisfied with the division of labor?"

The ultimate goal, he says, is not to replace humans in the workplace. Rather, it's to develop principles for how and to what extent AI should be integrated into complex design projects. And those guidelines will reflect different priorities—for example, a team may want to incorporate AI merely as an assistant, or they may want to give it significant responsibility. Teams may want to prioritize quick decision-making, innovation, or job satisfaction.

"The idea here is that we'll have quantitative evidence that reveals which practices work well to achieve specific objectives and which do not," he says. "This work could potentially shape how organizations are structured in the future."

Like all NSF CAREER proposals, Bayrak's project also includes an educational component. He plans to turn his model into a video game of sorts that will incentivize users to create better designs to solve problems.

"I'd like to teach people the principles of statistical analysis and data science in a practical way," he says. "The game will draw them into a problem, allow them to collect data in real time, and reveal how that data informs the models—and, ultimately, guide their decision-making."

He envisions using the game within existing courses related to data science and in future data analytics boot camps he plans to run for PhD students.

"Many of our students need to process data in their research," he says, "and using the game in these boot camps will teach them the principles of how data can be analyzed and used to draw meaningful and potentially exciting conclusions for their research."

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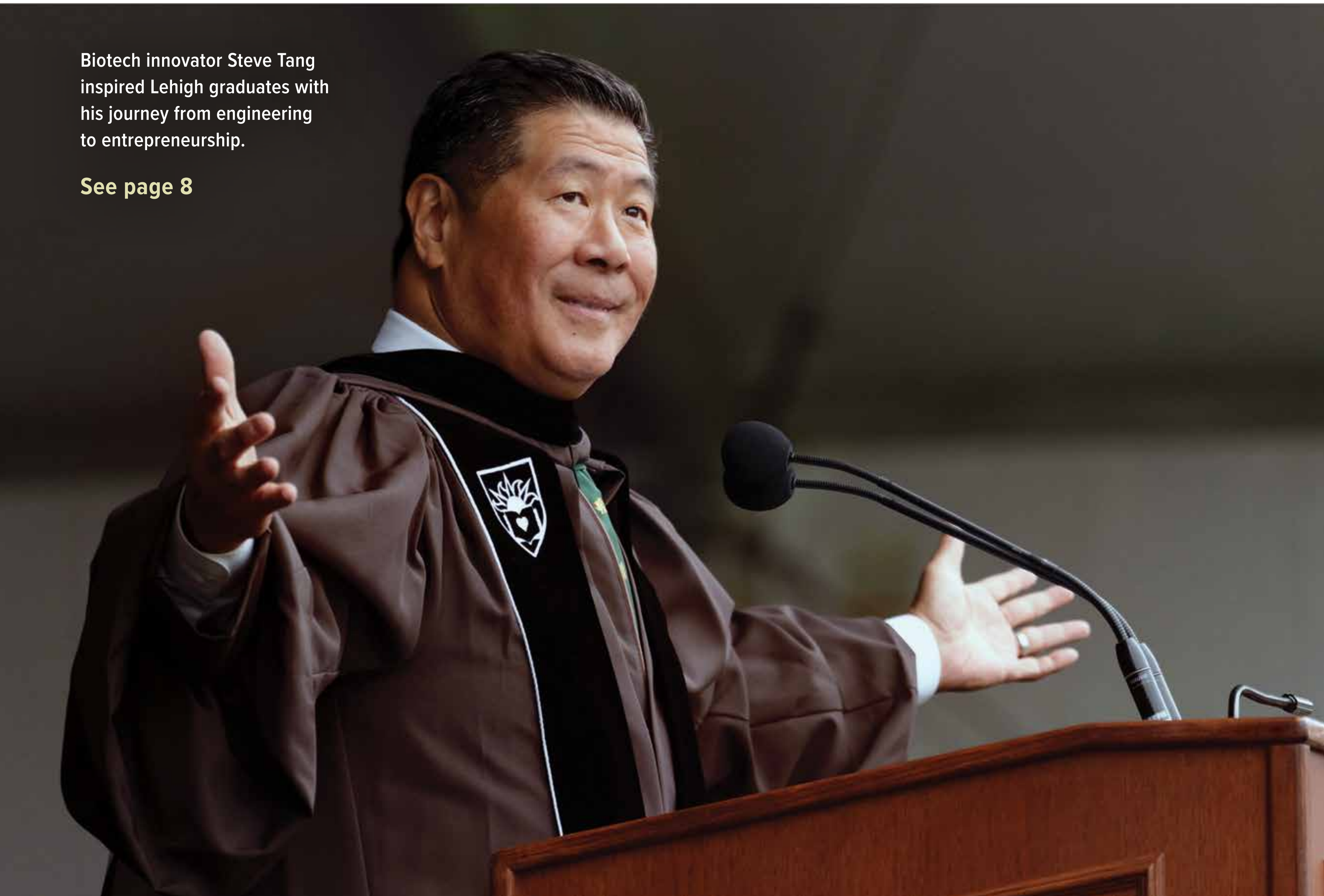
LEADING WITH VISION



Biotech innovator Steve Tang inspired Lehigh graduates with his journey from engineering to entrepreneurship.

See page 8