

SPECIAL
ISSUE

Spring 2020

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Engineering Innovation @LehighU

SUSTAINABILITY & RESILIENCE

Creating new knowledge to drive action on climate change

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/ Recycling for stronger manufacturing materials



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P.C. Rossin College of
Engineering and Applied Science



New partnerships and academic programs are furthering Lehigh's efforts to infuse sustainability throughout the university's campuses and curriculum (see "Many Disciplines, One Goal," opposite page).

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In the next issue of *Resolve*:

Meet the 2020 class of NSF CAREER award recipients

Since 2015, an astounding 16 Rossin College professors—more than 75 percent of eligible new faculty over this period—have secured CAREER funding.

COLLEGE DEANS

Stephen DeWeerth
Professor and Dean

John Coulter
Professor and Sr. Associate Dean
for Research and Operations

Gregory Tonkay
Professor and Associate Dean
for Academic Affairs

Svetlana Tatic-Lucic
Professor and Associate Dean
for Faculty Advancement

PUBLICATION DIRECTOR | Chris Larkin

EDITOR | Katie Kackenmeister

STAFF WRITER | Christine Fennessy

DIGITAL DIRECTOR | Marc Rosenberg

DESIGN | Gipson Studio LLC

CONTRIBUTING WRITERS

Lori Friedman, John Gilpatrick '10, Tim Hyland,
Richard Laliberte, Isabella Madrigal '20

COVER CREDITS

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P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

Lehigh University
19 Memorial Drive West
Bethlehem, PA 18015
610-758-4025
engineering.lehigh.edu

SUBSCRIBE OR SEND COMMENTS
engineering@lehigh.edu



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Many disciplines, one goal

Welcome to a special Spring 2020 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—focused on sustainability and resilience in response to our changing climate.

As our world grapples with myriad challenges presented by the interconnected ecological, social, and economic consequences of climate change, one thing is clear: Addressing the needs of a growing human population in an environment of finite resources will require contributions from every corner of the science and engineering community. And we will need to work with our colleagues in associated pursuits to innovate and refine solutions for generations to come.

Lehigh's faculty-led Interdisciplinary Research Institutes (IRIs) were created in 2018 as communities of scholars positioned to tackle complex, large-scale challenges and incubate “big ideas.” The first wave of IRI teams is gaining momentum, and a striking number of them are moving toward solutions that mitigate or reduce the negative effects of a climate in flux.

Our college's efforts to infuse sustainability across our research and educational programs have been met with passion and drive from students and faculty alike, and their focus and commitment inspired this special issue of *Resolve*. Collectively, their work has major ramifications for the future of our natural and built environments, the resilience of our communities, and the systems that support them.

I am proud to report that our university is embedding sustainability across all facets of our community. The offices of Creative Inquiry and Sustainability are developing the Campus Sustainable Impact Fellowship, an academic program that will form a cohort of students from all disciplines who are focused on re-envisioning our campus as a “living lab.” Furthermore, a new partnership with three other Pennsylvania

colleges will enable Lehigh to offset 100 percent of its electricity usage with renewable energy. I join President Simon in recognizing this milestone as an “opportunity for Lehigh to demonstrate climate leadership and to energize the campus and broader community” around achieving ambitious sustainability goals.

Innovative approaches to climate change also shine through in our Q&A with proud alumnus Paul Camuti '83 (page 8). Over the years, Paul has been a tireless supporter of our college, including as chair of the Dean's Advisory Council. In the interview, he delves into his leadership roles at Ingersoll Rand and its “pure-play climate innovation company,” Trane Technologies, working to fuse the interests of corporate sustainability and profitability.

This issue's Rising Star (page 24) features a Lehigh-led, multinational, multi-institutional exploration of

OUR COLLEGE'S EFFORTS TO INFUSE SUSTAINABILITY ACROSS OUR PROGRAMS HAVE BEEN MET WITH PASSION AND DRIVE FROM STUDENTS AND FACULTY ALIKE.

the interplay among society's competing interests in the provision of food, energy, and water on a global scale. The project is driven by recent National Science Foundation CAREER award recipient Ethan Yang. He joins a distinguished group: Nearly one-third of Lehigh's engineering faculty lay claim to this prestigious award, with an astounding 16 achieving this milestone in the past five years.

Of course, long-term advances in the face of climate change must also include redoubled efforts to attract the best and brightest into advanced science and engineering studies, as evident in our Educational Innovation article on page 22. I'm particularly



inspired by the creative philanthropic leadership of our friends at The Rossin Foundation, who have recently partnered with us to support early-career doctoral students as they develop and refine their individual research projects.

Our recently launched Pasteur PhD Partners (P3) Fellowship represents fresh thinking and a new approach to the network of support and resources around doctoral students. Developed in conjunction with colleagues at Corning

and the NSF, P3 adds a modern twist to industry-academia engagement—and may serve as a model for a new form of partnership among these communities on a national scale.

I hope you enjoy this special issue of *Resolve*; please drop me a note to share your thoughts and comments. Thank you as always for your interest in Lehigh Engineering!

Stephen P. DeWeerth, Professor and Dean
P.C. Rossin College of
Engineering and Applied Science
steve.deweerth@lehigh.edu

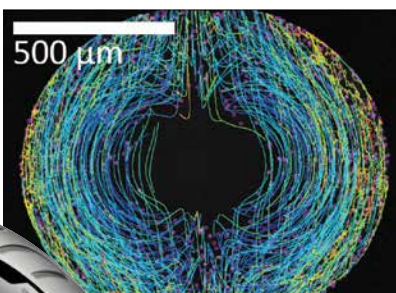


Wheels keep turning in friction research

Fueled by \$2M grant, Anand Jagota pursues new avenues with Michelin North America

Bioengineering chair Anand Jagota has arrived at a milestone in his 15 years of researching friction and adhesion—one that could lead to innovations in tires, robotics, and biomaterials down the road.

With nearly \$2 million in new support from the National Science Foundation over five years, Jagota



A better understanding of friction could influence future tire designs and production methods.

and collaborators from Cornell University and Michelin North America seek to develop two novel mechanisms to improve friction of soft materials based on bio-inspired design of near-surface structures.

“These are two difficult and new approaches to controlling friction of soft material surfaces and interfaces that have come to light through our previous work,” says Jagota. “This is our fifth and largest grant in this line of research—we continue to find fresh and exciting ideas to investigate.”

Increasing our understanding of friction, Jagota explains, could have wide-ranging implications for society: creating tires that make our cars safer and prevent crashes, improving robots’ ability to grasp and perform intricate tasks, or even just building a better-performing table tennis racket.

Lehigh’s first LEAP HI

The NSF funding comes as a Leading Engineering for America’s Prosperity, Health,

and Infrastructure (LEAP HI) Grant Opportunity for Academic Liaison (GOALI). The LEAP HI program supports interdisciplinary, multi-investigator proposals and encourages the engineering research community “to take a leadership role in addressing demanding, urgent, and consequential challenges.” This is the first LEAP HI grant awarded to a Lehigh researcher since the program’s inception in 2017.

Jagota has previously partnered with Michelin North America through the NSF’s GOALI program, which encourages academic-industry collaborations. Michelin manufactures and sells tires for airplanes, automobiles, earthmovers, farm equipment, heavy-duty trucks, motorcycles, and bicycles. The company operates 19 plants and employs 20,000 people in North America, with more than 1,000 in R & D roles.

Nationally, tire manufacturing is a \$148 billion industry that is responsible for more than 737,000 jobs, according to the U.S. Tire Manufacturers Association.

“The ability to use surface features to control the friction between surfaces opens many design possibilities; but in order to take advantage of the idea, we need to understand the mechanisms involved and that is what this research will allow us to do,” says Mike Andrews, director of external research for Michelin North America.

The project is also aligned with Lehigh’s Pasteur PhD Partners (P3) Fellowship, a new student-centric graduate training model that provides doctoral candidates in the Rossin College with long-term, hands-on industry experience and mentorship (see “Blazing New Trails,” page 22).

Scaling up on multiple levels

Jagota, who is also a professor of chemical and biomolecular engineering and is affiliated with Lehigh’s Institute for Functional Materials and Devices (I-FMD), will continue his long-standing collaboration with Cornell engineering professor Chung-Yuen Hui. The team also includes Constantine Khripin ’08 PhD, a materials perfor-

mance researcher at Michelin who did his dissertation work in Jagota’s lab.

The new project has origins in Jagota’s earlier work in biomimicry—investigating biological adhesion mechanisms in geckos, lizards, and frogs—but has evolved to a collaboration with industry focused primarily on friction.

“In making these biomimetic surface structures, employing fibrils or complementary shapes, we’ve been able to create very high sliding friction, which could be used to improve the braking performance of tires,” he says. “We’ve discovered several techniques that can turn friction up or down. Now we’re taking a deeper dive into these mechanisms, some of which are meso-scale versions of molecular level phenomena that underlie the fundamental question of how friction arises between surfaces in the first place.”

The team will investigate two mechanisms based on previous discoveries.

Meso-scale dislocation arrays are interfaces with a periodic array of features that accommodate misorientation by generating meso-scale interfacial dislocations, which can be used to control friction. Employing these arrays in the manufacture of tires and other products comprised of layers of soft materials like rubber could improve product quality, cut down on waste, and open up experimentation with new materials.

The second avenue of research explores a new form of elastic hysteresis based on periodic near-surface patterning of elastic modulus that can be used to set up additional hysteresis to yield significant friction enhancement. The mechanism could enhance friction of tires, especially in wet conditions, and contribute to a reduction in the risk of vehicle collisions and related fatalities.

“Tire manufacturing is a very mature field, so there’s a very different dynamic when it comes to implementing innovation,” says Jagota. “You have to be very, very careful before making changes because of the safety aspect, so there is a deliberate process for applying new ideas. It’s a challenge, but we take that as a positive.”



“Robot learning is an intrinsically multidisciplinary subject,” says Nader Motee, who organized a recent workshop on the topic, hosted by Lehigh’s Institute for Data, Intelligent Systems, and Computation (I-DISC).

Making robots more perceptive

Networks of robots working in tandem can accomplish complex tasks, but when one machine falters, it can cause chaos. Picture a drone flying away from its fleet and failing to photograph its assigned area, or a self-driving car getting too close to another and disrupting a carefully designed platoon.

Making networks like these smarter, more functional, and more efficient is the subject of two research projects, funded by more than \$1 million in grants, led by Nader Motee, an associate professor of mechanical engineering and mechanics.

With support from the Office of Naval Research, Motee is investigating how to represent streaming data (e.g., images taken by an onboard high-frame-rate camera) efficiently for feature extraction, learning, planning, and control objectives.



For context, he uses the example of map classification using a fleet of flying robots. Although a single robot could accomplish this task, he says, the process might take hours or days. The timeline shrinks to minutes when a hundred or so robots do similar, more focused tasks, but the robots must communicate with one another to exchange relevant information and increase efficiency and resiliency while working in uncertain environments.

“The challenge is to figure out which pairs of robots should talk to one another, and how often, and what information to share,” Motee says.

The amount of data the cameras on these flying robots collect is staggering—anywhere between 200 and 1,000 frames per second, with each frame at four or five megabytes in size. The robots must process this data in real time because storing it all would be impossible. But not all data is relevant to the success of the task, nor does every robot in the fleet need to receive every bit of data from every other

robot. It’s important to efficiently represent the data to enable real-time learning, task planning, and control.

Getting robots to make these determinations for themselves is a very complicated but important step in the long-term development of artificial intelligence and autonomy.


“[This work] will be relevant for time-sensitive missions and tasks when humans cannot stay in the loop to monitor the deployed robots,” Motee says. “Achieving long-term autonomy and using onboard intelligent mechanisms will help robots survive for long periods of time during their missions in uncertain environments.”

In a separate project focused on risk analysis of nonlinear dynamical networks, supported by the Air Force Office of Scientific Research, Motee seeks to improve robot planning and control by transforming a robot’s dynamic behaviors from nonlinear (in finite dimensions) to linear (in infinite dimensions).

“For instance, if we change the input signal to a robot by 10 percent,” he explains, “its output will not change by the same 10 percent. Robots’ nonlinear behavior makes control design and task planning problems very challenging.”

Motee’s team will investigate what conditions make nonlinear systems—such as platoons of self-driving cars or power networks—more prone to failure.

“If a tree branch falls on a power line, it may cause that line to fail, which may cause nearby power lines to overload and fail. These local events may result in a global power outage, or systemic failure. And with platoons of self-driving cars, if the two leading cars fail to maintain a safe distance and collide, it will result in several collisions.”

This project will explore how engineers can mitigate the effects of local failures in networks and prevent systemic failures. 

“IMPROVING ROBOTS’ AWARENESS AND DECISION-MAKING IS A COMPLICATED BUT CRITICAL STEP IN ADVANCING AI.”

—Nader Motee



A deep dive into deep learning

Highly cited paper co-authored by Frank E. Curtis emerges as a go-to resource for optimization algorithms for machine learning



The building blocks of artificial intelligence—data, computing power, and mathematical models—have been

around for decades. But only recently have they been employed at a level of sophistication and on a large enough scale to weave machine learning into our everyday lives.

“Anybody that’s been using tools powered by AI, like your smartphone recognizing speech or your photos app classifying images, has seen a substantial improvement over the past five to 10 years,” says Frank E. Curtis, an associate professor of industrial and systems engineering.

As researchers learned how to put the pieces together effectively and

“We saw the need to take all the different approaches people were proposing, solidify them, and share some perspective on what these algorithms could accomplish,” Curtis explains. “Doing so would not only help researchers better understand what others are doing but also characterize these approaches in a way that would help reveal new possibilities and new directions that people should explore.”

In 2018, the team authored an influential paper on “Optimization Methods for Large-Scale Machine Learning” published in *SIAM Review*. Less than two years since its publication, the work has been recognized as a “Hot Paper” and a “Highly Cited Paper” in the field of mathematics by Clarivate Analytics’ Web of Science and ranks in the top 5 percent of all

research outputs scored by Almetric, a tracker of online mentions of research articles.

“The stochastic gradient method is the most popular algorithm used in large-scale machine learning applications like text recognition and image classification,” says Curtis. “We analyzed that algorithm concisely,

generalizing the known theory for it in useful ways, so that someone could take some other algorithms that are modified versions and use the same analysis—citing our work instead of redoing things from scratch.

“When you have all these people working in the same area, the wheel tends to get reinvented many times,” he continues. “We’ve created a resource that characterizes different types of algorithms out there in an elegant way, and people can look at the landscape of

possibilities and identify where their work fits in and what gaps they can fill in our understanding.”

In the marketplace, Curtis says, Facebook, Google, and other big internet players are pouring vast amounts of money into machine learning and the high performance computers and data gathering that fuel the technology. More finely tuned algorithms cut associated costs and improve efficiency over the long term, he explains, and also have the potential to lower the barriers to entry—allowing smaller companies and even individuals to leverage artificial intelligence—and push the technology further.

In the future, Curtis says, more sophisticated algorithms could support machine learning models (in areas like text recognition, for example) that operate simultaneously across multiple computers instead of a single supercomputer.

“Millions and millions of people have smartphones. They’re constantly speaking to them and seeing the results. And if something is wrong, they’re correcting it. There is so much data that people are generating, but it’s not put together on one computer, nor would everyone want their data collected. But you’re essentially training your own model locally. What if you could create an algorithm that would allow you to share that intelligent model without the identifiable data?”

Although he’s keenly aware of the innovative (albeit sometimes unsettling) possibilities of AI, Curtis’ own work revolves around building foundational knowledge, rather than focusing on specific applications—a direction he, as a mathematician, finds particularly satisfying.

“The next level of machine learning models will require even more advanced algorithms,” he says. “That’s where the future is. The optimization problems I’m working on might involve energy systems or something else, but to me, it’s great that I can take the same expertise and apply it wherever algorithms are used.”



Frank E. Curtis (seated, center) is a member of Lehigh’s Optimization and Machine Learning (OptML) research group.

sought out bigger and better applications of AI, such as self-driving cars, new algorithms used to “train” machine learning models were springing up everywhere.

Curtis, an optimization expert who focuses on algorithm design, and his colleagues Jorge Nocedal, an engineering professor at Northwestern University (and Curtis’ PhD advisor), and Léon Bottou, of Facebook AI Research, recognized this as an opportunity.

ISE faculty on front lines of quantum computing revolution

With support from a \$2.1 million research grant from the Defense Advanced Research Projects Agency (DARPA), an international group led by industrial and systems engineering faculty members Tamás Terlaky, Luis Zuluaga, and Boris Defourny is working on optimization algorithms in quantum computing.

“We want to explore the power of existing quantum computers and those that are predicted to exist in the future,” says Terlaky. “We’ll be looking at combinatorial optimization problems for quantum computing with the goal that, in four years, we’ll be able to demonstrate that quantum computers are surpassing the capabilities of classical computers, at least on some problems.”

Terlaky says their work is related to the theory of quantum supremacy, which, very broadly, states that quantum computers will be exponentially better than current silicon computers at quickly solving problems that are unsolvable today. Those problems could relate to fields as diverse as finance, security, genetics, machine

learning, transportation, and manufacturing, and could model practical, binary questions such as whether to purchase or not purchase, to build or not build, and so on.

There is a long way to go to achieve that end. Current quantum computers are about where silicone-based computer chips were in the 1950s, says Terlaky, who is also affiliated with Lehigh’s Institute for Data, Intelligent Systems, and Computation (I-DISC).

“In the ’50s, we had gym-size computers with very little memory, and very little processing power,” he

“WE WANT TO EXPLORE THE POWER OF EXISTING QUANTUM COMPUTERS AND THOSE THAT ARE PREDICTED TO EXIST IN THE FUTURE.”

—Tamás Terlaky

says. “A lot of programming was written in assembly language, getting the machine the codes, and specifying every gate and route for the information. At this point with quantum computers, the programming language is very similar. It’s not a high-level language where you can write a complicated code easily. So all this software has to develop along with the upcoming hardware.”



Quantum computers, like IBM’s 50-qubit (quantum bit) machine, will quickly solve problems that are unsolvable today.

Until recently, he says, most of the work in this area was being done by theoretical physicists, electrical engineers, computer engineers, and theoretical computer scientists. But the theory of quantum supremacy is essentially one big optimization problem.

“And we are the optimizers,” says Terlaky. “Very few people in the optimization community have looked at these problems so far. We are definitely the first sizable group to do so.”

Other collaborators on the project include Giacomo Nannicini (IBM T.J. Watson Research Center), Stefan Wild (NAISE, Evanston, IL, and Argonne National Lab), Alain Sarlette (INRIA, Paris, France), Xiu Yang (ISE, Lehigh University), and Monique Laurent (Centrum Wiskunde & Informatica (CWI), Amsterdam, Netherlands). ❶

NAE MEMBER ELSA REICHMANIS TO JOIN ChBE FACULTY

Elsa Reichmanis, an acclaimed polymer chemist and member of the National Academy of Engineering, will join the Rossin College as the Carl R. Anderson Endowed Chair in Chemical and Biomolecular Engineering. She will begin her tenure on September 1, 2020.

Currently the Pete Silas Chaired Professor in the School of Chemical and Biomolecular Engineering at the Georgia Institute of Technology, Reichmanis is a groundbreaking researcher and pioneer in the world of microlithography. She is a former president of the American Chemical Society and served as director of the Materials Research Department at Bell Labs.

“Dr. Reichmanis is an exceptional scholar and academic leader,” says Stephen P. DeWeerth, professor and dean of the Rossin College.



“We expect that she will expand our research impact and catalyze new areas of interdisciplinary collaboration.”

Reichmanis, whose work cuts across the fields of chemical engineering, chemistry, materials science, optics, and electronics, says she is excited for the opportunity to build on already existing interdisciplinary research initiatives, and to conceptualize and develop new ones.

“One of the things that attracted me to Lehigh was the clear strengths the university has in terms of interdisciplinary research,” Reichmanis says. “My research during my time at Bell was very interdisciplinary and very collaborative, and that kind of work is something that I truly enjoy.” ❶

Solving a combinatorial quandary

Brian Chen develops software that can identify protein mutations and explain their significance

Why do certain proteins in the body bind with some substances but not with others?

The answer could be the difference between a drug working or not. The answer, however, is elusive by virtue of the sheer scope of mutations that make proteins vary between each other and between individuals.

“Amino acids are the building blocks of proteins, and my copy of a protein might have just one that is different than yours,” says Brian Chen, an associate professor of computer science and engineering. “But there are many different ways that one amino acid may change, and there are many different amino acids that may potentially change. So the natural question is, why don’t you test all the possibilities? Well, that would be a combinatorial nightmare. There are just too many possibilities to test in a wet lab, too many possibilities for a human to simulate on a computer, and too many possibilities for a person to keep straight in their head and consider in a systematic way.”

Currently, researchers must review the data and do their best to interpret whether or not proteins are interacting and how.

Supported by a four-year, nearly \$1 million grant recently awarded by the National Institutes of Health, Chen is developing software that can both handle the scale of possibilities and replace human interpretation of that data. But in a novel twist, the software will also generate an English-language translation that will explain the mechanism behind protein interaction or noninteraction. In other words, it will tell the researcher what it thinks is happening.

“The software provides the mutations to investigate and the reasons why it thinks those mutations are significant,” says Chen. “In essence, it allows us to reduce the scope of testing because it gives a rationale for that testing.”

The software will eventually utilize four of the biophysical mechanisms that control protein interactions—shape complementarity, electrostatic complementarity, hydrogen bonding, and hydrophobicity. It currently uses the first two.

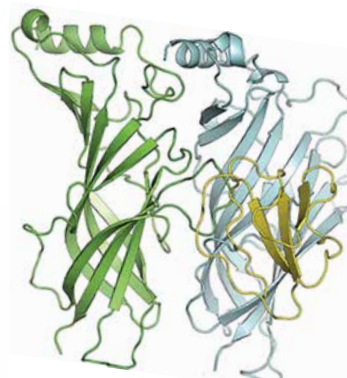
Chen’s NIH grant will support the continued development and testing of the software, the latter of which will be done in collaboration with Julie Miwa, an associate professor of neuroscience in Lehigh’s College of Arts and Sciences. Miwa’s lab studies the interaction between lynx proteins and nicotinic acetylcholine receptors in the brain.

“One of the questions that comes up in her research is, do certain variations of these lynx proteins turn the receptors on or off? And that’s really important because it’s believed that lynx mutations affect neuroplasticity,” explains Chen. “Discovering new mutations that affect this interaction could shed light on the mechanisms that affect learning and anxiety. But there are hundreds of possibilities. So I’ll be using my software to suggest mutations that could interrupt binding between the lynx and acetylcholine receptors. It’s a great opportunity to validate our software because it’s a completely

blind scenario, and a great opportunity to assist Dr. Miwa’s study of the lynx family of proteins. We don’t know which amino acids are going to be important, but her team will reveal if we were right or wrong when they find the biological truth.”

The ultimate goal of this research, he says, is for the software to utilize more than four biophysical mechanisms in its predictions and to provide even more robust explanations for why mutations might affect binding. He also looks forward to more opportunities for collaboration, especially with students, in this work that he calls “super exciting” and “deeply fascinating.”

“The interest in research among undergraduates here at Lehigh is really high,” says Chen, “and it has allowed me to get a lot of research done on this specific project that I otherwise would not have been able to do, specifically in terms of evidence and validation. I think undergraduate research is one of the great strengths of this university.”



Brian Chen will use his software to assist Lehigh neuroscience professor Julie Miwa in her study of the lynx family of proteins.






Illustration of an atomic force microscope tip in contact with a ferroelectric surface

AI technique yields ferroelectrics discovery

Neural network approach a game changer for nanomaterials research

Joshua Agar and his colleagues studying nanoscale ferroelectrics are using deep neural networks to extract useful information from the massive amounts of data generated by their experiments. Applying this artificial intelligence method, Agar and his team have discovered—and visualized for the first time—a new mechanism of ferroelectric switching.

Ferroelectrics exhibit spontaneous electric polarization—as a result of small shifts in charged atoms—that can be reversed by the application of an external electric field. Despite promise in applications including next-generation low-power information storage/computation, energy efficiency via harvesting waste energy, and environmentally friendly solid-state cooling, a number of issues still need to be solved for these nanomaterials to reach their full potential.

Agar, an assistant professor of materials science and engineering, uses a multimodal hyperspectral imaging technique (through Oak Ridge National Laboratory) called band-excitation piezoresponse force microscopy, which measures the mechanical properties of the materials as they respond to electrical stimuli. These *in situ* characterization techniques allow for the direct observation of nanoscale processes in action.

“Our experiments involve touching the material with a cantilever and measuring the material’s properties as we drive it with an electrical field,” he says. “Essentially, we go to every single pixel and measure the response of a very small region of the material as we drive it through transformations.”

The technique yields vast amounts of information about how the material is responding and the kinds of processes that are happening as it transitions between different states, explains Agar.

“You get this map for every pixel with many spectra and different responses,” says Agar. “All this information comes out at once. The

problem is how do you figure out what’s going on because the data is not clean—it’s noisy.”

The technique is described in an article in *Nature Communications*. Other authors include researchers from University of California, Berkeley; Lawrence Berkeley National Laboratory; the University of Texas at Arlington; Penn State University; and the Center for Nanophase Materials Science at ORNL.

Applying the neural network technique, which uses models employed in natural language processing, Agar and his colleagues were able to directly image and visualize an important subtlety in the switching of a classical ferroelectric material, lead zirconium titanate, which, prior to this, had never been done.

When the material switches its polarization state under an external electrical field, explains Agar, it forms a domain wall, or a boundary between two different orientations of polarization. Depending on the geometry, charges can then accumulate at that boundary. The modular conductivity at these domain wall interfaces is key to the material’s strong potential for use in transistors and memory devices.

“What we are detecting here from a physics perspective is the formation of different types of domain walls that are either charged or uncharged, depending on the geometry,” he says.

According to Agar, this discovery could not have been possible using more primitive machine learning approaches, as those techniques tend to use linear models to identify linear correlations. Such models cannot efficiently deal with structured data or make the complex correlations needed to understand the data generated by hyperspectral imaging.

This particular neural network approach could have immediate applications: “It could be used in electron microscopy, in scanning tunneling microscopy, and even in aerial photography,” he says. “It crosses boundaries.”

“WE GO TO EVERY SINGLE PIXEL AND MEASURE THE RESPONSE OF A VERY SMALL REGION.”

—Joshua Agar

FACULTY EXCELLENCE IN MATERIALS, ELECTRON MICROSCOPY

» CHRISTOPHER J. KIELY ELECTED TO ACADEMIA EUROPAEA

One of the world’s premier scientific organizations, *Academia Europaea* is an association of approximately 4,200 scientists and scholars who collectively aim to promote learning, education, and research. Kiely is an expert in the application of advanced transmission electron microscopy techniques for the study of nanoscale features in materials, and his election to the academy recognizes his continued contributions as a global leader in the area of catalyst material characterization.

» JEFFREY RICKMAN ELECTED FELLOW OF ASM INTERNATIONAL

The leading association of materials engineers and scientists recognized Rickman for his “significant contributions in computational materials science of defects and phase transformations, pioneering work on materials informatics, and distinguished service to the materials science community.” Rickman is a member of the multidisciplinary Nano/Human Interface Presidential Engineering Research Initiative at Lehigh and his research interests include the development of computer simulation methodologies for describing fluids and solids, determination of the elastic properties of defects, and the kinetics of phase transformations.

» MASASHI WATANABE ELECTED FELLOW OF THE MICROANALYSIS SOCIETY (MAS)

Watanabe, a former MAS president, was honored for outstanding leadership in analytical electron microscopy and the zeta-factor technique for quantitative STEM-XEDS microanalysis. His work emphasizes materials characterization using various electron microscopy approaches involving analysis via X-rays and energy-loss electrons in analytical electron microscopes and atomic-resolution high angle annular dark-field imaging in scanning transmission electron microscopes.



CHARTING A BOLD COURSE

Tech leader Paul Camuti on innovating with sustainability at the core

Over more than three decades, industrial and systems engineering alum Paul Camuti '83 has steered large-scale enterprises toward enhanced energy efficiency and sustainable business practices. Camuti served in senior leadership roles at Siemens Corporation, including as president of smart grid applications for Siemens Energy Inc. He is currently executive vice president and chief technology and strategy officer for Trane Technologies (formerly Ingersoll Rand)—a newly launched “pure play climate company”—where he continues to push for aggressive corporate sustainability goals while driving climate-focused innovations for commercial buildings, homes, and transportation. —Katie Kackenmeister

Q: What do you see as the responsibility of companies when it comes to confronting issues of sustainability and climate change?

A: Large, global challenges—like resource constraints, growing urbanization, and a demographic shift—are all putting stress on the planet. The built environment is responsible for about 15 percent of the world's carbon emissions today—and with current heating and cooling trends, it could go to as high as 25 percent by 2030. Transport refrigeration for food, pharmaceuticals, and other perishables

accounts for another 8 percent of all the world's emissions.

At the same time, there is a whole new set of energy efficient technologies that are advancing at an ever-increasing rate. For example, we're putting sustainability at the core of everything we do while implementing new thinking and devising new solutions at the convergence of these technologies and challenges.

For years, there has been a lot of focus on the regulatory environment and the role that governments and individuals play.

But collectively, companies have the largest and probably the most immediate impact in solving global challenges.

At Trane Technologies, we think it's our responsibility to take bold action around climate change. But we also don't see this as incongruent with creating a high-performing company that investors want to invest in and, more importantly, the type of organization that people want to work for. The idea that you have to choose between premier performance or bold sustainability action is a false choice: We see them as different sides of the same coin.

Q: Has something changed in the marketplace to make that so?

A: People are bringing a social conscience to the evaluation of heating and cooling equipment, and we're seeing demand for these solutions go up. Investors are in the same boat. Investors generally, and I think rightfully, are focused on returns. But all over the world right now, people know that the long-term stability of an investment is

Bottom left: Paul Camuti '83 speaks at an Alliance to Save Energy forum on energy efficiency policy in Washington, D.C.

Bottom right: Camuti, who serves on the Alliance's board of directors, accepts the coalition's 2019 Star of Doubling Down on Efficiency award on behalf of Ingersoll Rand.

and AI-enabled optimization of these systems—that will create significant system-level efficiencies. Finally, we're working on business model innovation, thinking about the shared economy and making sure that we're not dramatically over-deploying these technologies.

Q: What inspires you about the newest generation of engineers?

A: Our recruiting today on college campuses, particularly with engineers but also with finance people, marketing people, HR people, is that graduates are looking for more than just a job. They're looking for a job with a purpose and a place to pursue their passion, whether that's helping people through health care, or in our particular case, by lowering the energy intensity of the world. Our purpose is "to boldly challenge what's possible for a sustainable future," and it really resonates with people. I think for companies that don't have a clear and articulated purpose, it's increasingly difficult to recruit the best, the brightest, and the most motivated

engineers. I also see the convergence of technology in all disciplines and aspects of a business. My industrial and systems engineering background was really focused on the application of computer technology. And being really fluent and not afraid of information and communication technology has paid off for me personally. I think that's true now of everyone, right? I can't imagine people working in marketing or workforce planning or finance or legal departments that are not technology enabled.

Q: When you think about climate change, do you ever experience a sense of optimism or hope?

A: If you watch the news, you'll see things like the wildfires in Australia, and say, "My gosh, we have to get after it and do something." These are large-scale problems, and it's easy to get discouraged. We're not acting fast enough. Yet, what keeps me totally optimistic comes down to this: The majority of people who want to work for us today are

directly related to environmental, social, and governance topics. And our focus has put us at the lead of a set of people who look for sustainable investments. There isn't a trade-off between doing the right thing and making money. We are very focused on delivering good economics because we're focused on doing the right thing, not in spite of it.

Q: What innovations do you find most exciting in terms of their potential effects on sustainability goals?

A: Trane Technologies is in a unique position to address major sustainability issues and reduce our customers' carbon emissions. We're pioneering next-generation refrigerants and technologies to improve the efficiency and dramatically change the life-cycle impact of heating and cooling equipment. At the same time, we're also developing and applying new digital technologies—around information and communication, Internet of Things, artificial intelligence,



students. And, clearly for the work that we do—applying technology to these large challenges—engineers are critical.

Q: How does an engineering education—and in your experience, industrial engineering—serve as preparation for a career in corporate leadership?

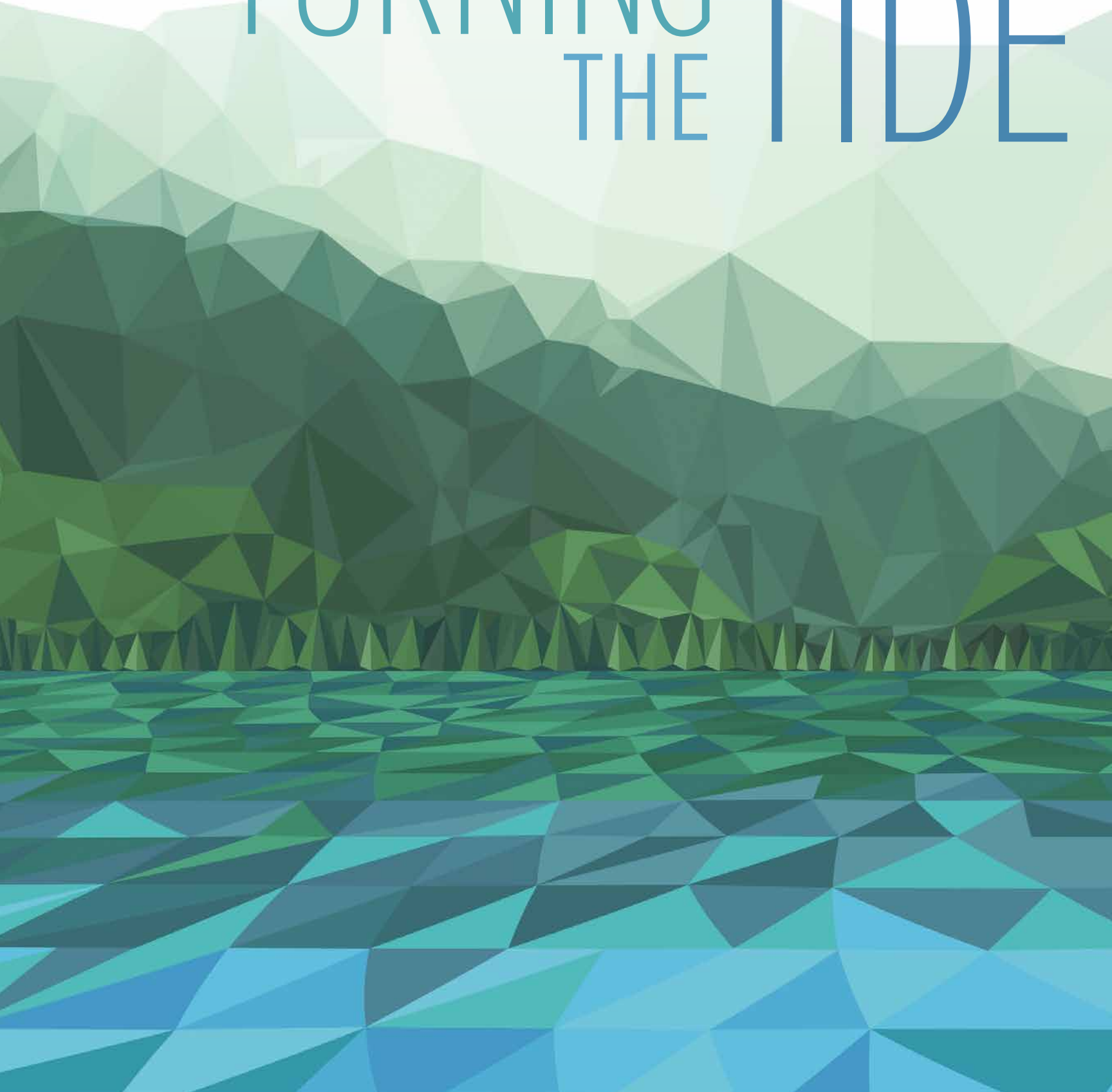
A: Engineers are problem solvers. The method and structure and analytics that come from the engineering discipline, and the passion for solving problems, have been really helpful in every role that I've had, including those in corporate leadership. I think Lehigh does a better job than most engineering schools in instilling practical and useful problem-solving skills in our undergraduate



searching for this sense of purpose and want to make a difference. If we can harness the creativity, ingenuity, and commitment of large groups of people, we can move faster than what anybody would predict. Reinforcing that is the pace at which we're seeing our customers, investors, and employees embrace sustainability. I'm optimistic that engaged people are going to put their energy and effort into finding solutions. And there's certainly enough technology around that we can harness to bend the curve faster than we might expect. That's why companies must set bold commitments—and that's what keeps me optimistic in the face of these challenges. 1

SPECIAL ISSUE

TURNING THE TIDE





Climate change may be the most complex and multifaceted problem of them all.

It is forcing engineers to solve for the unknown in terms of the extent, severity, and duration of the economic and social fallout from a warming world. It requires the kind of teamwork and collaboration that inspires and fosters out-of-the-box thinking. And it demands boundless creativity and persistence to develop the alternatives that can fuel our lifestyles without contributing to the emissions and waste that currently threatens them.

Climate change is a problem suited for the engineers in the Rossin College, where talented faculty and students are working

across disciplines to conceptualize smart transportation systems that will reduce pollution and make communities more liveable. They're building models to help government and industry leaders better prepare for superstorms, fortify their infrastructure, and take measures to reduce the impact of catastrophic flooding. They're proposing novel solutions to massive waste issues both here and abroad. And they're contributing to the foundational research that will advance the development of alternative sources of energy. —Christine Fennessy

RESEARCHING ALTERNATIVES: ► Solar hydrogen fuel

It's long been known that photocatalysts can capture sunlight, split water into hydrogen and oxygen, and generate hydrogen fuel. When hydrogen is used as a fuel, either on its own or to generate electricity, it emits no greenhouse gases. Only water vapor and warm air.

But, generally speaking, growing the materials that compose those catalysts is a chemically harsh process. They're typically grown at high temperatures using organic solvents—highly toxic, carbon-based substances that are known neurotoxins and carcinogens.

"There are a lot of developments and breakthroughs in the field of renewable energy," says Steven McIntosh,

"We are approaching the rates and efficiency of hydrogen generation at large scale, and doing it in a greener way."

—Steven McIntosh

a professor of chemical and biomolecular engineering and associate director of Lehigh's Institute for Functional Materials and Devices (I-FMD). "It's great to invent something in the lab and have a sample of what it could possibly do. But if there are fundamental barriers to creating

the enormous scale we need when it comes to clean energy generation, then that development will not lead to a cleaner environment."

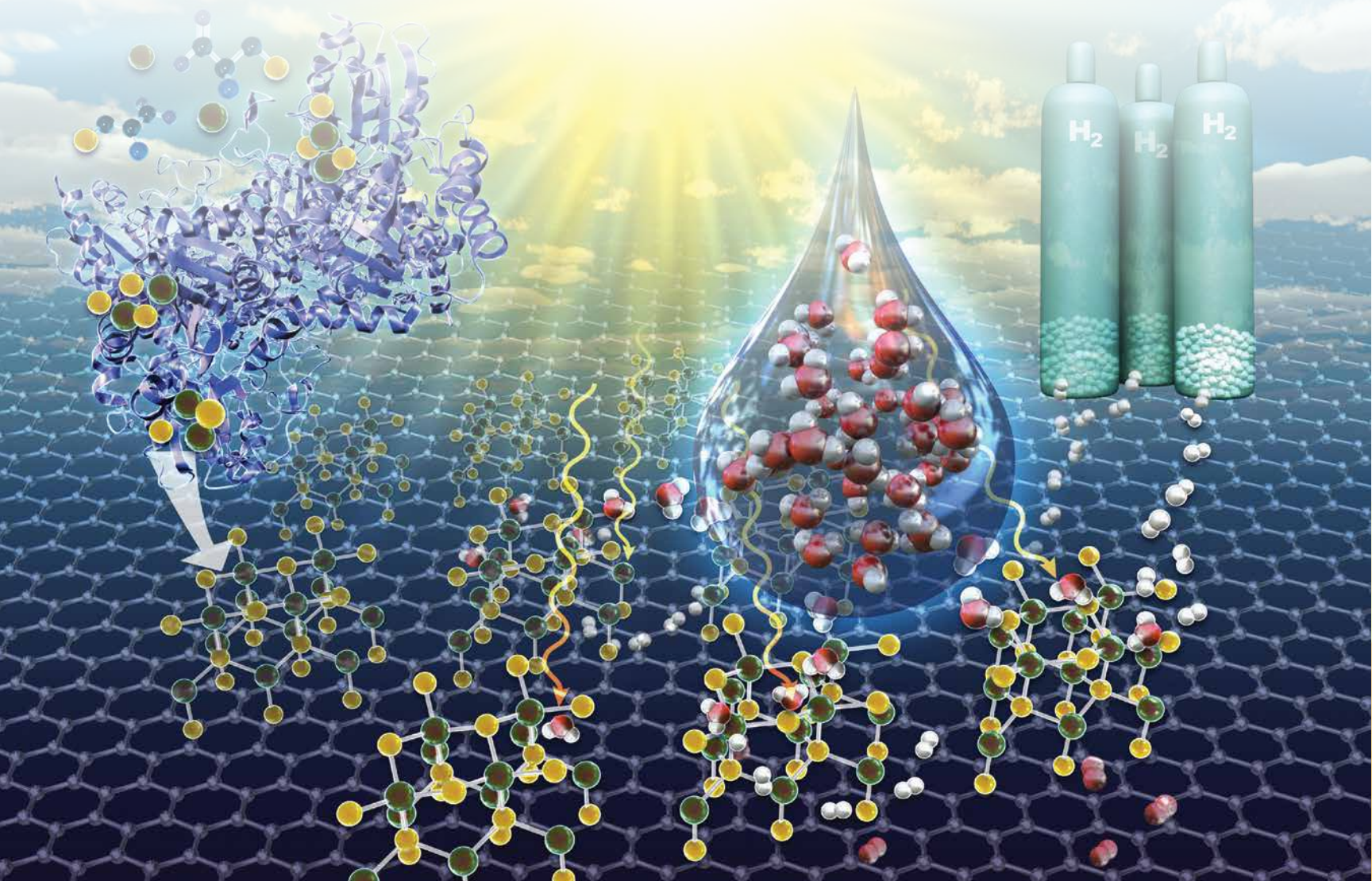
The use, accumulation, and recovery of those nasty organic solvents are one such fundamental barrier. So several years ago, McIntosh and his research team set out to determine if functional catalytic materials could be created without the harmful chemical processing. If, in fact, they could harness and control the biological system that living organisms use to form hard materials like bones, teeth, and shells, to make these catalysts. A process that occurs at room temperature, in water, and using abundant inorganic materials. A process that is environmentally friendly, and thus, potentially scalable.



It worked. The team was able to create the catalytic materials in the lab using this green process.

"Since then, we've worked to demonstrate that the materials can perform the function that we want," says McIntosh. "The materials we make are classified as quantum

confined nanoparticles [or dots], and they can be used in many applications, such as cancer biomarkers. In our most recent paper, we were able to show that you could split water with these. We also found that we can make



another component, a sheet of reduced graphene oxide, through the same process we made the dots. When you put the quantum dots and the graphene together, you make a much stronger catalyst. Many people have the same structure, but our work was featured on the cover of *Green Chemistry* because we're doing it in a green way. With that, in my mind, one huge barrier to scale went down."

Toppling those barriers one by one is essential. In the United States, hydrogen is used for refining petroleum, making fertilizer, treating metals, and processing foods—all giant industrial processes that consume huge quantities of hydrogen at enormous environmental cost.

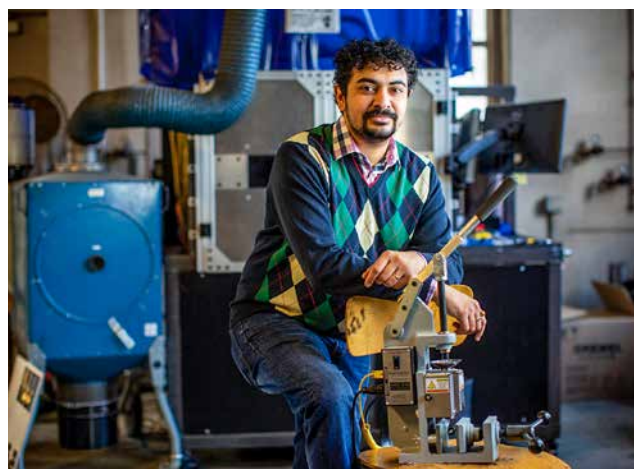
"Right now, for every two or so hydrogen molecules you make, you emit at least one carbon dioxide molecule" says McIntosh.

A greener process—coupled with a virtually inexhaustible supply of sunlight and water—would also have a huge impact on the use of hydrogen as a carbon-free fuel source, he says. Hydrogen could be used in fuel cells, or could be burned to make electricity.

"Think about it," says McIntosh. "What is a fuel? It's just a way to carry energy. And currently we carry energy in carbon-based fuels, such as coal, oil, and gas. Hydrogen and electrons are also energy carriers, and between the two of them, you can satisfy much of the world's energy demand. To date, the problem with scaling the use of hydrogen has been the amount of waste and the cost of being able to make these catalytic materials. But we know that, compared to the literature, we are approaching the rates and efficiency of hydrogen generation at large scale, and doing it in a cheaper, greener, more scalable way."

His team has another paper on deck that will show how they've made the bonding process of the quantum dots and the graphene even more efficient. And while his favorite vision is "swimming pools full" of these catalytic materials, he's thinking deeply about what it could mean to live in a world where houses might sport roofs of hydrogen-generating cells, where one household might generate more than it needs, and the sharing economy extends to the power we use to turn our lights on. He's part of an interdisciplinary group of researchers across the university who are collaborating on a proposal to study the societal change required to adapt to a new energy future, specifically to study how communities share their resources.

"The way we live right now is very much, my home is my castle. But that's not going to work if we all have to generate energy together and pool energy together. So say my hydrogen tank is full, and you needed some. How do I give it to you? And would people be okay with how we manage that? The societal change around this is huge because it's just not how we currently live. But could people really change the way they live? It's such an intellectual challenge, and an incredible opportunity to work with colleagues across the academic spectrum. An engineer alone can't answer that question."



FORGING STEWARDSHIP

Experiential learning places students front and center to one of the world's environmental crises

"So much of the garbage floating in the Pacific Garbage Patch can be traced back to the Philippines," says Brian Slocum, the managing director of Lehigh's Design Labs. "The landfills are located at the edge of the ocean, and so garbage just falls into the water or typhoons wash it out to sea."

The sheer magnitude of the plastic waste problem in the Philippines is hard to comprehend (although, says Slocum, "it's insane everywhere"). In fact, students participating in the Global Social Impact Fellowship (GSIF) and the Technical Entrepreneurship (TE) class have estimated that in metro Manila alone, plastic waste equivalent to the weight of 230 elephants is generated *every day*. Many of those same students spent nearly three weeks this past summer doing fieldwork in Manila as part of Project PlasTECH.

The project aims to create a viable community-based, micro-recycling business that employs local women who will manufacture upcycled products as a source of income. The students spent their fieldwork assessing the feasibility of sourcing and reusing plastic and employing the local female workforce. "We think those things are feasible," says Slocum, who is one of the project's mentors. "The big economic question now is, what can we make that's economically viable? The students are thinking about construction materials like bricks or roofing tiles. Then, on the engineering side, how can we make it?" It's a huge challenge, and one that will test the creativity, ingenuity, and persistence of many Lehigh students over the coming years.

"This project is a classic example of experiential learning," says Ganesh Balasubramanian, P.C. Rossin Assistant Professor of Mechanical Engineering and Mechanics and principal investigator for the project. "These students are connecting what they're learning in the classroom to a real-world problem. And they've realized the problem is multipronged. There's the plastics issue, but there's also the economic side of things, and students have realized their work may have an even stronger impact on employment in these communities, while making a dent in the problem of pollution."



INDUSTRY INTERVENTION

Saving time, money, and resources for more efficient processes

Recycling for stronger materials

The machining processes of metallic materials such as aluminum create tons of solid waste in the form of very small metal chips. Plus, aluminum scrap parts are usually cut down to small pieces prior to recycling.

The combined surface area of millions of tiny pieces creates an extremely high percentage of oxide that renders the material too difficult to melt in the traditional recycling process. Researchers in Germany have developed a solid state recycling technology that involves pressing machined aluminum chips together as a billet and then applying severe plastic deformation to break the oxide into pieces, which allows it to mix homogeneously with the metallic material. Mixing superstrong oxide particles into the aluminum matrix makes the material stronger than regular aluminum.

“What you end up with is a semi-product that you can use for whatever you want, and its mechanical properties are improved,” says Wojciech Misioliek, Loewy Professor and Chair of the Department of Materials Science and Engineering and director of the Loewy Institute.

Misioliek, Masashi Watanabe (an associate professor of materials science and engineering), and Natasha Vermaak (an associate professor of mechanical engineering and mechanics) are studying the mechanism behind the breaking and mixing of the oxide into the matrix of aluminum. Doing so would yield benefits beyond reducing the burden on landfills.

“Creating aluminum from recycled materials requires only 5 percent of the energy required to make aluminum out of the ore,” says Watanabe.

“We want to reduce that to 2 or even 1 percent. And if we have better properties in these alloys, we’ll need less material for a given use. So we’re talking about a cheaper way to make stronger material. That’s the target.”

“We’re talking about a cheaper way to make stronger material. That’s the target.”

—Masashi Watanabe

Neutralizing NO_x

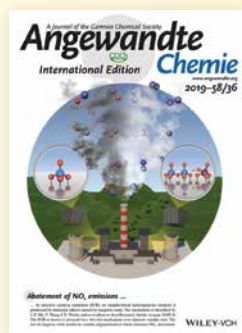
When power plants burn fossil fuels like coal and natural gas, they produce dangerous contaminants like nitrogen oxides (or NO_x) that contribute to acid rain, ground-level ozone formation, and greenhouse gases. A common abatement strategy is the selective catalytic reduction (SCR) of nitrogen oxides by ammonia. One such catalyst is titania-supported vanadium oxide.

“The catalyst consists of vanadium oxide and tungsten oxide dispersed on the surface of a titania (TiO₂) support,” says Israel Wachs, the G. Whitney Snyder Professor of Chemical and Biomolecular Engineering. “The vanadium oxide is the active component performing the selective catalytic reduction towards N₂ formation. There’s been a debate in the literature for 40 years over what exactly does the tungsten oxide component do?”

In a paper published in *Angewandte Chemie*, Wachs describes how he and his team used a High Field (HF) Nuclear Magnetic Resonance

(NMR) spectrometer in conjunction with reaction studies to determine the mechanism. “It turns out that the amount of vanadium oxide is very low in the catalyst making the vanadium oxide present as isolated species, or monomers,” says Wachs. “When you add the tungsten oxide, vanadium oxide changes from monomers to oligomers or polymers. We found that these oligomers of vanadium oxide are 10 times more active than in the isolated vanadium oxide sites. So the tungsten oxide changes the structure of vanadium oxide from a less active form to a highly active form.”

This understanding will help guide future designs of SCR catalysts, and will have huge ramifications for industry and air pollution control, he says. “Easily, 40,000 to 50,000 people in the United States die annually due to complications from poor air quality.”



Improving energy storage

The addition of renewable energy into the electrical grid is now forcing conventional power plants to adapt to new power generation realities.

“Fossil power plants once generated power at maximum capacity all day long,” says Carlos Romero, director of Lehigh’s Energy Research Center (ERC). “They were base-loaded, and that’s the best operating point for the plant in terms of thermal efficiency. But with renewables like solar and wind on the grid, these conventional plants now operate on load-following mode and at extremely minimum loads. Because of the deviation, fuel consumption increases, and there is a corresponding monetary loss during the operation of the power plant.”

An interdisciplinary team, promoted by the Institute for Cyber Physical Infrastructure and Energy (I-CPIE), is starting a project on thermal energy storage (TES) for applications in fossil-fired power plants. The group received a three-year, \$2 million grant from the Department of Energy to develop an optimized prototype of a “thermal battery.” Their novel concept, called TCM-TES, utilizes engineered cementitious materials enhanced with devices called thermosiphons, which would allow for combined sensible and latent heat storage.

“The fluid inside these devices very quickly changes phases,” says the ERC’s Sudhakar Neti, the project’s principal investigator, “and it is that ability to change phase that enables the heat to move so quickly into and out of the concrete block.”

“The ultimate goal is to develop a TES prototype designed and built for up to 400°C operation, 100 kWhth, with 90 percent round-trip efficiency, and a cost of at least \$25/kWhth.”

—Carlos Romero

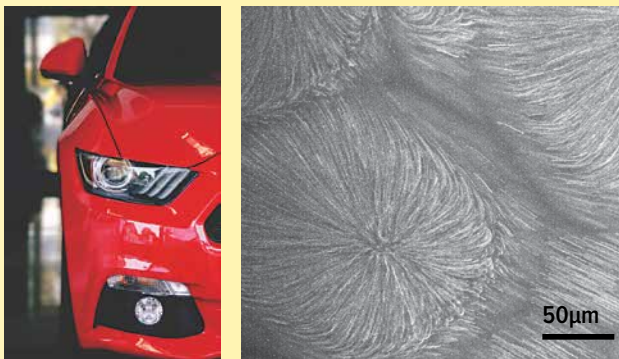


Predicting the drying process

Paint is highly energy intensive to apply, accounting for 60 percent of the energy consumed by a single automotive plant, says James Gilchrist, a professor of chemical and biomolecular engineering.

When an application isn't done correctly, the vehicle must be recoated and touched up—a process that can cost a single plant more than \$10 million per year. Recently, Gilchrist and his collaborators received a grant from the National Science Foundation's

"The idea of applying microrheology to automotive plants has the potential to save millions of dollars in energy use and help companies get their products to market faster." —James Gilchrist

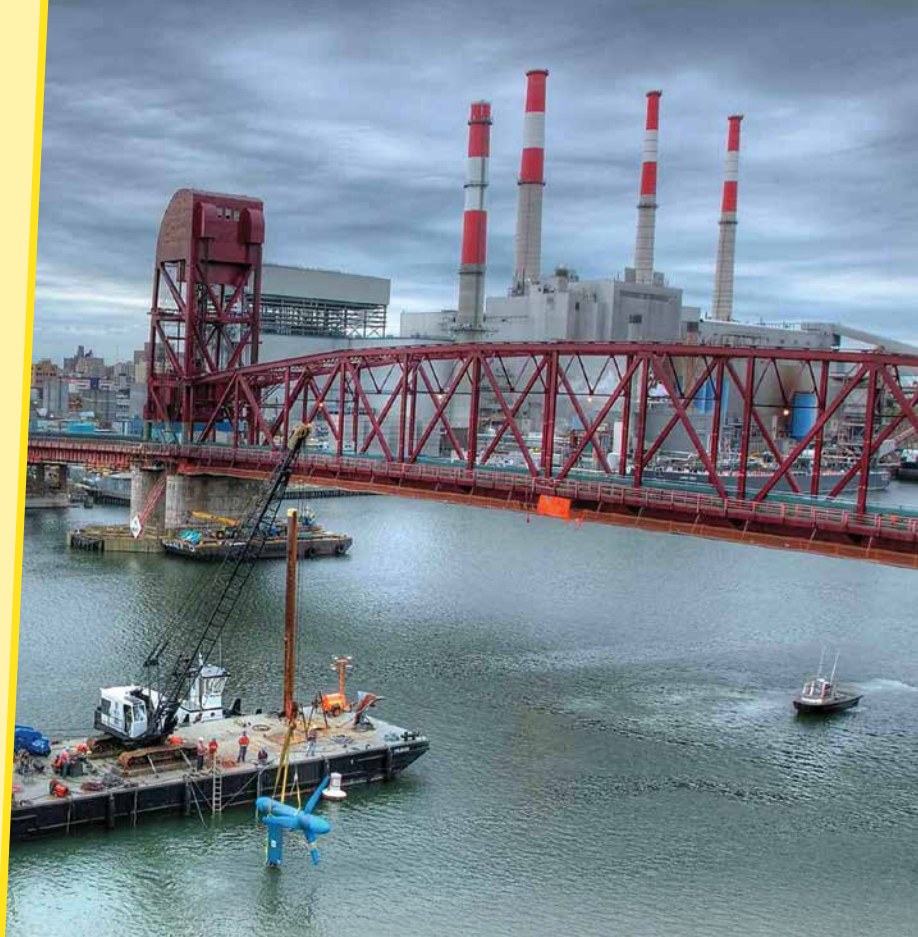


Fluid Dynamics program to better understand paint through kinematics and rheology (the study of how substances flow). "We're trying to understand the fundamental drying process, and how these paints chemically and physically evolve while they're drying," Gilchrist says.

He and his team are using microrheology to study the effect of adding different rheological modifiers—particles with a range of geometric and surface properties—to automotive paint. By putting fluorescent probes in the paint and tracking with a microscope how they move, the researchers can determine if a particular formulation is causing the paint to act like a solid or a liquid as it's drying.

The goal, says Gilchrist, is to develop a testing method that can be used to both predict how a given formulation will behave, and quickly identify the problem if something goes wrong in the plant.

Concrete specimens engineered with different formulations to enhance thermal and mechanical properties for use in a thermal battery



RESEARCHING ALTERNATIVES:

► Tidal energy

Imagine a single tidal turbine capable of powering a community of 50 to 70 homes all year long. That's the potential of turbines being developed by Verdant Power, a New York City-based company that builds marine energy systems.

"Verdant's turbine is a downstream turbine, which means the flow goes over the nacelle where the electronics and generator are located, before it hits the rotor blades," says Arindam Banerjee, an associate professor of mechanical engineering and mechanics. "But as the water flows around the pylon (the tower that supports the nacelle and rotor), the flow is disturbed and creates a velocity deficit, which reduces the amount of energy that is available to the turbine. In addition, vortex shedding from the pylon introduces periodic disturbances in the flow, which is known to reduce the life of the rotor blades themselves."

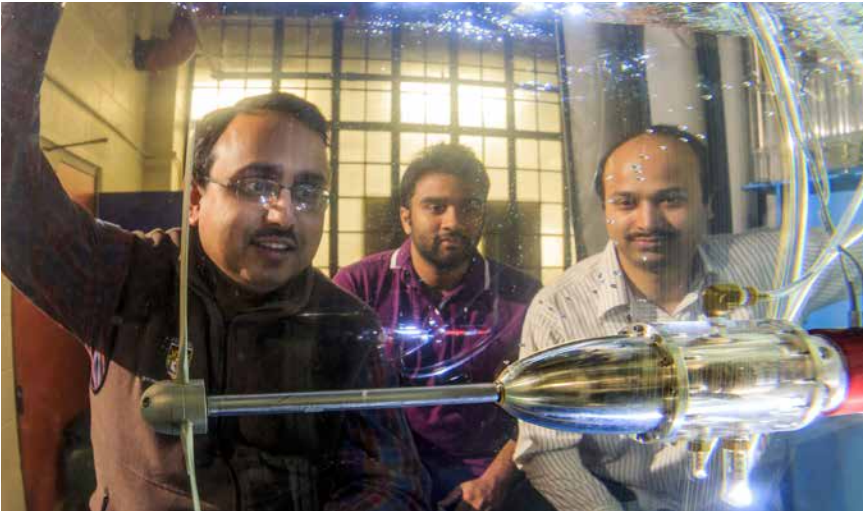
Banerjee and his team recently received a \$250,000 grant from the NSF as part of the organization's Partnerships for Innovation program to design a pylon with fairings that will reduce this disturbance.

"We're trying to create a fairing that can steer the wake away from the rotor blade and reduce the energy loss," says Banerjee. "Verdant's previous design had a fairing that was essentially a straight plate, and we found through preliminary lab experiments at Lehigh that it was a poor design."

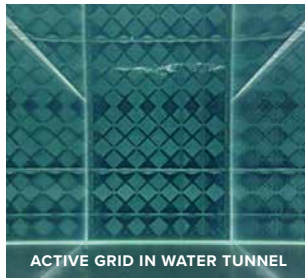
The funding will allow Banerjee and his Turbulent Flow Design Group to study different fairing shapes in a water ►

tunnel facility in Packard Laboratory. The facility is equipped with an active grid turbulence generator, which Banerjee designed, that can mimic the free-stream turbulence that occurs in the East Channel of the East River, site of Verdant's Roosevelt Island Tidal Energy (RITE) Project.

Banerjee and his research team will test the effect of each shape on the downstream flow at different turbulence intensity levels. "This active grid turbulence generator is a series of winglets inside a water tunnel that are placed upstream of the test section," says Banerjee. "We operate



The active grid turbulence generator is the first of its kind developed in an open channel/water tunnel facility.



ACTIVE GRID IN WATER TUNNEL

them at a predetermined frequency, which makes them spin and create turbulence that exactly mimics what is naturally happening in the East River. The goal is to give Verdant prescriptions for the type of fairing that would be advantageous

for the next generation of their turbine."

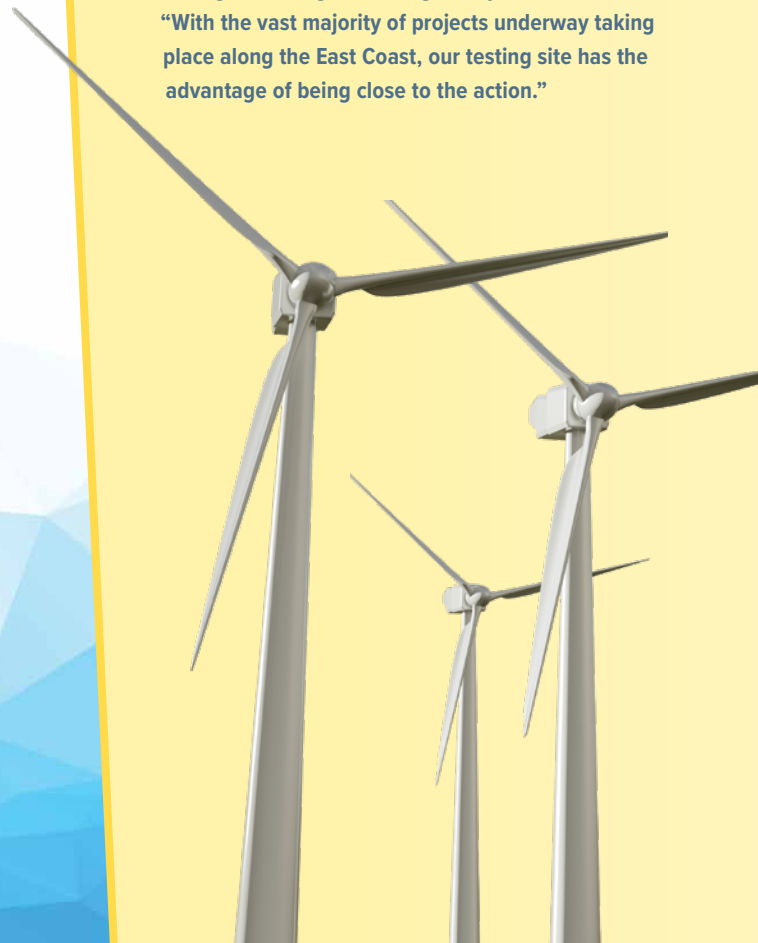
"By more accurately characterizing the fluid dynamics around the pylon, we believe we can make cheaper, better performing blades that will help drive the cost of these units down and make them competitive with more traditional forms of renewable energy," says Jonathan Colby, director of technology performance at Verdant Power.

In preliminary testing, Banerjee and his students designed a double-sided fairing that they offset at an angle, or yaw, from the pylon. "We were able to cut the energy loss almost in half," he says. Ultimately, Banerjee would like to see that loss hovering around 1 percent. Such a target would require extensive optimization, but aiming high is the point.

"We're not going to have coal forever, we're not going to have natural gas forever," he says. "Renewable energy is probably going to be one of the drivers for the energy that we need to have the quality of life that we demand. We know we're going to be successful at this, and that's what keeps me motivated."

HARNESSING THE WINDS OF CHANGE

After years of lagging behind Europe, offshore wind energy in the United States is about to take off: It's projected to be a \$1 trillion industry by 2040. New funding from the Department of Energy will focus on upgrading the Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center to support work in advancing research, testing, and design of offshore wind turbines. Improvements to the facility's soil-foundation interaction laboratory, as well as structural testing and modeling capabilities, will allow engineers to apply hybrid simulation to offshore wind turbines and related structures that are subjected to wind, waves, and current loading. The hybrid approach combines computer simulation with physical testing and is currently used for studying onshore structures subjected to earthquakes. Muhannad Suleiman, an associate professor of geotechnical engineering, leads the project team, which includes civil and environmental engineering and mechanical engineering faculty affiliated with the Institute for Cyber Physical Infrastructure and Energy (I-CPIE), as well as industry partner Fugro USA. "We're taking a holistic, top-to-bottom approach to offshore wind turbines in the pursuit of better understanding and more efficient testing, modeling, and design," says Suleiman. "With the vast majority of projects underway taking place along the East Coast, our testing site has the advantage of being close to the action."



AN ELECTRIC IDEA



Members of the team include (from left): Mahdis Modaresi, Mertcan Yetkin, Héctor Muñoz-Avila, Shaline Kishore, Shamim Pakzad, and Alireza Khani.

USING DATA TO IMPROVE OUR QUALITY OF LIFE AND OUR ENVIRONMENT

HOW CAN TRANSPORTATION SYSTEMS BE TRANSFORMED TO MAKE COMMUNITIES MORE LIVEABLE? That question drives an interdisciplinary team that includes the Institute for Cyber Physical Infrastructure and Energy (I-CPIE), six departments, and three colleges at Lehigh, as well as outside academic institutions, national labs, and industry partners. One of those industry partners is the Santa Clara Valley Transportation Authority (VTA) in California. As part of its Innovative Clean Transit regulation, California has a statewide goal for all public transit bus fleets to be zero-emission by 2040, and the VTA has agreed to be the team's testing bed. Optimizing the transportation sector is a daunting challenge, says Héctor Muñoz-Avila, a professor of computer science and engineering and co-director of Lehigh's Institute for Data, Intelligent Systems, and Computation (I-DISC). "Our group continues growing because there are so many technical, societal, and policy aspects to consider. The future will bring megacities, and we must have an integrated solution for the implications of that growth." Here, team members share approaches to solving the problem.

"To optimize the transportation system, we need to understand how people use the system. We're trying to understand the reaction of users to changes in that system, such as rerouting or schedule changes. Based on that, we'll use optimization techniques to design the infrastructure network of stops and terminals, and make the schedule more convenient. When it comes to electric buses, they have limited operational hours, so we need to design the schedule so buses can meet demand while minimizing operating costs. We're also seeing a change in behavior of users like millennials and Generation Z who want to use shared mobility like Uber and Lyft. As engineers, we need to understand these needs and find a way to optimize these modes."

—Alireza Khani, *assistant professor of civil, environmental, and geo-engineering, University of Minnesota*

"These microgrids will actually be managed and operated by the transit agency, as opposed to the utility, and that's not something transit agencies

have ever been asked to do. They've traditionally operated almost independent of what the power grid is doing. But with electric buses, the system is tied in with the power infrastructure. So agencies are faced with questions like: Where can we charge? How much capacity do we have? How many buses can we support and how does that affect their routes? Our research is in smart cyber infrastructure, how to make power systems smarter by gathering data, processing that data to understand how the systems operate, and figuring out how to make better real-time decisions."

—Shaline Kishore, *Iacocca Chair Professor of Electrical and Computer Engineering; associate director, I-CPIE*

"We're approaching this from a smart cities perspective, and one aspect of that is addressing the environmental issues connected with transportation. You can make buses zero-emission, but if you burn fossil fuels at the power generation site, then you haven't solved the emission problem. We envision a microgrid supplied by renew-

able energy, basically small generation plants distributed across the network. When you need extra energy, you can get it from the main power grid, and when the microgrid generates excess energy, it can give back to the main grid."

—Shamim Pakzad, *associate professor of civil and environmental engineering*

"I study cities and how they work for people, and it's becoming almost irrefutable how much place matters. Not only to physical and mental health, but to economic mobility. A lot of that has to do with how well or not places are connected to the stuff people need, like food or jobs, to clean air, clean water. So we're looking at where are the households that have cars? Where are the households that don't have cars? Where are employment rates higher or lower? Basically, how are people arrayed in space and how can we rethink public transit and access for neighborhoods that may be underserved or disconnected from job centers or other resources. It's an interesting

moment to rethink how these systems are designed."

—Karen Beck Pooley, *professor of practice, political science, Lehigh University College of Arts and Sciences*

"We're trying to address the co-optimization of the transportation network and the power network. For now, we're focused on the after-operation times of the buses—how should they charge and discharge so the load on the power network is within limits, but the vehicles can still operate the next day? We're trying to come up with the best policy for charging with respect to the current infrastructure. And if we're leveraging solar farms for the microgrid, you end up charging in the middle of the day, which is when buses operate, so that also poses a problem. Another challenge is coupling how long buses should charge with scheduling demands—picking passengers up, routing, break times. We need a smart scheme to handle all these elements."

—Mertcan Yetkin, *PhD candidate, industrial and systems engineering*



RESEARCHING ALTERNATIVES:

► Nuclear fusion

It's hard to believe, but there *is* actually one initiative that currently unites the world—the quest to build a fusion reactor. The European Union, China, South Korea, Japan, India, Russia, and the United States have all committed funding and scientific resources to build ITER (Latin for “The Way”), the largest fusion reactor in history.



Schuster working with graduate students (above); the KSTAR tokamak in Daejeon, South Korea (right)

“Almost all of us are working toward ITER,” says Eugenio Schuster, a professor of mechanical engineering and mechanics. “ITER is the mission of the majority of the fusion research groups, universities, and national labs here in the United States, and around the world.”

Schuster recently received two grants from the Department of Energy to help him contribute to that mission. The first supports work he and his team—the Lehigh University Plasma Control Group—will perform on the tokamak at the DIII-D National Fusion

Facility in San Diego. The second supports experiments they’ll do on the EAST tokamak in Hefei, China, and on the KSTAR tokamak in Daejeon, South Korea. (A tokamak is a donut-shaped, magnetic-confinement device designed to produce fusion reactions.)

The promise of nuclear fusion is a big one. It’s often referred to as harnessing the power of the sun here on Earth, and if it can be achieved, it could provide a limitless supply of clean, safe, and reliable energy. Its abundance would stem from its fuel source—water and lithium, both of which are relatively plentiful around the world. Fusion would produce no greenhouse gases, and its waste products would have a relatively short half-life. And because fusion requires such precision for it to occur at all, the process would be safer.

“Nuclear power plants based on fission work by permanently containing the fission reaction,” says Schuster. “Once the system fails, there is an uncontrolled release of energy. In fusion, we exploit similar physics, but the process is completely

different. It’s very difficult to have an accident because if anything goes wrong, the condition for fusion just disappears.”

In fact, a fusion reaction is extremely complicated to sustain, he says. “That’s why we don’t yet have a nuclear reactor based on fusion, and we’ve been working on this for more than 50 years.”

Schuster’s team tries to model the response of the “sea” of ions and electrons that is formed when two hydrogenic atoms are superheated inside the tokamak. In theory, if this plasma could be stabilized and sustained, the energy produced by fusion would create heat that would be absorbed by the reactor’s donut-shaped walls. That heat would create steam that in turn would power generators and turbines and produce electricity. Specifically, they are modeling the response of the plasma to actuators like radio frequency waves to better predict the behavior of that response, and to design control solutions to keep the plasma stable.

“In the end, everything we do and learn at DIII-D, at EAST, and at KSTAR, is so we can extrapolate it and do it on ITER,” says Schuster.

The ITER tokamak has been under construction since 2007 in southern France. It’s expected to be operational in 2025, and it will be massive. According to the ITER website, the reactor will weigh 23,000 tons (the Statue of Liberty weighs 225 tons), have a total height of 239 feet, and contain enough superconducting strands to wrap around the equator twice.



The primary difference between ITER and all other tokamaks—other than its size—is that it will be the first nuclear reactor based on fusion.

“All tokamaks today are experimental devices,” says Schuster. “They are not generating power. They are designed to help us study the physics of the plasma, how to stabilize it, confine it, and keep it safe.”

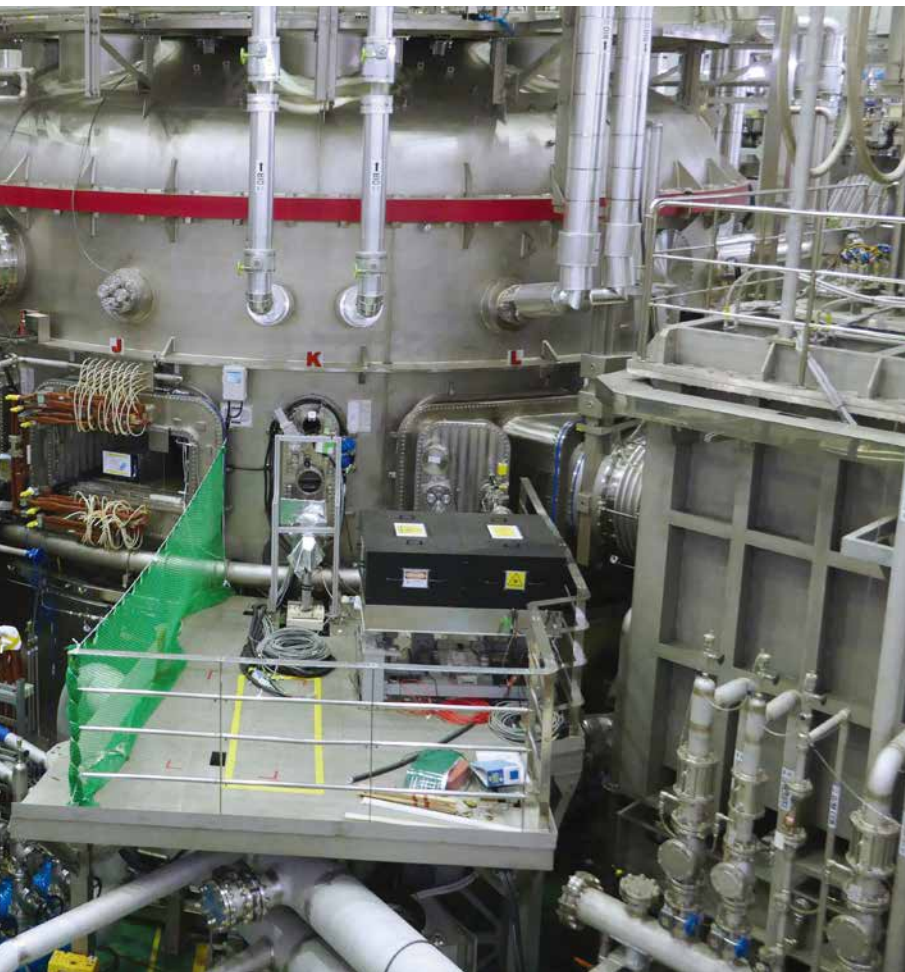
ITER’s mission is different, he says. The goal is to produce power from fusion, specifically, to produce output at 10 times the input. But even after it’s operational, it will take ITER 10 to 15 years to get to that gain of 10, says Schuster.

“I might be retired before we have a nuclear power plant based on fusion, but I hope my students, and their students,



“Nuclear fusion presents such a challenging problem to solve, but it has the potential to make a huge impact on humanity.” —Eugenio Schuster

will see it,” he says. “Nuclear fusion presents such a challenging problem to solve, but it has the potential to make a huge impact on humanity. It could solve problems around energy generation, pollution, climate change. And there is a whole cohort of Lehigh students focused on plasma control who have been contributing not only to our domestic program, but to the international program focused on ITER. It makes me very proud and excited, and it’s impossible to not want to keep moving forward.”



M.ENG. STRUCTURAL ENGINEERING

The potential threats to our infrastructure from climate change pose a particular challenge to structural engineers. The Rossin College’s professional master’s of engineering degree program in structural engineering prepares students to face these realities head-on, with a foundation in resilient design and an understanding of the cutting-edge data analytics that support performance-based design. “New thinking and bold solutions are needed to design large-scale structures that can withstand more extreme conditions,” says the program’s director, Jennifer Gross ’94, a professor of practice in the Department of Civil and Environmental Engineering. “Our 10-month program combines accelerated coursework with a group project on the design of a real-world structure, so graduates get the right balance of theoretical knowledge and practical experience that opens up doors to leadership roles in industry.” For more information, visit engineering.lehigh.edu/structures.

**DID
YOU
KNOW?**

BRACING FOR IMPACT

Lehigh engineers are helping communities prepare for the fallout from climate change

Building resilience

What would be the consequences of a storm like Hurricane Sandy hitting your city? If you could simulate the impact a superstorm of that magnitude would have on your roads and



power lines, you could make better decisions to fortify your infrastructure. That's the goal of the Probabilistic Resilience Assessment of Interdependent Systems (PRAISys), a multimillion-dollar project funded by the NSF that includes three universities, two research centers, six departments, and more than 50 people.

The project came in response to a federal mandate for municipalities to conduct resilience assessments. "The goal was to create a simulator of the damage caused by a hazard, and the decision-making and recovery processes that follow," says Paolo Bocchini, an associate professor of civil and environmental engineering and a member of the PRAISys team. "We're doing a scenario-based analysis that looks at damage caused by hurricanes or earthquakes on three systems—transportation, power, and communications."

The team focused heavily on interdependencies between those systems, and their effect on recovery. The more interdependencies they introduced into their model, the more challenging the recovery.

"So one of the conclusions," says Bocchini, "is if a power company is looking at either building a second transmission line or retrofitting a line, the best option may be to do neither and instead have a temporary bridge available in case the department of transportation can't respond quickly enough. Because we included how all these systems rely on each other, the model allows you to think outside the box and find new solutions

to these problems." The project is in its fifth and final year, and has begun beta testing.

Assessing safe passage

Climate change will ultimately affect our bridges. But to what extent?

"We know it will increase the frequency and intensity of hurricanes and extreme rains," says David Yang, a postdoctoral research associate in civil and environmental engineering. "We were looking at increased temperature and increased precipitation and their impact on bridge safety. The challenge was that we didn't know how to quantify those impacts to predict scour risk."

Scour is created when floodwaters erode the materials around a bridge's foundation, creating scour holes that compromise the integrity of the structure. It's the primary source of bridge failure in the United States.

Together with Dan M. Frangopol, a professor of civil engineering and the Fazlur R. Khan Endowed Chair of Structural Engineering and Architecture, Yang filled the gap between climate data and structural safety quantification by using hydrologic modeling to convert climate simulation data to flow discharge data in the Lehigh River. "We took a holistic approach," says Yang. "It started with a global climate model that was downscaled to regional hydrology, then we used structural engineering to get the failure probability of a structure in a future flooding event. We could then assess, does this failure pose risks to a community? So our model included climatology, hydrology, structural engineering, and risk assessment."

"We wanted to devise something the community can use to become adaptive to future climate change."

—Dan Frangopol

Perhaps their most important conclusion involved the question of mitigation. Specifically, what engineering measures should be deployed to reduce risk, and in which bridges. "Budgets are limited," says Frangopol. "So it's important to determine, what is the priority here? We wanted to devise something that the community can use to become adaptive to future climate

change." The pair published their paper in the *ASCE Journal of Bridge Engineering*.

Interpreting floodwaters

"Scour is the main cause of failure to structures like retaining walls that protect river banks," says Panayiotis Diplas, P.C. Rossin Professor and Chair of Civil and Environmental Engineering. "We're looking at ways to protect those structures and mitigate the impact of floods."

As such, Diplas and one of his team members are simulating flooding situations in lab flumes. State-of-the-art equipment helps them monitor the scour process taking place in the vicinity of those retaining walls and other structures and better understand the mechanism by which it happens. The goal is twofold: to predict the scour and learn how to reduce its extent. "A proper engineering approach might be to weaken the agent responsible for local scour, meaning the hydrodynamic forces caused by flowing water. If we do that, we can avoid or reduce the extent, especially the depth, of scour."

Consistent with prior studies, the team has identified the development of a horseshoe vortex as primarily responsible for the erosional process. Diplas and his students



are also researching how major floods tend to change the dimensions of a river channel, and how these dimensions can be correlated with major rainfall events.

"If we're expecting climate change to generate more intense rainfall events, then potentially we can predict how the river will adjust. This will then guide the selection of the site to build a structure," he says. "If you don't allow for that adjustment and you interfere with nature, you can expect an increase in flooding in surrounding communities and enhanced damage in our infrastructure. Identifying the impacts of climate change is just very complicated and multifaceted."

RESEARCHING ALTERNATIVES:

► Biomass

A perfect world might look like a circle. A conceptual circle that begins with the sun stoking the photosynthesis that allows a crop to be frequently harvested. Such harvests could then be processed, generating energy for heat or electricity and releasing just enough carbon dioxide to feed the next field of biomass and restart the cycle.

That is, of course, not the world we live in.

"There's no free lunch," says Jonas Baltrusaitis, an associate professor of chemical and biomolecular engineering. "We need to maximize our yields, and crops only grow if there are enough nutrients, which means using fertilizer. And fertilizer is hugely energy intensive to make. So at the end of the day, when it comes to using biomass as a source of energy, we're always in the red."

And yet, researching the potential of biomass (aka "energy crops," plants or trees grown not as food but for combustion) as a source of renewable energy is worth the effort. That's because biomass recycles CO₂—using it to make sugar and oxygen to grow, then releasing it when it's burned—making it, ideally, carbon neutral. And with the ability to be harvested on a yearly basis, it's renewable on a timescale that's compatible with our needs. Unlike coal, methane, and oil.

Warm climates have a somewhat easier time getting closer to this circular economy of biomass. Abundant sun and long growing seasons provide enough energy for rigorous growth. In a recent paper published in *Renewable Energy*, Baltrusaitis and researchers at the Lithuanian Research Centre for Agriculture and Forestry tested energy crops in Lithuania with its colder climates and shorter growing seasons.

"Countries that span Northern Europe, Scandinavia, and Russia are not known for growing things efficiently," says Baltrusaitis. "We wanted to know if there were plant species that could adapt to these colder climates. So we planted those that are known to grow efficiently in warmer climates, and after harvesting, we evaluated their energetic potential, or how much heat per hectare or per acre they emit when burned."

One species in particular thrived: *Miscanthus giganteus*. "Most of the modeling results presented in the previous research indicated that it wasn't possible to grow *Miscanthus* in Lithuania



because of the country's low winter temperatures, but we found this crop to be very promising even in Northern countries," says Vita Tilvikiene, senior researcher at the Lithuanian Research Centre for Agriculture and Forestry and lead author of the paper.

The study was an assessment of the potential of certain crops that might achieve a closer balance of energy input versus energy output. Like so many approaches to reducing climate change, utilizing biomass as a sustainable source of renewable energy is still a long way off. That virtuous energy circle will likely not happen for a long time. But it's enough of a promise to warrant not only attention but excitement.

Prior research has shown *Miscanthus giganteus* to be suitable for the production of heat, biogas, and bio-liquids.



"Engineers are enamored with what we can do that will be important and meaningful for others, so we tackle problems that are of global significance." —Jonas Baltrusaitis

"Methane, gas, oil, and the technologies around those things have been around for 150 years, but biomass has really only been done at the rudimentary level. That was how my parents heated their house," says Baltrusaitis. "It represents a very different problem of carbon dioxide capture. It is so stimulating to tackle problems that are on the global scale that haven't been addressed yet." ⓘ



BY LORI FRIEDMAN AND KATIE KACKENMEISTER

BLAZING NEW TRAILS

Lehigh's student-centered Pasteur PhD Partners (P3) Fellowship may be the disruptive force that academia needs

THE U.S. APPROACH TO GRADUATE EDUCATION—in which students pursue answers primarily to satisfy the intellectual curiosities of their faculty advisor—hasn't changed much since the period after World War II, according to professor Himanshu Jain.

Yet students embarking on advanced degrees are more driven by their own research interests and social compass and have a clearer vision of their post-graduation

aspirations than ever before. Today, he says, a "one size fits all" graduate educational model no longer suffices.

"We need to empower highly motivated students who are interested in making a mark on society and seeing the impact of their work in a reasonable time frame," Jain explains. "A student-focused graduate education more closely aligned with solving real-world, industry problems should be available as an alternative to the conventional path."

The idea of a student-centric, "use-inspired" track captured the attention of the National Science Foundation as a pilot program of sorts that, if proven successful, could bring about significant change in the way that talented young minds engage in advanced pursuits across science and engineering academia.

Lehigh's innovative Pasteur PhD Partners (P3) Fellowship provides fresh thinking and a new approach

to the ecosystem of support and resources around candidates pursuing doctoral degrees in science, technology, engineering, and math (STEM).

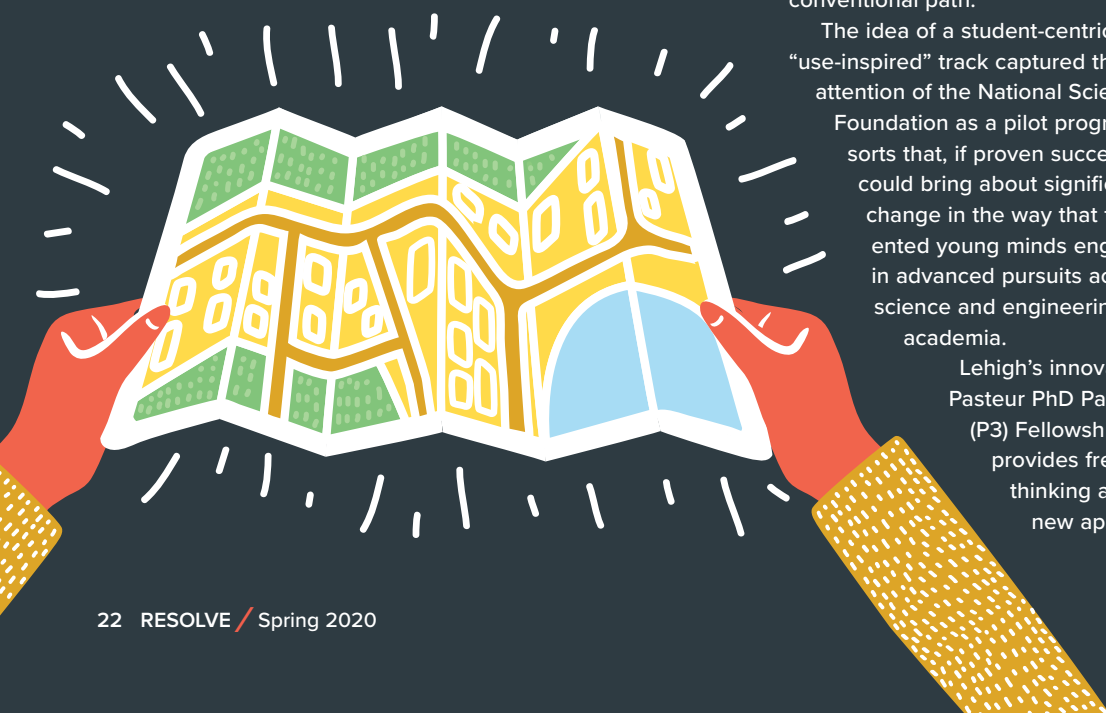
"Students selected as P3 Fellows are actively involved in defining the scope of their dissertations, and this itself is a remarkable departure from traditional PhD studies," says Jain. "Working with their academic and corporate-sponsor advisors, these students forge a path that aligns their individual goals with the research objectives identified by one of the program's external partners."

Jain, the T.L. Diamond Distinguished Chair and Professor of Materials Science and Engineering and the director of the Institute for Functional Materials and Devices (I-FMD), serves as the principal investigator of the project, partnering with fellow science and engineering faculty, as well as faculty from Lehigh's College of Education and a colleague at Corning Incorporated.

Critical insights from practical problems

The P3 program's namesake, Louis Pasteur, heralded use-inspired research as a fundamentally different approach to the discovery and understanding of natural phenomena. The 19th-century scientist and father of microbiology started with a practical need or problem and employed it as a guide to identifying important fundamental questions. For instance, his study of fermentation and work in removing microorganisms from beer and wine led him to critical insights that advanced the germ theory of disease and the development of vaccines.

P3 is based on a stronger collaboration between academia and industry that reflects the rapid advance of technology and the demand for technologically astute leadership across all sectors. The program maintains the academic rigor of existing doctoral programs while building sometimes overlooked soft skills, including communication, intellectual property awareness, and team/project management.



"We're excited to help catalyze the P3 program," says Gary Calabrese '79, senior vice president of global research at Corning, which is sponsoring one of the pilot fellowships. "We conduct use-inspired research every day, gaining knowledge that allows us to invent new products. Bringing PhD students into the process will allow them to be more mindful of the relevance of their work and its impact."

Calabrese, who is a member of the National Academy of Engineering and served on the American Chemical Society's Presidential Commission on Graduate Education in the Chemical Sciences, also sees P3 as a way to solidify communication skills in the next generation of research scientists. "Being able to explain research questions—what you're doing and why—to both technical and nontechnical audiences is not something every student can do. That ability may seem subtle, but it makes a profound difference in the workplace."

P3's overarching goal, says Jain, is to prepare graduate students to thrive in an industrial setting, or to be more well-rounded faculty members if they choose to go into academia. "We also believe this approach will help invigo-

rate the pipeline of domestic doctoral students," he adds, "which is of interest to our colleagues at the NSF."

Bridging the industry-academia gap

One of the P3 model's defining factors is early and sustained industry engagement. Each student starts off with a summer internship with their corporate partner. The company is then involved in identifying the research question that forms the basis for the student's doctoral thesis and provides mentoring and professional development. Later on, students complete an on-site residency (similar to medical school training), spending six to 12 months working as a "scientist in training."


Moreover, where traditional curiosity-driven research is open-ended, P3 has a more defined timeline: The fellowship provides a competitive stipend and full tuition for the duration of doctoral studies, which are expected to be completed in just four years.

Corporate partners reap in-depth understanding of critical issues related to new processing methods, devices, and products, along with relevant technological expertise. At the same time, they gain recruiting access to the most

highly trained R&D-capable prospects while building productive partnerships with Lehigh's expert faculty.

"Companies and universities have distinct roles," says Alan Snyder, vice president and associate provost for research and graduate studies at Lehigh. "Companies strive to produce products and services that address their customers' needs. University research, by taking on deep, difficult, long-term questions, produces knowledge and understanding that enable future progress. Our goal here is to bring these endeavors close together in a way that respects our separate roles and enriches our students' experiences."

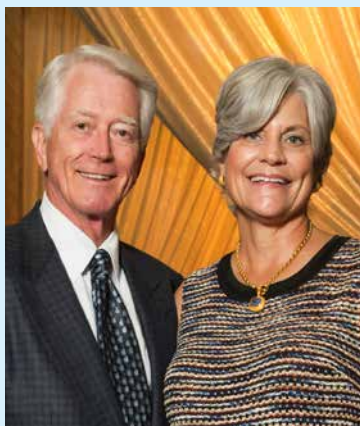
The team plans to compare outcomes of the initial cohort with a reference group of students taking a more traditional route.

"We hope to demonstrate the viability of this approach at Lehigh," says Jain, "and for this method to eventually be adopted at institutions across the U.S., ushering in a system-wide change." 

IN THE SPIRIT OF LOUIS PASTEUR, Lehigh's new P3 Fellowship supports doctoral research that expands scientific knowledge while tackling practical problems.



MOVING THE ROSSIN COLLEGE FORWARD: THE ROSSIN FOUNDATION



A \$1 MILLION GIFT from Joan Stephans, daughter of Peter Rossin, and her husband, Peter, through The Rossin Foundation will directly support engineering students launching their doctoral studies, enhancing the college's ability to attract top-tier students and expand its graduate programs.

This support will cover costs for 10 PhD students during their first year—a critical time when students are identifying their research direction—and will advance the college's progress toward its goal of securing first-year funding for all incoming doctoral students.

Eliminating financial obstacles, says Stephen P. DeWeerth, professor and dean of the Rossin College, will also open doors to a more diverse pool of applicants, including more women, under-represented minorities, and domestic students.

"A cloud of financial uncertainty often hangs over the PhD recruitment process because outside research funding doesn't necessarily coincide with the academic calendar," says John Coulter, senior associate dean for research. "Guaranteed funding will help level the playing field as Lehigh competes with larger universities for the most talented graduate students."

Ethan Yang leads
the Complex Adaptive
Water Systems (CAWS)
Research Group
at Lehigh.



A nexus thinker

NSF CAREER award recipient explores society's competing interests at the interface between humans and the environment

For a scholar recently honored by the National Science Foundation's Faculty Early Career Development (CAREER) Program, Y.C. "Ethan" Yang's professional goals seem almost anti-careerist.

"When PhD students train, they tend to focus narrowly," says Yang, an assistant professor of civil and environmental engineering. "To publish, you need to be an expert—the only person who fully understands a specific topic." Yang takes a broader view. "The world is complex and interconnected," he says. "Your expertise may be specific and problem-driven, but it's linked to other topics that the broader society cares about."

"THE WORLD WILL BECOME ONLY MORE COMPLEX. STUDENTS WILL NEED TO TEST LAYERED SCIENTIFIC QUESTIONS AND CREATE INTERCONNECTED SOLUTIONS."

—Ethan Yang

It's called nexus thinking—and it especially applies to the study of water, which was Yang's narrow focus early in his academic life. "I didn't want to focus entirely on natural processes or entirely on human society," he says, "but rather on their intersection." He didn't realize at first that this would position him to study an area of emerging importance called the FEW—food, energy, water—nexus.

Yang's undergraduate major was geography. "I was always interested in the interface between humans and the environment. Water is an obvious link because we need it to survive," Yang says. That led to training in environmental engineering.

"I wanted to build my capacity in quantitative methods," he says. "When engineers calculate, they answer precise questions, like the capacity that a reservoir requires."

But after earning his PhD in civil engineering, the pendulum of Yang's interests began to swing toward humanistic matters. "Often, the reason we have an environmental problem is because society has an issue," he says. "It has nothing to do with the natural environment. It's because the human drive to compete often forces us to make decisions that are not necessarily good for the environment, other people, or even ourselves." Yang started to look more deeply into psychology and social science

to get at why and how people make decisions.

Studying the FEW nexus demands insights and data from sources representing interests with differ-

ent—often competing—values, goals, and priorities. In the field's parlance, stakeholders are known as agents, and Yang's innovation has been to attempt never-before-seen agent-based modeling to understand, forecast, or manage water usage. Such modeling would account for both the needs and motivations of disparate agents within a water system such as the Columbia River basin (U.S./ Canada) or the Mekong River basin (Southeast Asia). The two basins are the focus of an ongoing NSF-funded project on creating quantitative and computational modeling of complex FEW systems.


"People understand there's a deep link between water and food," Yang says. "But

water is also essential for energy, with systems like cooling and hydropower. Until a 2011 conference in Europe, people didn't put all three together."

Numerous gaps challenge the development of a comprehensive framework for studying the FEW nexus. "One is data," Yang says. Agents often decide their water needs using different scales of space and time. A farmer might calculate water requirements for 200 acres over the next year. A utility might figure needs for half a state over the next 45 minutes.

Yang's team and colleagues at the University of Houston are now developing an agent-based model that links food and water, while a team at George Washington University is working on an energy model that they hope can merge into a single framework. "It's challenging to make these models talk to each other," he says. "We're not there yet."

Yang's newest research endeavor also involves agent-based modeling in another water-related application. The project funded by his CAREER award will study decentralized sustainable stormwater management using real-time data from an Internet-of-Things-connected green infrastructure network.

Recognition from the NSF helps confirm the relevance of Yang's multidisciplinary approach. "Nexus thinking is a good way to agitate for the next generation," he says. "The world will become only more complex. Students will need to test layered scientific questions and create interconnected solutions to fix the problems they'll face." 



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Mechanical engineering Ph.D. student Peter Schwarzenberg '16 '21G applies high-level research in orthopedic trauma to aid bone fracture healing. Let's go help every Rossin College graduate student solve real-world problems by supporting research with impact.



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SPECIAL ISSUE

COLLECTIVE IMPACT

Achieving bold corporate sustainability goals through tech innovation will move the needle on carbon emissions, says Trane Technologies (formerly Ingersoll Rand) exec Paul Camuti '83.

See page 8

