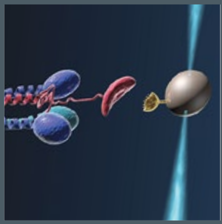

THE ART OF THE HEAL

Clot-inducing protein may advance the fight against heart disease.

See page 16

WATER FOR ALL

Researchers devise nano-inspired systems to slake global thirst.

See page 20

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A FOCUS ON LEHIGH ENGINEERING • VOLUME 2, 2016

ELECTRIFYING INNOVATION

LEHIGH ENGINEERS CHARGE TOWARD A CLEANER, SAFER POWER INFRASTRUCTURE SEE PAGE 10

LEHIGH UNIVERSITY | P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

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VOLUME 2, 2016

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LEHIGH UNIVERSITY

Drawing power from the team

Welcome to the 20th issue of* Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

This issue is also my first as Dean of the Rossin College. It is a great honor to have been chosen to serve in this capacity. I extend my deepest gratitude to Lehigh's visionary leadership, and to Professors John Coulter and Dan Lopresti for continuing the College's forward momentum as deans during the interim period.

Lehigh is an outstanding university: The excellence, enthusiasm, and potential that I have experienced have exceeded my highest expectations. The Rossin College, in particular, has a long heritage of important contributions to engineering education and research, and stands proudly as one of the most competitive engineering institutions in the country.

The quality and innovation in our curricula and research initiatives are truly inspirational.

Lehigh's "effortless" unleashing of interdisciplinary thinking manifests itself most obviously in our integrated undergraduate and master's programs, which demonstrate our leadership in innovative approaches to education. These programs allow us to partner with Lehigh's other Colleges at key intersection points, and sharpen our alignment with issues important to our external constituencies and highly relevant to our graduates and our research agendas.

Innovation is also evident in so many other contexts around campus, including the Baker Institute's constellation of entrepreneurship programs, the intellectual freedom embodied in the Mountaintop Initiative, and a rich spectrum of faculty-led research endeavors that dissolve traditional boundaries to solve grand challenges.

One great example of this is our team-based approach to improving and modernizing the interlocking systems that capture, transport, and distribute electricity. For this issue of *Resolve*, our cover article (p. 10) delves into this work in great detail. Electrical engineers, economists, computer scientists, and mathematicians coalesce around a single goal: manage and optimize the electricity, information, and finances that constitute the complex network of global electrical energy grids.

Another is our feature on the research team studying vWF, the shape-shifting protein responsible for allowing wounds to heal. Experts in bioengineering, fluid dynamics, microfluidics, and computational mechanics are working together to understand the mechanics behind vWF's behavior. It's a potential game changer in the fight against heart disease.

As you'll see on page 22, our innovative Professional Master's program in Technical Entrepreneurship, one of the stars in the Baker Institute's portfolio, assembles students from a wide variety of disciplines. It's a "melting pot" of innovators, encouraging cross-pollination of ideas, knowledge, and thinking.

The feature on page 20 demonstrates some wildly different nanotechnological approaches to the provision of clean, healthy water to people around the world most in need. It's Lehigh at its best: ensuring the impact of a humanitarian technological breakthrough by building a business-model that supports its usage.

Our "Rising Star" this issue is Dr. Angela Brown (p. 24), a chemical engineer with a radical thought: maybe the best way to fight the rising threat of resistance to antibiotics is to thwart bacteria's "advance team" from ever reaching healthy cells.

For expanded articles, profiles, and video/animation of research in action, please visit the online component of the magazine at **lehigh.edu/resolve**.

"The excellence, enthusiasm, and potential that I have experienced at Lehigh have exceeded my highest expectations."

I hope you enjoy this issue of *Resolve*. Please drop me a line with your thoughts and comments.

Stephen P. DeWeerth, *Professor and Dean*
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A high-tech peek into antiquity

Advanced nano-techniques shed new light on the Roman Empire

A study by Lehigh chemical engineers and materials scientists demonstrated that ion scattering and other types of spectroscopy can be used to analyze archaeological objects without damaging them.

The group, which studied five Roman coins minted roughly between 225 B.C. and 244 A.D., reported its findings in the journal *Applied Surface Science*. The paper's authors included Israel E. Wachs, the G. Whitney Snyder Professor of chemical and biomolecular engineering, and Michael R. Notis, professor emeritus of materials science and engineering. The lead author, Christopher J. Keturakis '09, '15 Ph.D., is now a research engineer for Cummins Emission Solutions of Wisconsin.

The team used spectroscopic techniques to determine the composition of the highly reactive outer layers of the coins, where corrosion occurs.

"Metal surfaces are very reactive with things that are present in only trace amounts in the air," said Wachs. "Whatever is in the air will concentrate on the surface of the metal."

Wachs said the Lehigh group was the first to use high sensitivity-low energy ion scattering spectroscopy, or HS-LEIS, to examine archaeological objects. Lehigh's HS-LEIS system is one of less than a dozen in existence.

"LEIS is the only technique that can identify the atoms on the outermost layer of a solid surface," said Wachs. "It enabled us to do a very detailed corrosion analysis and determine the atomic composition layer by layer."

HS-LEIS had previously been considered a destructive investigative method.

Chemical engineer Chris Keturakis '09, '15 Ph.D. at work with Lehigh's HS-LEIS system.

However, the researchers found it could be rendered "virtually nondestructive" with the utilization of high sensitivity toroidal analyzers that require 3,000 times fewer ion-surface collisions.

In addition to HS-LEIS, the group employed Lehigh's Scienta ESCA-300 HR-XPS spectrometer, the only one of its kind in North America.

The researchers believe the advanced surface-analysis techniques they employed could also help improve the preservation of ancient artifacts via quantitative study of environmental effects for both indoor and outdoor museums.

Tiny avalanche, big results

International partnership yields a boost to glass science

In a discovery with potentially broad ramifications, Lehigh researchers have found that applying direct current across glass reduced its melting temperature significantly.

Professor Himanshu Jain of materials science and engineering, and doctoral candidate Charles McLaren, were intrigued by the possible application—including more efficient glass manufacturing, nano-stamping of glass, and supercapacitors for energy storage.

The duo had been following the work of Dr. Roling at the University of Marburg in Germany, who uses electro-thermal poling to modify glass in remarkable ways, through temperature manipulation and electrical field applied locally to glass. "Our observations had shown that much of the activity in the experiments occurred where the anode was attached to the glass," Jain said. "So we came up with a hypothesis, and reached out to Dr. Roling for a closer look."

McLaren traveled to Marburg in 2015 and ran several experiments in Roling's lab. As he and Jain had posited, McLaren found that a very thin and active depletion layer formed in the glass at the anode, as alkali ions migrated into the bulk of the glass. Electrical resistance in the nanoscale depletion layer rose sharply and concentrated a high electric field. It then cratered just as dramatically as dielectric breakdown ensued. "It's like an avalanche," explained McLaren. "There's a positive feedback system where the depletion layer first becomes so resistant you get Joule heating, and as that increases the layer gets more conductive, and you get more Joule heating, and so on."

"Our collaboration with Marburg has helped us see the kinetics of the process, what it takes to deplete a layer," Jain said. "Charlie's work allows us to see the changes in the depletion layer and the rest of the glass as a function of time. Now we can think about modifying the surface without changing the rest of the glass."

The National Science Foundation supported the work in Marburg via the International Materials Institute for New Functionality in Glass at Lehigh; findings were published in the September 2016 *Journal of The Electrochemical Society*.

Reversing the trend of nature

Exploring the atomic mechanisms that govern anti-thermal behavior

Martin Harmer and his team are exploring a phenomenon about which very little is currently known: atoms that behave in a manner contrary to nature.

The W.M. Keck Foundation has awarded the team a $1 million grant to discover and study the mechanisms that govern newly-discovered anti-thermal characteristics in materials—properties that seem to contradict accepted conventions of physics. The project could revolutionize scientists' basic understanding of thermal processes and inform the development of new materials that withstand higher temperatures.

Harmer, the Alcoa Foundation Professor of materials science and engineering, collaborates on the project with Elizabeth Holm and Gregory S. Rohrer, both professors of materials science and engineering at Carnegie Mellon University, along with new Lehigh postdoctoral researchers Amanda Krause and Christopher Marvel '12, '16 Ph.D., and a team of students.

For Lehigh, the Keck project represents a significant milestone—a partnership with an organization renowned for supporting "impossible" science and engineering projects with the potential to create tremendous impact.

Pursuing atomic scofflaws

The atoms in solids typically move exponentially faster with increasing temperature, obeying a classical law of physics. This fundamentally limits the properties and performance of materials. A major challenge in condensed matter science is to overcome this tendency in order to produce materials that are more resilient.

The Keck team believes that the cause of the anti-thermal phenomenon lies in the behavior of what are known as grain boundaries, or the interfaces between microscopic crystals that form materials. The team has identified examples of several anti-thermal processes where the atomic motion actually becomes slower, or does not change at all, as temperature increases. Some materials have been found to melt upon cooling, or solidify upon heating—behaviors that have been detected in isolated cases within metals, ceramics, semiconductors, polymers and biomaterials.

The researchers' goal is to discover and study the mechanisms that govern this intriguing behavior, and use this knowledge to design new materials with enhanced thermal performance.

Consider, for example, how a breakthrough in anti-thermal material design could impact airline travel.

An important factor in jet engine design is a protective aluminum oxide coating on the engine's turbine blades. The coating is roughly 10 micrometers thick—about one tenth of a sheet of paper. As hot air causes the oxide layer to grow and flake off, the blades are left exposed to an oxidative and corrosive environment and eventually fail catastrophically. Anti-thermal behaviors could be leveraged to limit growth of the oxide layer, saving billions of dollars in fuel and maintenance cost. (See accompanying video at lehigh.edu/resolve.)

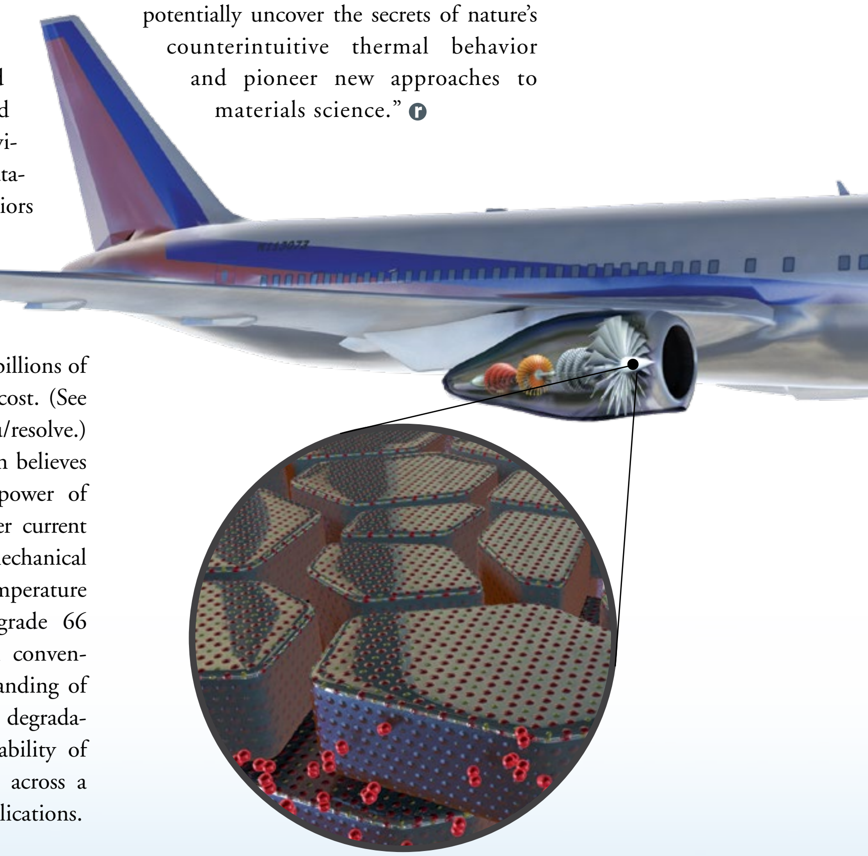
As another example, the team believes their work could unleash the power of nanocrystals—materials that shatter current records for strength and other mechanical properties. However, at room temperature nanocrystals are known to degrade 66 orders of magnitude faster than conventional materials. Greater understanding of the mechanisms of anti-thermal degradation could unleash the full capability of nanocrystalline materials for use across a broad range of industries and applications.

A long, pioneering trail

Prior to the Keck project, Harmer and collaborators pioneered a concept known as grain boundary complexions, which treats grain boundaries as distinct states of matter in thermodynamic equilibrium. Harmer described the concept of grain boundary complexions in an article in *Science* magazine in 2011.

With support from the Keck Foundation, Harmer and his colleagues will drive the design of new materials and develop further techniques for the study of grain boundaries. The group will also apply a novel method for measuring grain boundary motion inside multigrain materials, and connect those findings to high-throughput computer simulations using Lehigh's world-class atomic resolution electron microscopy facilities to directly image atoms that demonstrate anti-thermal behavior.

Says Harmer: "This project will allow us to explore uncharted territory that could potentially uncover the secrets of nature's counterintuitive thermal behavior and pioneer new approaches to materials science."



A breakthrough in anti-thermal behavior could bring about more durable materials for use where intense heat is involved, including jet engines.

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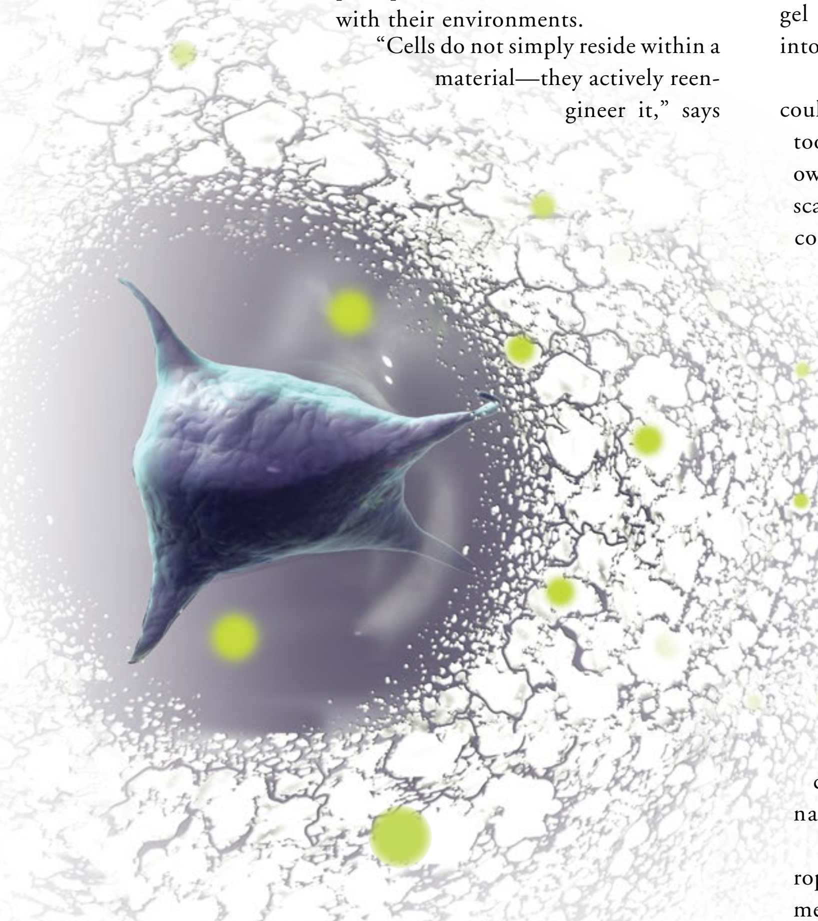
A scaffold to speed healing

NIH-backed project observes living cells "remodeling" their environment



Replacing and repairing human tissue is becoming feasible largely due to advances in the use of stem cells. Yet scientists have yet to develop a complete picture of how these cells interact with their environments.

"Cells do not simply reside within a material—they actively reengineer it," says Kelly Schultz, P.C. Rossin Assistant Professor of chemical and biomolecular engineering. "Characterizing how they behave in 3D synthetic material will advance biomaterial design for wound healing, tissue engineering and stem cell expansion."

Schultz recently received a three-year grant from National Institutes of Health (NIH) to study how cells remodel their natural environment—a crucial step toward engineering cells that can speed through synthetic materials to enable faster wound healing and tissue regeneration.

Though the research has broad biomaterial design implications, Schultz is specifically focused on engineering mesenchymal stem cells that can mimic a wide array of tissues. These adult stem cells will differentiate into a variety of cell types; Schultz's goal is to embed them into a scaffold of hydrogel that would then be implanted into a patient.

"For example, a hydrogel scaffold could be used where a piece of bone, too large to heal or regenerate on its own, is missing," she says. "Inside the scaffold would be stem cells already coaxed into bone cells; the stem cells would reproduce and 'fill in' the missing bone. While bone grows around the implant, new tissue is also growing on the inside—speeding the healing process dramatically. And as the bone regenerates its own tissue, the implant disintegrates."

Hydrogels are more than 90% water and very porous, which allows them to be tuned to change physical properties and mimic anything from bone to fat tissue. An implanted hydrogel can also act as a support for native tissue in large wounds.

"We take videos of the microparticles and observe their movement," says Schultz. "The amount they wiggle reveals their properties and enables us to see spatially what's occurring. That is how we characterized the unexpected degradation profile."

This recording process is known as multiple particle tracking microrheology, and Schultz's team will utilize this method to identify the role of inhibitors.

Cells secrete four different enzyme inhibitors, called tissue inhibitors of metalloproteinases. The researchers will inhibit each to discover which one is responsible for stopping the material degradation, or if it is a combination of them.

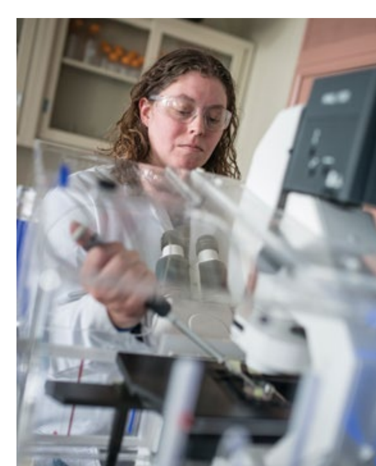
Schultz and her collaborators will also mimic diverse tissue types in order to observe how the inhibitors might change depending on the material.

Schultz's studies will focus on the remodeling of synthetic scaffolds by human mesenchymal stem cells. The techniques and strategies she and her team develop are expected to contribute to the understanding of cell-material interactions. "We intend to identify how these interactions can be exploited," she says. "We hope to manipulate cellular behavior toward advanced 3D cell culture platforms and tissue regeneration applications."

This September, Schultz was one of 83 researchers honored by the National Academy of Engineering to participate in its prestigious U.S. Frontiers of Engineering symposium; the event recognizes early-career engineers from industry, academia and government making significant impact in their fields.

"Cells do not simply reside within a material—they actively reengineer it."

—Kelly Schultz



Kelly Schultz (right) studies how living cells actively reengineer their surroundings (above).

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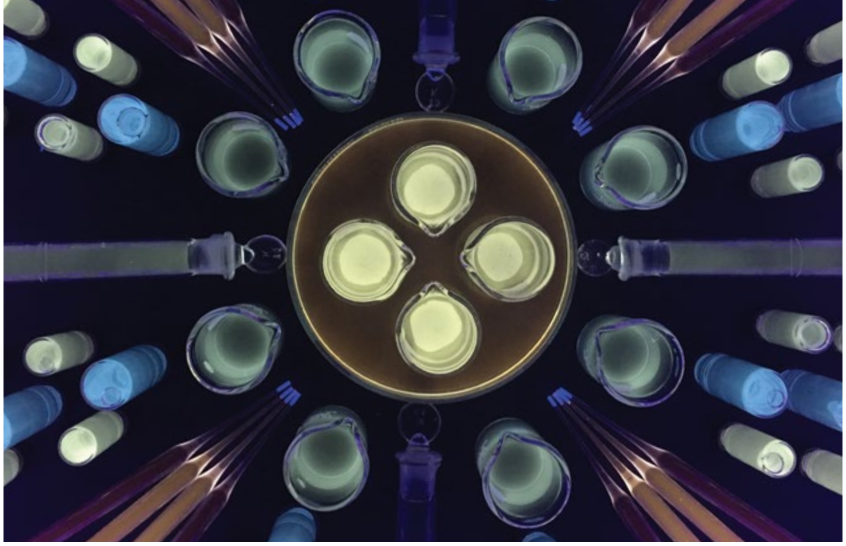


Spawning a quantum dot revolution

A biosynthetic breakthrough holds a rainbow of potential

Quantum dots (QDs) are semiconducting nanocrystals prized for their optical and electronic properties. The brilliant, pure colors produced by QDs when stimulated with ultraviolet light are ideal for use in flat screen displays, medical imaging devices, solar panels and LEDs. Yet the difficulty and expense associated with current manufacturing methods—often requiring heat, high pressure and toxic solvents—has stood in the way of mass production and widespread use of these wonder particles.

But now, three Lehigh University engineers have successfully demonstrated the first precisely controlled, biological way to manufacture quantum dots using a single enzyme, paving the way for significantly quicker, cheaper and greener production methods.

"The biological approach reduces production time and resources while easing environmental impact," says Bryan Berger, Class of 1961 Associate Professor of chemical and biomolecular engineering.

Conventional QD manufacturing costs can total $1,000 to $10,000 per gram. The new Lehigh technique is expected to slash the price by at least a factor of 10.

Berger happened across this idea while on a completely different mission, studying the ability of a nasty hospital-borne bacterium—a so-called superbug—to thrive on metal. The microbe, *Stenotrophomonas maltophilia*, or steno for short, appeared to be collecting metal ions and converting them into QDs.

Berger joined forces with Steven McIntosh, another Class of 1961 Associate Professor of chemical and biomolecular engineering, and Chris Kiely, Harold B. Chambers Senior Professor, materials science and engineering, to make sense of the processes involved. Soon, the team—which eventually grew to include graduate students Chris Curran, Li Lu, Leah Spangler, Zhou Yang and undergraduate Robert Dunleavy '16—was focused on re-engineering the bacteria into miniature QD factories.

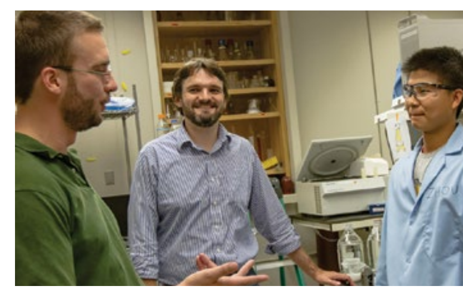
> "The biological approach reduces production time and resources while easing environmental impact."
>
> —Bryan Berger

Last year, the researchers discovered that a single enzyme produced by the bacteria was responsible for selectively producing cadmium sulfide QDs, and their breakthrough was featured on the cover of *Green Chemistry*.

"We'd evolved the enzyme beyond what nature intended," says McIntosh. "It has been engineered to form and control QD crystal structure and size. This allows for uniform manufacturing of QDs that emit any particular color—the very characteristic that makes this material attractive for many applications."

The prospects for widespread adoption of a system with a highly-contagious and deadly superbug at its core seemed slim at best, so the team searched for—and found—a more suitable biofactory environment. Earlier this year in the *Proceedings of the National Academy of Sciences*, they demonstrated that the required enzyme can be synthesized from easily-engineered—and less problematic—bacteria such as *E. coli*.

Lehigh's renowned Electron Microscopy and Nanofabrication Facility allowed for detailed structural analysis of individual nanoparticles, composed of tens to hundreds of atoms. A new, $4.5 million instrument scanned an ultra-fine electron beam across a field of QDs. The atoms scattered the electrons in the beam, producing a kind of shadow image on a fluorescent screen. A digital camera recorded the highly magnified atomic resolution image of the nanocrystal for analysis.



Tubes filled with quantum dots (above left) are produced in the Lehigh lab; Bryan Berger, Steven McIntosh, and Ph.D. candidate Zhou Yang (l to r, above).

"Even with this new microscope," says Kiely, "we're pushing the limits of what can be done."

Current commercial QD development takes many hours, and requires additional processing and purifying steps. Biosynthesis, on the other hand, takes minutes to a few hours to create a full range of quantum dot sizes in a continuous, environmentally-friendly process under ambient conditions—with no post-processing steps needed.

The team is poised to scale-up its laboratory success into a manufacturing enterprise. Their goal is to help develop a plethora of QD applications such as greener manufacturing for a diverse set of products and industry sectors, power generation, water purification and even recycling.

PROFILE VIDEO
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Safeguarding data's lineage

New cybersecurity thinking, and a few well-placed calculations

Yinzhi Cao (left) with graduate student Song Li.

In the typical large-scale computing system, raw data goes through a series of computations to calculate relationships. These calculations allow end users to provide more precise weather predictions, improved corporate decision-making, even eerily-accurate personalized recommendations for books and movies.

The computations and information derived by these systems form a complex propagation network that Yinzhi Cao, an assistant professor of computer science and engineering, has coined "data lineage." Working with Junfeng Yang of Columbia University, Cao is pioneering a novel approach to virtual privacy and security that effectively stops cyberintruders from using data lineage to piece together personal or private information.

"Steps and processes that manipulate or aggregate data are like breadcrumbs that can lead hackers to a trove of potentially damaging information," says Cao. "We're trying to make sure they can't find the path."

The team has focused on securing lineage in machine learning systems as a "proof of concept" toward even wider adoption. Their concept, called "machine unlearning," introduces a small number of summations between the algorithm and the data; these eliminate interdependency and allow the algorithms to depend only on the summations. Thus, data and its lineage are removed completely—and much more efficiently than by system retraining.

The team has successfully tested its approach on four diverse, real-world systems: LensKit, an open-source recommendation system; Zozzle, a closed-source JavaScript malware detector; an open-source social-network spam filter; and PJScan, an open-source PDF malware detector.

"We envision forgetting systems eventually playing a crucial role in emerging data markets where users trade data for money, services, or other data," says Cao. "The mechanism of 'forgetting' enables a user to cleanly cancel a data transaction, or even to 'rent out' data, without forfeiting ownership. It's a new way to think about cybersecurity."

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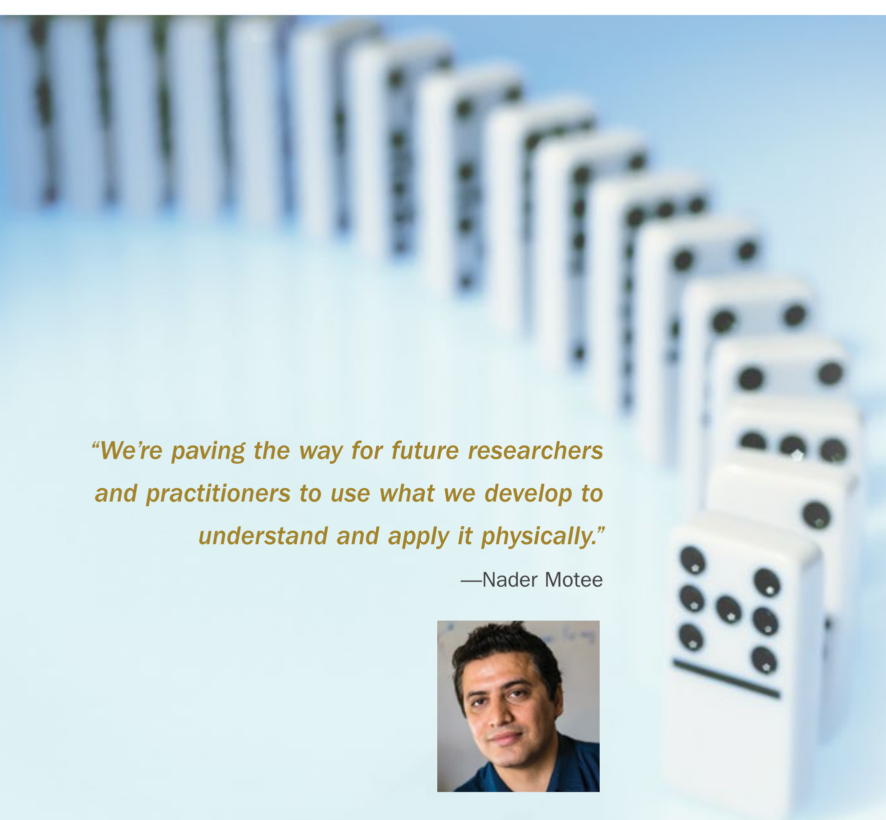


Keeping the dominoes standing

Nader Motee, P.C. Rossin Assistant Professor of mechanical engineering and mechanics, focuses on the field of distributed control and dynamical systems—a rapidly growing branch of engineering.

"A networked system can be almost anything," he explains. "It can range from Facebook to a power grid to a fleet of drones, and what makes it so interesting to study is the relationship every node in a network has with others. All of these systems encounter distinctly different challenges, but they follow the similar mathematical laws."

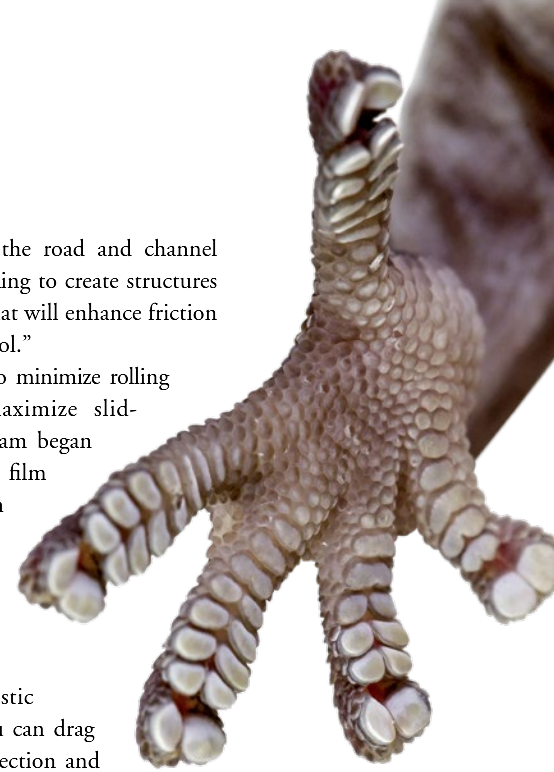
Most real-world networks have an inherently undesirable feature, usually referred to as cascading failure or a domino effect: if a subsystem endures an external shock, there is a chance that the entire network may collapse. Motee's research, one could imagine, focuses on determining why the dominoes "line up" and how the first one may fall.

"The vulnerabilities of dynamical networks are real, and can have massive consequences," he says. "As examples, consider the 2003 power blackout in the U.S. Northeast, the 2008 financial crisis, the 2011 Fukushima earthquake and associated power plant disaster, not to mention air traffic congestion around the globe and the spread of disease such as of H1N1. These events caused lives to be lost and billions of dollars in damages, and every one of them can be linked back to a network-wide breakdown."

"We're paving the way for future researchers and practitioners to use what we develop to understand and apply it physically."

—Nader Motee

Where the rubber meets the road—literally



Interest in biomimicry among researchers has been on the rise since a team at Lewis & Clark College published their seminal paper on geckos in 2002. The team described how the combination of nanoscale fibrils in the toes of the gecko combined with the van der Waals force, giving the lizard its remarkable capacity to scale sheer surfaces.

Anand Jagota, a professor of chemical and biomolecular engineering and director of Lehigh's bioengineering program, has been working in the biomimicry field for well over a decade. He and colleagues Zhenping He and Ying Bai, along with Chung-Yuen Hui of Cornell University and Benjamin Levrard, a researcher at Michelin Corporation, recently published a paper in *Scientific Reports* entitled "Strongly Modulated Friction of a Film-Terminated Ridge-Channel Structure."

The paper outlines their research into new microstructures that could have industrial implications for, among other things, tires. The team is collaborating with Michelin to advance the design of new films.

Jagota and his colleagues at Cornell and Michelin are recipients of an NSF Grant Opportunities for Academic Liaison with Industry (GOALI) award that will fund their work for three years.

For tires, there is a classic performance conundrum among traction, tire life and fuel efficiency. Improving one quality almost always degrades another.

"High quality tires minimize rolling resistance, which improves fuel efficiency, while maximizing the sliding friction that basically helps to brake quickly," says Jagota. "To help increase this sliding friction, tires currently employ millimeter-scale structures to grip the road and channel water. We are working to create structures at the microscale that will enhance friction and adhesion control."

With an aim to minimize rolling resistance and maximize sliding friction, the team began with an isotropic film structure. "You can put these pillars or posts in hexagonal array and cover them with a thin coating. That gave some fantastic properties, and you can drag the film in any direction and get the same friction," Jagota says. "But tires don't need these properties in all directions, so we went to a vertical array of ridges."

In these experiments, the researchers worked with ridge heights of 40 microns, and situated the ridges at varying distances, dragging a spherical object across the film. At the wider spacings used, 110 microns and 125 microns, the sliding friction was more than three times higher than with the flat-surfaced control. Narrower spacing of the ridges resulted in significantly lower sliding friction.

"This was the most unexpected thing, that the film improved sliding friction so much without affecting static friction," Jagota says. "We showed that with an anisotropic structure you could maintain the level of 'bad' static friction while increasing the 'good' sliding friction by a factor of three or four by dramatically increasing surface area contact among the ridges at optimal distancing."

"This has been a very fruitful collaboration already," says Jagota. "The project is still in its early stages, but working with Michelin and supported by NSF, we're attempting to apply nature's designs to make better tires."

RESEARCH VIDEO
@ **lehigh.edu/resolve**

His goal is to find and understand the conditions of networks that could experience systemic rare events and undermine the network's reliability, and then identify the triggers for possible cascading failure. Large-scale, crucial networks are precarious and interdependent, and there exists a huge research gap between theory and practice—a situation Motee is addressing through his research.

"This is absolutely theoretical work," he says. "We're trying to pave the way for future researchers and practitioners to use what we develop to understand and apply it physically."

Motee has recently been recognized by the Office of Naval Research Young Investigator Program—one of the oldest and most selective scientific research advancement programs in the country—for his project *"Risk is New Robustness: A Systemic Perspective."* Motee and his students are developing data-driven algorithms to assess global performance, risk, and fragility features of various real-world networks by computing the value of their systemic measure in real-time.

The ONR award will also support laboratory equipment, graduate student stipends and scholarships, and other expenses critical to ongoing and planned investigational studies.

Motee is also recipient of a 2013 Air Force Office of Scientific Research (AFOSR) Young Investigator Award, as well as a 2015 NSF CAREER Award.

 INTERVIEW BY KURT PFITZER PHOTOS COURTESY OF U.S. EMBASSY, NEW DELHI AND PIB, GOVERNMENT OF INDIA

"CHALEIN SAATH SAATH"

SHARED VALUES UNITE THE WORLD'S OLDEST DEMOCRACY AND ITS LARGEST

Richard Verma '90 was appointed U.S. Ambassador to India in 2014 by President Obama and approved unanimously by the U.S. Senate. In two years in India, he has visited more than 50 towns and cities in 21 states, a level of activity that prompted U.S. Secretary of State John Kerry to say, "We may [be doing] more with India, on a government-to-government basis, than with any other nation." Verma, the 2016 recipient of Lehigh's Industrial and Systems Engineering Distinguished Alumni Award, holds a B.S. in industrial engineering from Lehigh and law degrees from American University and Georgetown. As assistant secretary of state for legislative affairs under Hillary Clinton, he received the Distinguished Service Medal, the State Department's highest civilian honor.

Q: ***What attributes are most critical to the diplomatic profession?***

A: U.S. diplomats share a core set of values and characteristics. These include curiosity, creativity and a passion for policy, people and cultural ties; strong analytical, communication and interpersonal skills; developing subject area expertise; and a genuine interest in the country of assignment. Flexibility and patience are also key, and my personal favorite is the ability to listen closely to others. If you understand the situation, perspective and personality of the people you are working with, good decisions and real progress will follow.

Q: ***What common values and interests do India and the U.S. share?***

A: Both of our constitutions start with the same three words "we the people." We both respect minority rights and diversity, and we have federal systems, with a multitude of states that can be so different. We are societies bound by the rule of law. We both are working to uphold the post-World War II order across the Asia Pacific and beyond, an order where international law and rules matter. And our people share commitments to education, innovation, learning, family and so much more. It's no surprise that the Prime Minister recently called us "natural allies."

Q: ***What can U.S. faculty members and students and their Indian peers learn from each other?***

A: The U.S. and India have a number of formal education programs that foster dialogue and exchange. Check out this program focused on engineering: RISE. The U.S. Department of State's Passport to India initiative was set up to encourage more Americans to consider studying in India. The number of Americans doing so has remained relatively flat at approximately 4,500, and we hope that this will increase in the future!

I would encourage American students to get out of the U.S. and see the world. By meeting people in other places, you will begin to see similarities, universal truths and some local realities. Spend time with the youth and academics in your host country. Compare their teachers, teaching styles, libraries, laboratories with what you have. By making personal connections, you can begin to get a feel for avenues of cooperation.

Q: ***How can we increase the flow of college and high school students from India to the U.S.?***

A: India is already the second-highest sender of

Clockwise from left: visiting Jama Masjid; lecturing at Lehigh; a selfie during Earth Day, New Delhi; welcoming P.M. Modi to the U.S.

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students to the U.S. after China. Last year, there were a record 132,000 Indian students in the U.S.—two-thirds of them at the graduate level and four-fifths in STEM and business fields.

The U.S. promotes student mobility through EducationUSA—the U.S. Department of State's official network of advising centers providing information about higher education in the U.S. EducationUSA in India has seven centers with more than 30 advisors, and this year we are focused on ensuring that even more Indians make EducationUSA a part of their higher education journey.

Q: ***The achievements of Indian scientists rival those of Westerners. Will these advances help India bypass certain stages in the typical progress from developing to developed nation?***

A: Yes. "Leap frogging," particularly in energy, telecommunications, health, and infrastructure, will be a big part of India's development. It is often said that two-thirds of the buildings and infrastructure of India in 2030 have yet to be built. This allows India to incorporate best practices into infrastructure projects that are built from scratch, rather than retrofitting existing buildings (at quite an expense). Everything from energy efficiency and safety codes to using environmentally friendly materials can be part of the process—to an extent city planners in the developed world could only dream of. By 2030, India will be the world's largest country by population and the third-largest economy. The advances that are bound to occur here will be transformational.

Q: ***What are some facts regarding India's progress in technology that might surprise American readers?***

A: Today's young Indian innovators are creating new products, services and ideas that offer solutions at a fraction of the cost of traditional technology solutions. The penetration of cell phones in India has been phenomenal, with over a billion users. Not only has the cell phone allowed people in the farthest reaches of India to be connected, it has enabled a surfeit of services to be rolled out. From banking and financial inclusion to health, education and entertainment, the cell phone has become a literal lifeline. Other advances like India's indigenously developed railway infrastructure have created physical connectivity among people, along with important industrial connections such as ferrying goods from Jharkhand to Punjab; grains from Punjab to Tamil Nadu; and automobiles from Tamil Nadu to Assam and Kashmir. Thanks to India's creative youth, free market economy, strong educational system, and social and economic mobility, we see a lot of potential for yet even more progress, but given India's size, it will take time.

India also has a very active and advanced space exploration program. India launched its first satellite more than 40 years ago. It also launched a moon orbiter, and in 2014, India became the first country to launch a Mars orbiter which succeeded on the first attempt.

Q: ***How much progress has India made in building its energy infrastructure?***

A: A lot. Until 2014, India, from a national electricity grid perspective, was really five disconnected regions. Today, because of investment in transmission infrastructure, it is now possible to "wheel" electricity generated from a wind turbine in the South up to the North East where it is needed, or vice versa. This drives down prices and adds stability to the national grid such that if there is no wind in one area of the nation, solar generated power can be wheeled in to compensate.

India has also been forward leaning in opening up infrastructure development to foreign ownership, which encourages capital investment. India has the world's most ambitious renewable targets—175 GW by 2022. We have been strongly supporting those goals, which, if achieved, will revolutionize how power is generated, transmitted and consumed. It will also have a dramatic impact on carbon emissions and our collective battle against climate change.

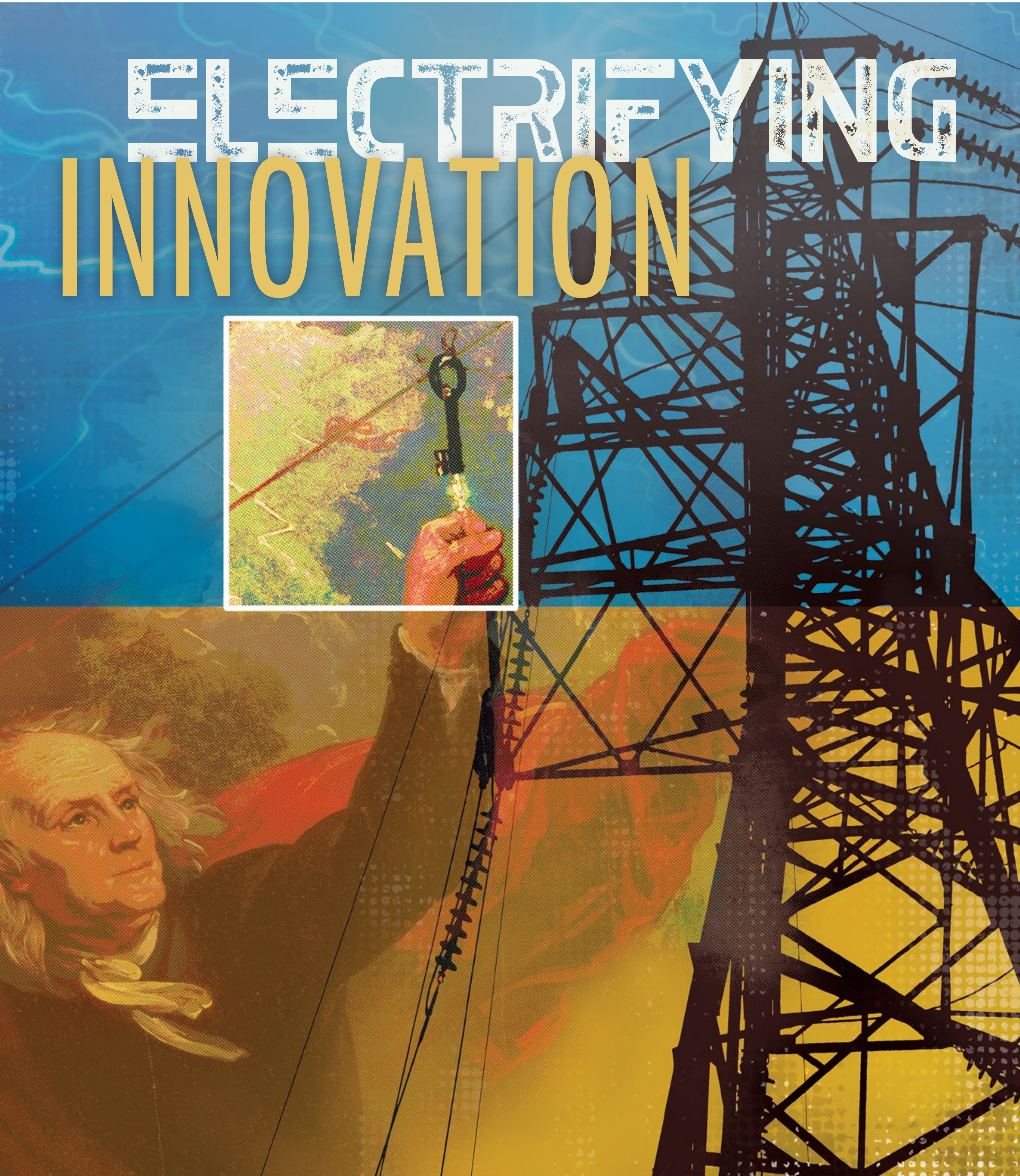
Q: ***Discuss some examples of U.S.-India scientific and technical cooperation.***

A: So many to choose from! If I had to name a few, I would say the space program where NASA and the Indian Space Research Organization (ISRO) have collaborated for decades; agriculture where U.S. experts helped India usher in a green revolution, becoming a food-exporting nation; education—the U.S. was instrumental in the establishment of the Indian Institute of Technology at Kanpur, and our exchange programs have, for decades, brought American teachers and students to India and Indians to the U.S.; energy—the Tarapur Nuclear Power Plant that was the product of U.S.-India cooperation in nuclear energy in the early 1960s; science—American and Indian scientists have collaborated in a variety of fields. And of course there are the many other people-to-people connections, be it in information and communication technology, physics, chemistry, biochemistry, nanotechnology, agriculture or health sciences. You name it, and we've been there, done that, and are building more ties every day. As they say in Hindi about the U.S.-India relationship, "Chalein Saath Saath," Forward Together We Go.

Q How can a modern engineering education help prepare one for a diplomatic career?

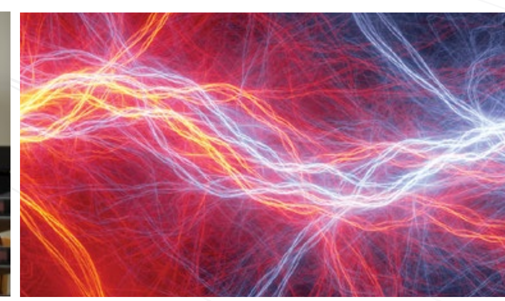
Engineering and diplomacy both require careful problem-solving skills, rooted in facts, science and critical thinking. Like engineering, diplomacy and statecraft require an ability to analyze, interpret and apply information; create and implement solutions; work in multidisciplinary teams; as well as resourcefulness, oral and written communication, and attention to detail. An education that develops these qualities in students prepares them well for life in a globalized world, as much as it does for their specific discipline, including diplomacy.

ELECTRIFYING INNOVATION



STORY BY **RICHARD LALIBERTE**

RESEARCHERS CHARGE TOWARD A CLEANER, SAFER POWER INFRASTRUCTURE



Professors Wenxin Liu (above) and Larry Snyder are members of Lehigh's Integrated Networks for Electricity research cluster.

MAYBE BEN FRANKLIN REALIZED IT IN JUNE 1752, AS HE (LEGENDARILY) DANGLED FROM THE SPIRE OF CHRIST CHURCH IN PHILADELPHIA TO LAUNCH A KITE INTO A THUNDERSTORM: the small piece of metal he'd attached to it was both literally and figuratively a key—one that held the power to unlock a modern, technological way of life.

Power is so essential to daily existence that, paradoxically, people often don't think much about the commonplace wonder of flipping a switch that actuates an enormous, intertwined, and complex set of systems—production, transmission, distribution, and control—and brings to life all manner of technology.

Whatever its original energy source, electricity boots our devices, lights our screens, computes our data, moves our money, heats and cools our homes, illuminates our buildings and streets, refrigerates our food, cleans our dishes and clothes … it gets to be an exhaustive list, as does the inventory of expertise needed to support it.

"Electrical networks by their nature are interdisciplinary," says Larry Snyder, associate professor of industrial and systems engineering. "They involve electrical engineering, industrial engineering, computer modeling, optimization and control, communications and networking security, and economics, to name a few."

According to Snyder, who plays a key role in Lehigh's Integrated Networks for Electricity (INE) research cluster, the key is to integrate and capitalize on innovation from across these interconnected disciplines in order to ultimately solve the complex challenges of modernizing global power infrastructures.

The INE is a collaborative, multi-faceted team of Lehigh researchers focused upon the interdependent flow of electricity, information, and money needed to operate what's popularly known as the "smart grid"—a term that represents broad efforts across industry, academia, and government to incorporate and leverage modern technologies across power infrastructures. It's an evolving, complex approach to modernizing electricity provision, and would entail overlaying the existing power grid itself with an Internet-like information network that ultimately allows the system to be more responsive, efficient, reliable, and conducive to alternative energy sources.

Lehigh researchers are also expanding horizons of what's possible in energy generation by developing or refining technologies and understanding fundamental scientific phenomena that promise to help unleash new energy resources. These include power from ocean waves, nuclear fusion, geothermal reserves, and techniques to enhance the sustainability of traditional energy sources.

Professor Rick Blum (above, left) says "few academic research centers can do what Lehigh does."

The overarching goal: to meet global energy demand while protecting the environment for future generations. "In a research area where teams tend to be dominated by traditional fields and perspectives, few academic research centers can do what Lehigh does," says Rick Blum, the Robert W. Wieseman Professor of Electrical and Computer Engineering and director of the INE. "We excel at developing interdisciplinary teams that incorporate and leverage expertise in areas like systems engineering, electrical and computing fields, data analytics, and economics—and solving real problems."

With support and collaboration from stakeholders in industry and government, Lehigh's investigations into the future of power generation and distribution are making progress in a number of key areas.

MAKING THE SMART GRID GREENER

A key to future energy networks will be integrating renewable energy resources. The challenges of doing so are rooted in limits on storing electricity. Energy generally must be produced in amounts that balance with demand, and forecasting how much energy will be available at any given time becomes important for keeping the system stable. But that's difficult in a system that incorporates significant amounts of solar or wind energy, which can vary unpredictably when clouds roll in or the breeze dies.

Other complexities arise from a growing profusion of relatively small, decentralized energy sources. Readily controlled power generation from, say, coal-fired power plants must now integrate with everything from spinning turbines on wind farms to individual homeowners with excess power to offer from rooftop solar arrays.

"You've got power flowing in multiple directions, more parties, smaller players, different kinds of users, third parties buying and selling power, complexities in demand response—there are just many more pieces to the system," Snyder says. "They're all good, but they introduce new risks and opportunities for things to go wrong."

INE research projects address many of these challenges through analyzing, quantifying, and modeling data associated with the flow of power and information, along with their economic effects.

"When renewables under-produce, the system needs to turn on relatively dirty fossil-fuel generators," Blum says. "There are costs associated with that. In other words, what's often thought of as 'free' renewable energy actually isn't, especially in the face of uncertainty."

Researchers including INE faculty member Alberto Lamadrid, assistant professor of economics with Lehigh's College of Business and Economics, work to quantify costs associated with energy variation and consistency, along with a wide range of other factors. These include problems associated with economic dispatch—determining how electricity-generating facilities can produce optimal output to meet system loads at the lowest possible cost, given operational and transmission constraints.

Wenxin Liu, P.C. Rossin assistant professor of electrical and computer engineering, studies control and optimization of microgrids and power electronic systems. His advanced experimental platform, developed with meaningful contributions from his postdocs and students, facilitates hardware experimentation to test a wide range of algorithms for microgrids, the smart grid, and the so-called "energy Internet."

"We're helping to prove the viability algorithms and models for energy management systems and demand response," says Liu. "Our high-fidelity testing will help new techniques be 'ready for prime time' as the smart grid ecosystem develops."

Running a grid with many levels of complexity requires vast amounts of information, and related Lehigh investigations are studying data science methods such as how data

GREATEST. FIELD TRIP. EVER.

Supported by the National Science Foundation, INE faculty worked with Lehigh undergraduates and the campus' Sustainable Development program to design and run a weeklong course for 20 high schoolers teaching the science and technology behind capturing wave energy. The course took place at the world-class ocean science research and education center the Bermuda Institute of Ocean Sciences, and was co-taught by representatives from BIOS and from renewable energy firm Eccosolution.

from sensors and measurement units can optimally be collected and processed.

"We're not only advancing knowledge," Blum says, "we're making contributions that can be used in real systems."

HARVESTING WAVES

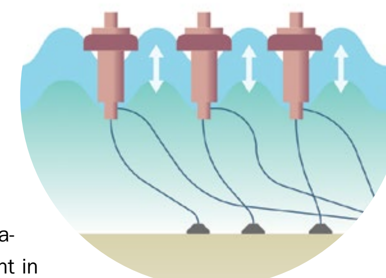
The problematic, unpredictable nature of renewables begs a question: What if you could find an abundant natural energy source that was more consistent than wind and sunshine? If you live in a coastal area—as the majority of the U.S. population does—you don't have far to look for a prospect: the ocean.

Studies find that statistical wave parameters can be predicted as far as two days into the future, according to Shalinee Kishore, associate professor of electrical and computer engineering. That means wave energy could factor into daily supply-and-demand planning, which would open electricity markets to renewable producers because they'd be better able to guarantee delivery of power.

Kishore is principal investigator for a nearly $1 million grant from the National Science Foundation (NSF) has provided to Lehigh's PORT (Power from Oceans, Rivers, and Tides) Lab. It's part of a Department of Energy (DOE) initiative to expand the nation's renewable portfolio to include marine hydrokinetic (MHK) energy.

"We have the capacity to generate one-third of the country's electricity just based on MHK resources," says project co-investigator Arindam Banerjee, associate professor of mechanical engineering and mechanics, who specializes in fluid dynamics.

Harvesting that energy depends on developing wave energy converters (WECs) that would be arrayed just below the surface in clusters or farms near shore. Such farms promise to have higher capacity factor than wind farms in which windmill blades often aren't turning. "If you ask what percentage of its useful life a device generates at rated capacity, with wind it might be as high as 40 percent," Banerjee says. "Waves are flowing all the time, so MHK is significantly higher—in the 70 or even 90 percent range."

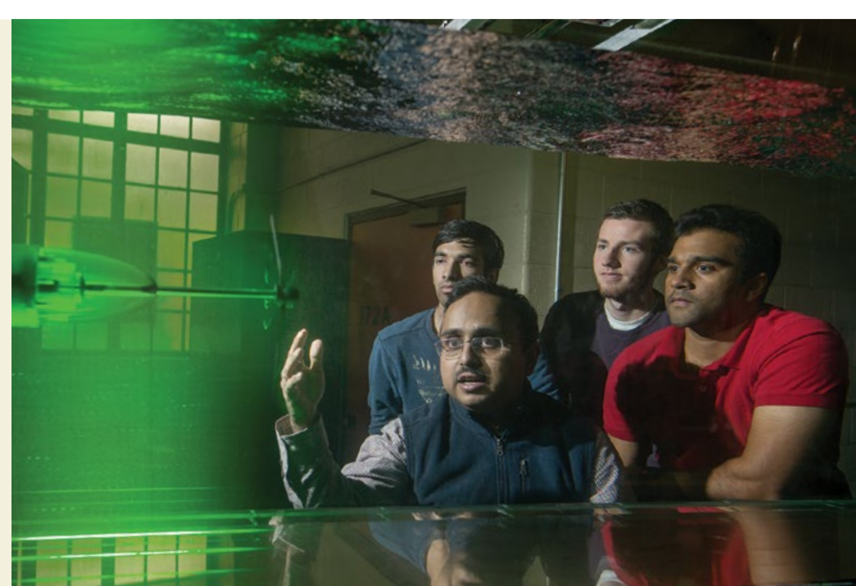


But while tidal energy technology is relatively mature, WEC technology is in its infancy, and Lehigh researchers are creating ripples of innovation on problems such as optimal buoy placement in wave farms. "By better understanding WEC hydrodynamics, we can see how wave states affect the devices, how WECs interact with each other, and how to lay them out to increase the amount of power they can generate," Banerjee says.

The more that's known about how WECs perform and behave, the easier it will be for wave-energy technologies to attract investors. "Right now, wave energy resources provide zero watts of power to the grid," Banerjee says. "We're trying to speed the process of bringing technology from bench to site by understanding the fundamental physics."

MIXING AT THE EXTREMES

Arindam Banerjee's expertise in hydrodynamics bolsters Lehigh MHK research, as well as work in the development of fusion energy. He studies what are known as Rayleigh-Taylor (RT) instabilities, which can wreak havoc on the yield of inertial confinement fusion. Along with his work in Lehigh's Turbulent Mixing and Fluid Mechanics Laboratory, pictured at right, he has developed a rotating wheel experimental facility that will allow physicists and engineers to better understand and mitigate the impact of hydrodynamic instabilities on fusion processes. Data from this new Lehigh facility, supported by grants from DOE and NSF, will help validate and verify "mix models" currently under development by his group in collaboration with scientists at Los Alamos National Laboratory.



FOCUSING ON FUSION

Obtaining controlled energy production from nuclear fusion has intrigued and eluded scientists for more than 60 years. Fusion could produce vast amounts of energy using readily available fuels such as water-derived hydrogen isotopes and lithium.

"Compared to fission, which is currently used to generate nuclear power, fusion offers a number of advantages," says Eugenio Schuster, director of Lehigh's Plasma Control Laboratory and professor of mechanical engineering and mechanics. "Fuel is abundant, there's little risk for nuclear accidents, and power generation doesn't produce long-term radioactive waste or materials that can be dangerous on any number of levels."

Yet fusing these atoms requires temperatures of around 100 million degrees Kelvin. At much lower temperatures than this, the fuel gas ionizes and becomes a plasma. This incredibly hot plasma must be contained and controlled for a reactor to work. Because plasma is ionized, it's readily affected by electromagnetic forces, which are used to confine the ionized gas in sophisticated experimental devices called tokamaks.

Few control systems are as complex as those required to optimize a nuclear reactor, says Eugenio Schuster (center), pictured with team members at the DIII-D National Fusion Facility in San Diego.

"It's like creating an invisible bottle that prevents the plasma from touching the inner wall of a reactor," Schuster says. "But under the intense heat and pressure required to fuse normally repellent ions together, plasma becomes unstable, making a sustained reaction difficult. It's a very complicated problem, and controlling plasma variables in a tokamak is the main focus of our work."

A small number of tokamaks exist around the world, and thus research into plasma control often takes on international dimensions involving collaborations between nations. A major new facility called ITER—the world's largest tokamak—is now being constructed in France in a cooperative effort involving 35 countries. It's designed to be the first fusion device to sustain reactions, produce more power than it consumes, test integrated technologies, and prove fusion's feasibility as a large-scale, carbon-free energy source.

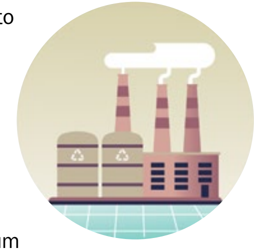
Schuster led a Lehigh team directly involved in the design of ITER's plasma control system, and continues to work toward solving many related issues. The work has included the control of plasma variables such as temperature, pressure, and current in time and in space, using complex, partial differential equations and models while avoiding and mitigating magnetohydrodynamic instabilities.

"ITER represents a critical moment in fusion worldwide," Schuster says. "If it succeeds, nuclear fusion will proceed. If not, we'll need to find new, creative ways to get there. Either way, I'm very proud of what we're achieving at Lehigh."

LEGACY SOURCES, NEW PERSPECTIVES

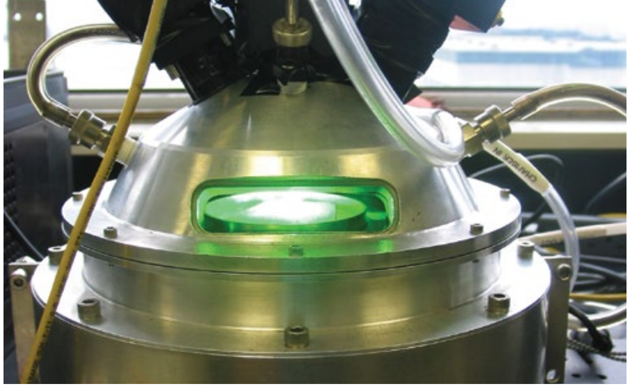
While some researchers investigate future technologies, others work to advance innovation and efficiency in mature ones. Consider the usual way that traditional thermal power plants, fired by fuels like natural gas or coal, condense steam that propels turbines—by using water-based condensers and cooling towers. The process requires huge amounts of water, accounting for some 40 percent of U.S. freshwater use. In dry areas such as the West where freshwater supplies are dwindling, air-cooled condensers (ACCs) are an appealing alternative. Yet they account for only 1 percent of condensers in U.S. thermal plants. One reason: "As midday air temperatures rise, you lose a lot of cooling efficiency," says Carlos Romero, director and principal research scientist at Lehigh's Energy Research Center (ERC).

With funding from the DOE, a team composed of Advanced Cooling Technologies, the University of Missouri, Evapco and Lehigh University is working to improve ACC efficiency by using phase-change materials that absorb thermal energy and later release it as the material shifts from solid to liquid form.



"We've tried a variety of inorganic salts, including calcium chloride hexahydrate, magnesium chloride, and potassium nitrate, and are narrowing them down as we design and build cycling machines that will take us to a prototype," Romero says. "We expect to scale up a design and test it in a power plant in the future."

Using innovative ideas for a familiar process is also at the heart of an ERC collaboration with academic and government bodies in Mexico. The three-year project is studying and testing ways to use carbon dioxide emitted from fossil fuel power plants, in a supercritical state (sCO_2), to extract geothermal energy from underground dry hot rock and hydrothermal geothermal reservoirs. Geothermal extraction generally relies on water or brine to capture heat.



"But sCO_2 is a better fluid that can double the ability of water or brine to pick up heat, especially at lower temperatures," he says. "Recycling CO_2 in geothermal reservoirs also provides the added benefit of sequestering greenhouse gas emissions under the ground."

Further efficiencies can be found in handling fuels themselves. Coal-burning plants, for example, burn coal of varying quality from various mines. Analyzing quality so that coal can be burned more efficiently relies on nuclear instrumentation that makes use of potentially dangerous radioactive materials.

"We're working with energy research firm ERCo on a commercial instrument that uses a laser beam, instead of radioactive materials, to excite a sample on a coal conveyer and analyze it," Romero says. "This laser-induced breakdown spectroscopy (LIBS) system is being tested at a power plant near Pittsburgh—it is easy to install, has a smaller footprint and is lighter than nuclear instruments, and doesn't require cumbersome radioactivity safety measures. It provides an accurate entire analysis of the coal—elemental composition, heating value, sulfur, ash content, fusion temperature of the ash—it's all valuable knowledge for managing the coal supply."

"The energy field is at an inflection point driven by the economies of fuels, environmental constraints and rapid scientific advancement," he continues. "Through efficiency improvement, innovation, and new technology development, we're helping the power industry meet the challenges of this century."

Lehigh's LIBS technology (left) engaged in plasma testing at a coal-fired power plant.

GUARDING THE GRID FROM CYBERTHREAT

When you put all the elements together, however, the grid faces still more challenges beyond those of generating, transmitting, controlling, and analyzing power. In an era marred by terrorism and between-nation cyberattacks, there's also a need for security and attack resilience.

That's why the DOE has invested in a five-university Center for Cybersecurity for Energy Delivery grant that's bringing $3.5 million in funding to Lehigh over five years to develop technologies that will protect the grid from threats. Lehigh's work focuses on five distinct areas that nine Lehigh faculty members—the largest concentration of investigators in the project—approach from a variety of perspectives. These include detecting attacks, mitigating attacks that can't be identified, managing security systems, and testing and validation—including the discovery of false data.

Suppose, says Larry Snyder, that a demand-response system with time-dependent rates was susceptible to injections of false information about usage or pricing.

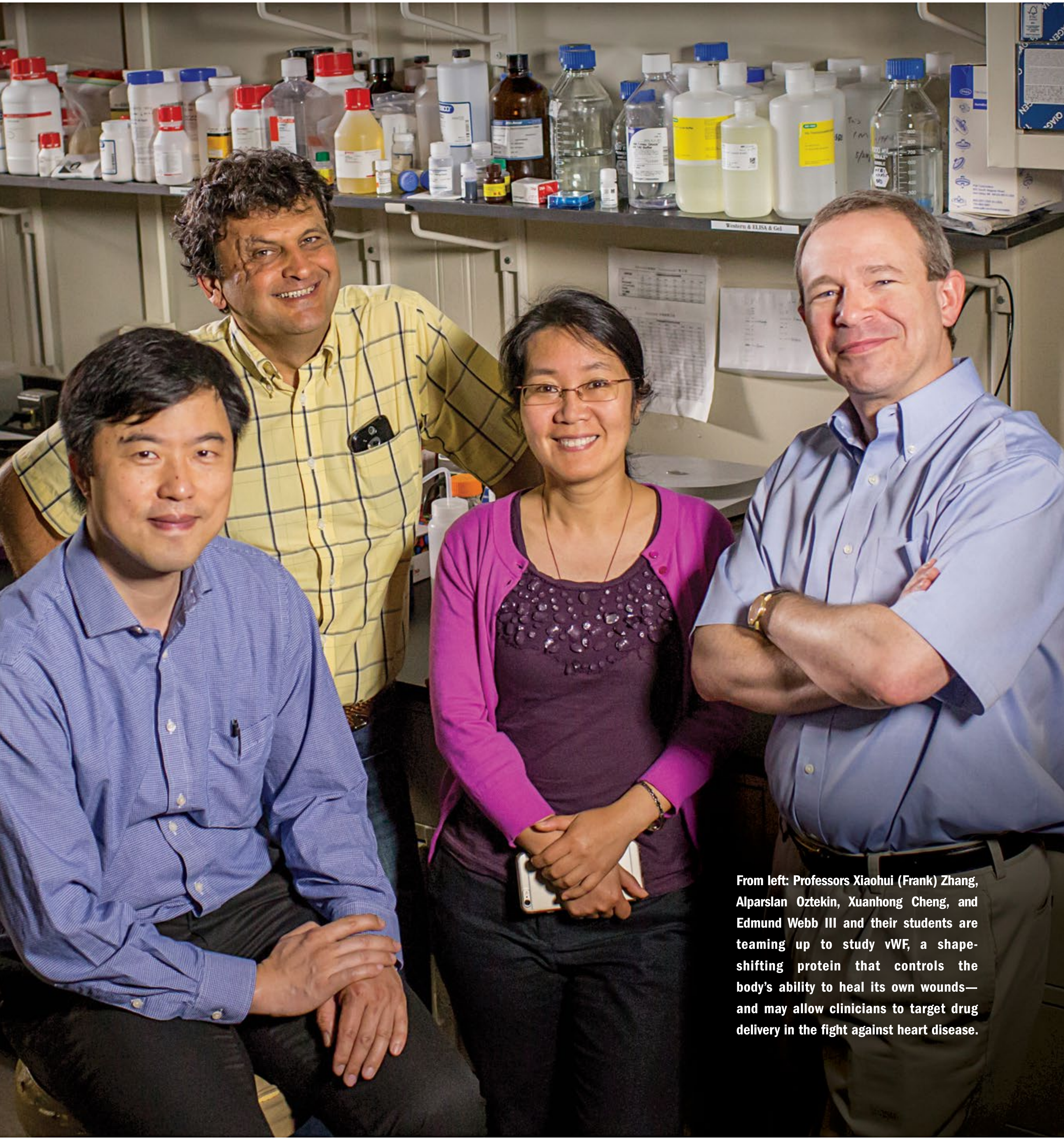
"Bad guys could misuse demand-response signals and controls to steal energy or money, or simply to cause damage to the system or its users," he says. "Malicious data indicating swings in demand could imbalance the relationship between energy supply and consumption. It could cause significant problems like big oscillations or even blackouts."

Lehigh researchers are developing algorithms and optimization tools that, for example, could detect, measure, and compare redundant signals at multiple locations in the grid. If two signals that should be the same are different, one could be a lie. Such problems will be critical to the energy future whether the grid uses legacy resources, renewables, or fusion—all of which significantly overlap in Lehigh's multidisciplinary research model.

"The INE research cluster has done really well in the five years it's been in existence," Blum says. "But research into the energy infrastructure is broad work, here on our campus and elsewhere, and progress will require a lot of interconnection. With a strong interdisciplinary work ethic already in place, Lehigh is well positioned to help lead the way."

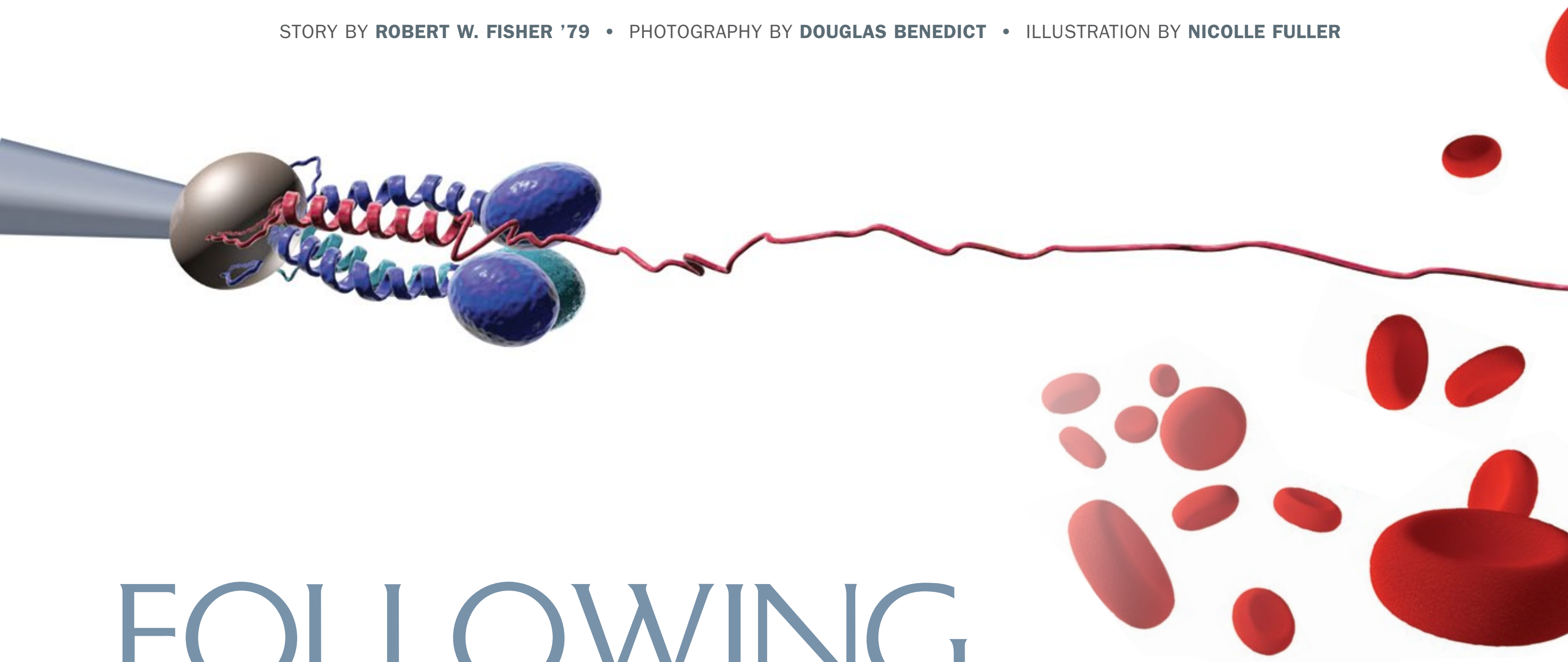
LEANER, GREENER MANUFACTURING

Lehigh has been home to a DOE-supported Industrial Assessment Center (IAC) since 1998, when Professor Sudhakar Neti founded it to tackle ineffective procedures, excessive waste, and other production-related problems that, left unchecked, wreak havoc on the environment and on the bottom line of companies across eastern Pennsylvania and New Jersey. Approximately 350 firms have partnered with the Center since then, bringing about energy conservation, waste reduction, and millions of dollars' worth of productivity enhancement. According to Neti, pictured at left giving remarks at a 2016 U.S. Senate meeting and celebration of the national IAC program's 40th anniversary, students run the entire program, from partner development, to data collection, to quantification of potential energy savings, to preparation of reports for the firm and DOE.



From left: Professors Xiaohui (Frank) Zhang, Alparslan Oztekin, Xuanhong Cheng, and Edmund Webb III and their students are teaming up to study vWF, a shape-shifting protein that controls the body's ability to heal its own wounds—and may allow clinicians to target drug delivery in the fight against heart disease.

STORY BY **ROBERT W. FISHER '79** • PHOTOGRAPHY BY **DOUGLAS BENEDICT** • ILLUSTRATION BY **NICOLLE FULLER**

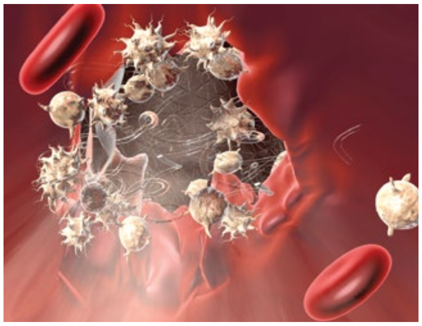


FOLLOWING NATURE'S LEAD

ENGINEERS MIMIC A MEGA-MOLECULE TO IMPROVE CARDIOTHERAPY

There's a mechanical sensor journeying silently through your blood, ready to spring into action at any sign of major bleeding. This first responder molecule, known as von Willebrand Factor (vWF), latches on to the lining of damaged blood vessels and grabs nearby platelet cells, helping them to clot off the bleeding.

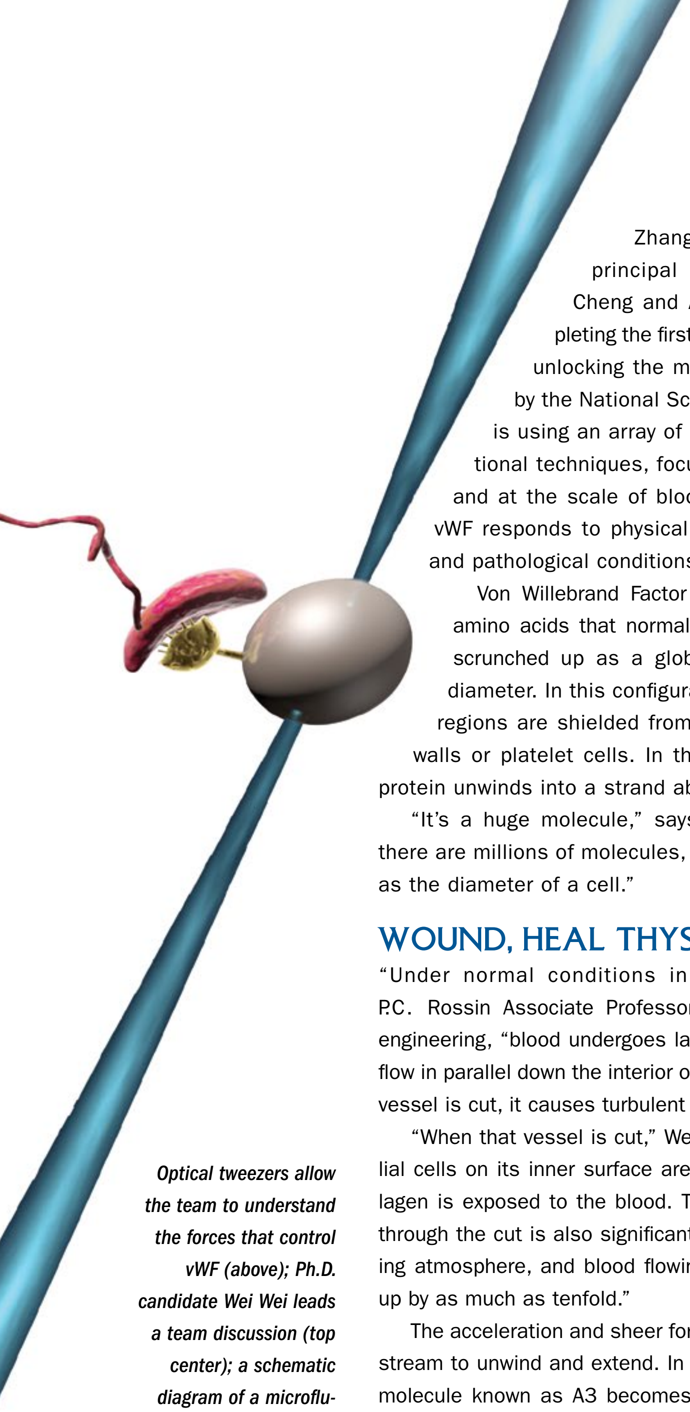
"vWF's singular ability to sense changes in hydrodynamic flows is not completely understood," says Xiaohui (Frank) Zhang, assistant professor of mechanical engineering and mechanics, who leads a Lehigh team exploring its behavior. "While it can be a life-saver in cases of physiological injury, vWF can make things worse by activating in certain pathological situations, such as a narrowed artery which, if closed, can trigger a stroke."



Knowing the mechanisms that actuate and disable vWF could someday help researchers design custom molecules that could safely deliver drugs to the precise location of a dangerous clot, narrowed blood vessel, or other cardiovascular emergency—a potential gamechanger in the fight against heart disease.

"That's our focus," says Edmund Webb III, associate professor of mechanical engineering and mechanics. "Can we engineer a molecule to respond and preferentially deliver an active drug right on target? Researchers have yet to develop controlled-release medications that respond to biochemical conditions in the body; the next best thing could be drug carriers that respond to mechanical forces as vWF does."

Understanding the mechanical triggers of vWF could also help to treat clotting disorders known as von Willebrand disease, in which clots either don't form properly or emerge spontaneously in the body in the absence of bleeding. These conditions affect two out of every 100 persons.



Zhang, Webb, and fellow co-principal investigators Xuanhong Cheng and Alparslan Oztekin are completing the first of a 3-year project aimed at unlocking the mysteries of vWF. Supported by the National Science Foundation, the team is using an array of experimental and computational techniques, focused at the molecular level and at the scale of blood vessels, to explore how vWF responds to physical events, such as bleeding, and pathological conditions, such as arteriosclerosis.

Von Willebrand Factor is a complex collection of amino acids that normally flows in the bloodstream scrunched up as a globule about .25 microns in diameter. In this configuration, the molecule's active regions are shielded from contact with blood vessel walls or platelet cells. In the right circumstances, the protein unwinds into a strand about 40 times as long.

"It's a huge molecule," says Zhang. "In a typical cell there are millions of molecules, yet vWF is the same length as the diameter of a cell."

WOUND, HEAL THYSELF

"Under normal conditions in the body," says Cheng, P.C. Rossin Associate Professor of materials science and engineering, "blood undergoes laminar flow where molecules flow in parallel down the interior of a vessel. But when a major vessel is cut, it causes turbulent flow and chaotic motion."

"When that vessel is cut," Webb continues, "the endothelial cells on its inner surface are severed and a layer of collagen is exposed to the blood. The pressure pumping blood through the cut is also significantly higher than the surrounding atmosphere, and blood flowing through the area speeds up by as much as tenfold."

The acceleration and sheer forces trigger vWF in the bloodstream to unwind and extend. In the process, a region of the molecule known as A3 becomes "sticky" and latches on to the exposed collagen layer. At the same time, a nearby region on the molecule known as A1 grabs platelets from the blood as they flow past. In this way, the extended vWF becomes the glue that binds platelets together and plugs the wound.

According to Cheng, vWF's shape-shifting behavior is not uncommon, but it does exhibit some unexpected properties that are capturing the team's interest.

"Most of the time when a protein transitions from a globular form to extended form it denatures—it loses function," she says. "Yet vWF has no known function when it is contracted, and only goes to work when it is extended.

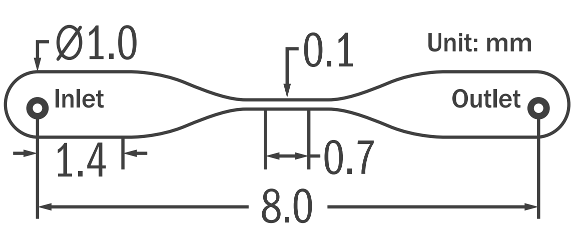
"And when you increase a fluid's flow, a hydrodynamic lift effect would normally move globule polymers in the fluid away from the surface of the channel," Webb says. "Until now, it's been a mystery why the adhesion of vWF goes up with increased flow." The researchers believe that, because vWF only reveals its active regions when extended, it adheres to the vessel before the increasing flow can peel it away.

Researchers have generally understood the mechanism by which vWF acts. However, to use its secrets to design drug carrier molecules, the Lehigh team believes that it is crucial to know exactly how vWF responds to specific flow conditions, and how it deactivates.

Zhang has been studying this mysterious molecule for years. As a postdoctoral fellow at Harvard Medical School in 2009, Zhang and a team including his mentor, Timothy Springer, proved that vWF has "a safety factor," a section known as A2 that, when extended, reacts with an enzyme called ADAMTS13 to cleave the molecule, rendering it harmless. Otherwise, healing a simple cut could cause an ever-growing clot that would soon block the entire vessel.

Today, Zhang is measuring the precise energies needed to trigger the unwinding of vWF using a technique known as optical tweezers, which uses a laser to generate a tiny force to grab and manipulate tiny molecules.

In his lab, Zhang and his students attach a small segment of vWF to a collagen layer, then grab the molecule and pull them apart, watching the strand deflect like a rubber band. "Using the optical tweezers we can stretch it slowly and measure the force [required to break the bond] to a very high resolution," Zhang says. The experiment also allows precise measurement of the length of the molecule.



Zhang pulls on the vWF molecule at various rates, revealing a distribution of energies required to break the bond in different flow conditions. This energy landscape, as Webb calls it, is integral to developing a computer simulation of the molecule.

This dynamic approach is important because how a protein functions depends on how it folds and unfolds, not just on its atomic sequence, Cheng says.

Optical tweezers allow the team to understand the forces that control vWF (above); Ph.D. candidate Wei Wei leads a team discussion (top center); a schematic diagram of a microfluidic channel made of polydimethylsiloxane (center right).

RESEARCH ANIMATION
@ **lehigh.edu/resolve**

"We are also trying to find out which part of the vWF molecule plays roles in the sensory function," Zhang says. "We see different forces as we add different sections of the molecule."

Zhang predicts that this array of results will allow him to determine which section of the molecule is responsible for activating vWF. He hypothesizes that a section known as the D-prime D3 assembly is at work, but results so far have been inconclusive.

A COMPUTATIONAL ASSIST

The energy landscapes revealed by Zhang's experiments feed directly into the computer models being developed by Webb and Oztekin, a professor of mechanical engineering and mechanics.

"The development of truly robust computer models, based on initial experimental results, will allow us to get ahead of the lab experiments," Webb says.

Much of Webb's research focuses on molecular and atomic scale models of interfaces, in this case the torn cell wall that facilitates contact between vWF and collagen.

Oztekin's expertise in fluid dynamics adds critical detail to the model, offering descriptions of the interaction between molecules and the background flow, and how each bead in the molecule changes the flow field for subsequent sections.

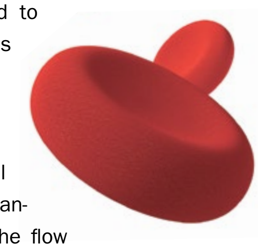
"These models are very compute intensive, and the math is very complex," Webb says. "It has been invaluable to have both of our perspectives at the table."

The team has published a model of the molecule's behavior in the bloodstream that has become generally accepted by the research community. Other researchers have made attempts at the more difficult problem of modeling the vWF-collagen interaction—without the benefit of Zhang's real-world results. The team recently submitted a paper for review that proposes a model for this process.

"We feel we are the first to have taken our numbers from experiments rather than educated guesses," Webb says. "It gives us a closer connection to the real physical system."

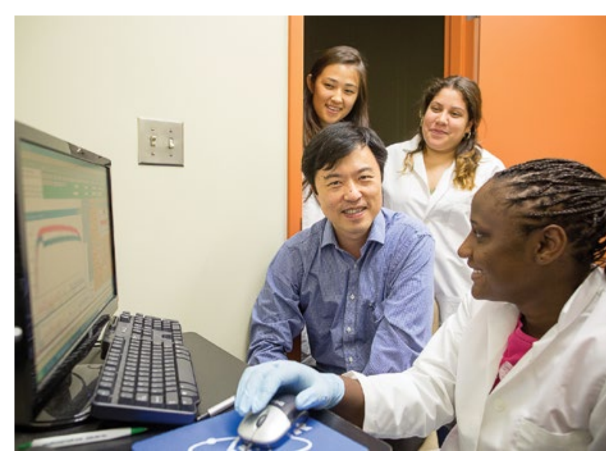
That connection will be strengthened by Cheng's work to validate the computational results. In her lab, Cheng designs and fabricates microchannel environments that simulate conditions in the bloodstream. The body has large vessels, such as the aorta, that are three orders of magnitude larger than the tiniest capillaries, each with unique flow geometries, she says.

Using a technique similar to that used to manufacture computer chips, Cheng carves very small features into sheets of transparent polymer small enough to be observed under an optical microscope. The behavior of blood in small and large vessels is well known, she says, "so we can design the channel dimensions and geometry to give us the flow field we want to study."



"BEING PART OF A PROJECT THAT INCLUDES EXPERIMENTAL WORK AND SIMULATION AT BOTH MOLECULAR AND SYSTEMIC SCALE IS ALSO A BENEFIT TO OUR GRADUATE STUDENTS." —Xuanhong Cheng

Tagging vWF samples with fluorescent dye, Cheng can observe the flow of molecules under the microscope, measuring how many of the balls extend at given flow rates. She can also coat the microchannels with a collagen like that inside damaged vessels, to describe how vWF behaves differently when bleeding occurs. Eventually she will study how the shortened and elongated molecules that cause von Willebrand diseases respond in the same conditions.

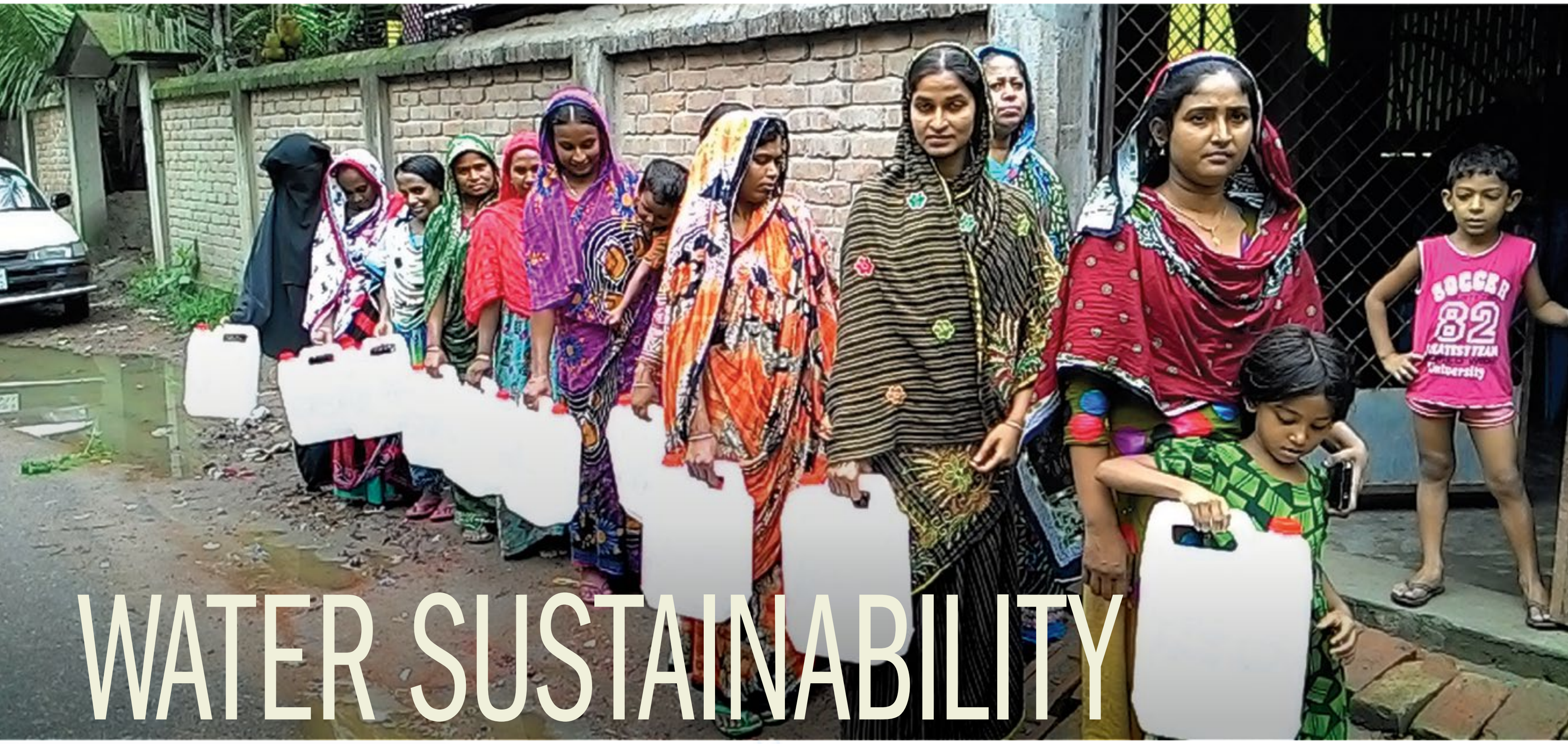


Frank Zhang with students (clockwise from left) Helen Chamley '18, Isabel Amaya '19, and Adama Shaw '17.

"Being part of a project that includes experimental work and simulation at both molecular and systemic scale is also a benefit to our graduate students," Cheng says.

Speaking of the students involved in the project, Webb says it is beautiful to see them maturing into truly multidisciplinary researchers.

"The four of us from different backgrounds in mechanics, materials, and bioengineering have been collaborating for more than three years, building on shared interests across traditional disciplines," he says. "I think the interplay has been very valuable to our collective group of students. Overall, Lehigh has proved to have all the right elements to bring this multidisciplinary team together with agility."



WATER SUSTAINABILITY THROUGH NANOSCIENCE

LEHIGH RESEARCHERS ADVANCE HEALTHY, ECONOMICAL WATER FOR ALL

1.8 BILLION PEOPLE AROUND THE WORLD LACK ACCESS TO SAFE WATER.

water.org (2016)

Hydrogen peroxide is among the most common and versatile of household products: disinfecting wounds, bleaching hair, whitening teeth and removing stains, cleansing contact lenses and killing mold.

Zirconium, one of the most abundant elements in the world, is stable and just as chemically innocuous. A corrosion resistant metal used in nuclear reactors and high performance pumps and valves, in oxide form it even serves as jewelry and in treating poison ivy.

In two separate nano-inspired projects, Lehigh researchers are working to add to the credit reels of these workaday chemicals a shared, and perhaps loftier usage than ever before—providing healthy water to parts of the world that need it most.

QUENCHING GLOBAL THIRST

Nanoparticles of zirconium oxide, says Arup SenGupta, P.C. Rossin Senior Professor of civil, environmental, and chemical engineering, possess adsorption properties that make them uniquely beneficial to human beings. They can remove four major toxins—arsenic, fluoride, phosphate and lead—from water.

SenGupta, a highly-awarded, three-decade pioneer in engineering for clean water around the world, and his students have extended their lab's impact on global health, using zirconium oxide nanoparticles to invent the world's first filter capable of removing both fluoride and arsenic from groundwater.

Nearly 400 million people in Asia and Africa drink groundwater that contains toxic levels of these contaminants. Exposure to excessive amounts of fluoride can cause skeletal fluorosis; this decreases the elasticity of bones, making them more prone to fracture and causing bone and joint damage. Elevated levels of arsenic can cause skin lesions, a variety of cancers and blood vessel disorders.

The materials used in the filter are polymeric ion exchangers doped with zirconium oxide nanoparticles. The doping procedure, says SenGupta, plays a critical role in producing optimum hybrid particles that are robust and accessible to water while maintaining their integrity. In late 2015, SenGupta and Surapol Padungthon '13 Ph.D. earned a U.S. patent for the invention.

"This is the only material currently available that can remove both arsenic and fluoride, and it can be reused for years without being wasted," he says.

SenGupta has also developed a business model that enables people who lack clean groundwater to install and operate purification systems in an economically sustainable way. He and Ph.D. candidate Mike German recently received the 2016 VentureWell-Lemelson Sustainability Award for co-founding DrinkWell, an organization that provides purification technologies and business opportunities to people who lack access to clean water.

Bangladeshi villagers queue up for water each morning (above, left); installation of an arsenic removal unit in a Cambodian village (above).

GREENER GREYWATER

Around the world, many people still rely on decentralized community- or household-based systems for a safe source of water. For many in these communities, the reuse of so-called "greywater"—wastewater streams from showers, baths, basins and washing machines—can help ensure that water needs are met. Greywater can be contaminated with a range of substances such as soaps and detergents, skin, and dirt, yet it can be recycled for toilet flushing, irrigation, and other non-potable uses.

Hydrogen peroxide can prepare greywater for safe reuse; however, it is typically made in a multi-step, energy-intensive process. Large quantities are produced, shipped and stored in a highly concentrated form, and eventually diluted for personal or commercial use. The sheer logistics of this have stymied the use of hydrogen peroxide for water treatment in underdeveloped or disaster-stricken regions—until now.

A group of researchers from Lehigh, Cardiff University in Wales, and Oak Ridge National Laboratory has developed a way to produce hydrogen peroxide through a simple, economic, one-step process. In an article published earlier this year in the journal *Science*, the group reported that bimetallic compounds consisting of palladium and any one of six other metallic elements can effectively catalyze the hydrogenation of oxygen to form hydrogen peroxide.

The new catalysts, says Christopher J. Kiely, a professor of materials science and director of Lehigh's Electron Microscopy and Nanofabrication Facility, can be made by combining palladium with tin, cobalt, nickel, gallium, indium or zinc.

"Using our new catalyst, we've created a method of efficiently producing hydrogen peroxide on demand in a quick, one-step process," said Simon J. Freakley of the Cardiff Catalysis Institute, the current article's lead author. "Being able to produce hydrogen peroxide directly opens up a whole host of possibilities, most notably in the field of water treatment."

The latest *Science* article is the fourth on the topic from Lehigh and Cardiff researchers over the past decade. Their previous three *Science* papers dealt with advances in creating and using an alloy catalyst of gold and palladium; one, published in 2009, discussed the catalyst's potential to produce hydrogen peroxide quickly and efficiently while preventing its decomposition.

"Scientists have known for more than a century that palladium can catalyze the direct reaction of hydrogen and oxygen into hydrogen peroxide," Kiely says. "Unfortunately, palladium also rapidly decomposes the peroxide. Previously, we discovered that gold-palladium nanoparticles prevented this undesired reaction. But gold is expensive. For widescale adoption, especially in the developing world, we needed cheaper metals."

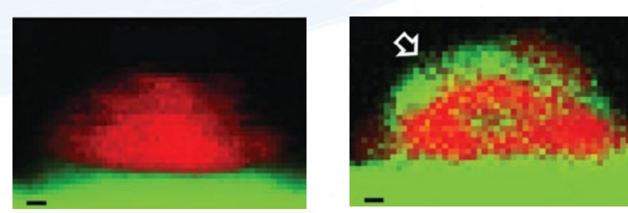
According to Kiely, all of the six new alloying elements are cheaper than gold. Furthermore, the catalysts can be made without nitric-acid pre-treatment, a requirement of the gold-palladium alloy.

In the current research, the team found that palladium, combined with tin, for instance, promoted the reaction as effectively as gold-palladium catalysts. Electron microscopy helped explain why.

Variation in particle size and composition—a given in catalyst production—turned out to be the culprit. Researchers detected that larger alloy particles, roughly 5-10nm in diameter, were slightly palladium-deficient, and were responsible for producing the desired hydrogen peroxide. The source of the subsequent undesired peroxide decomposition was traced back to the presence of ultra-small, palladium-rich particles with diameters of a single nanometer.

To stop these smaller particles in their tracks, the team deposited a palladium-tin catalyst onto a titanium dioxide support. Some tin formed into an oxidized layer across the support, while the remainder made palladium-tin alloy particles. A simple, three-step heat treatment process caused the tin-oxide films to encapsulate the smaller, palladium-rich particles, thus preventing them from decomposing the peroxide, while leaving the larger productive alloy particles uncovered.

"The heat treatment buried the small palladium-rich particles in the tin-oxide and averted the undesired reaction," says Kiely. "This so-called 'strong-metal-support-interaction' phenomenon is normally unwelcome, yet in this case we have used it to our advantage."



An EELS chemical map shows tin oxide migration over the palladium particle after heat treatment. (Scale bar = 1 nanometer)

The group spent five years developing the palladium-tin catalyst and optimizing to the heat treatment regimen; according to the *Science* article, the team has achieved overall selectivity to hydrogen peroxide of more than 95 percent.

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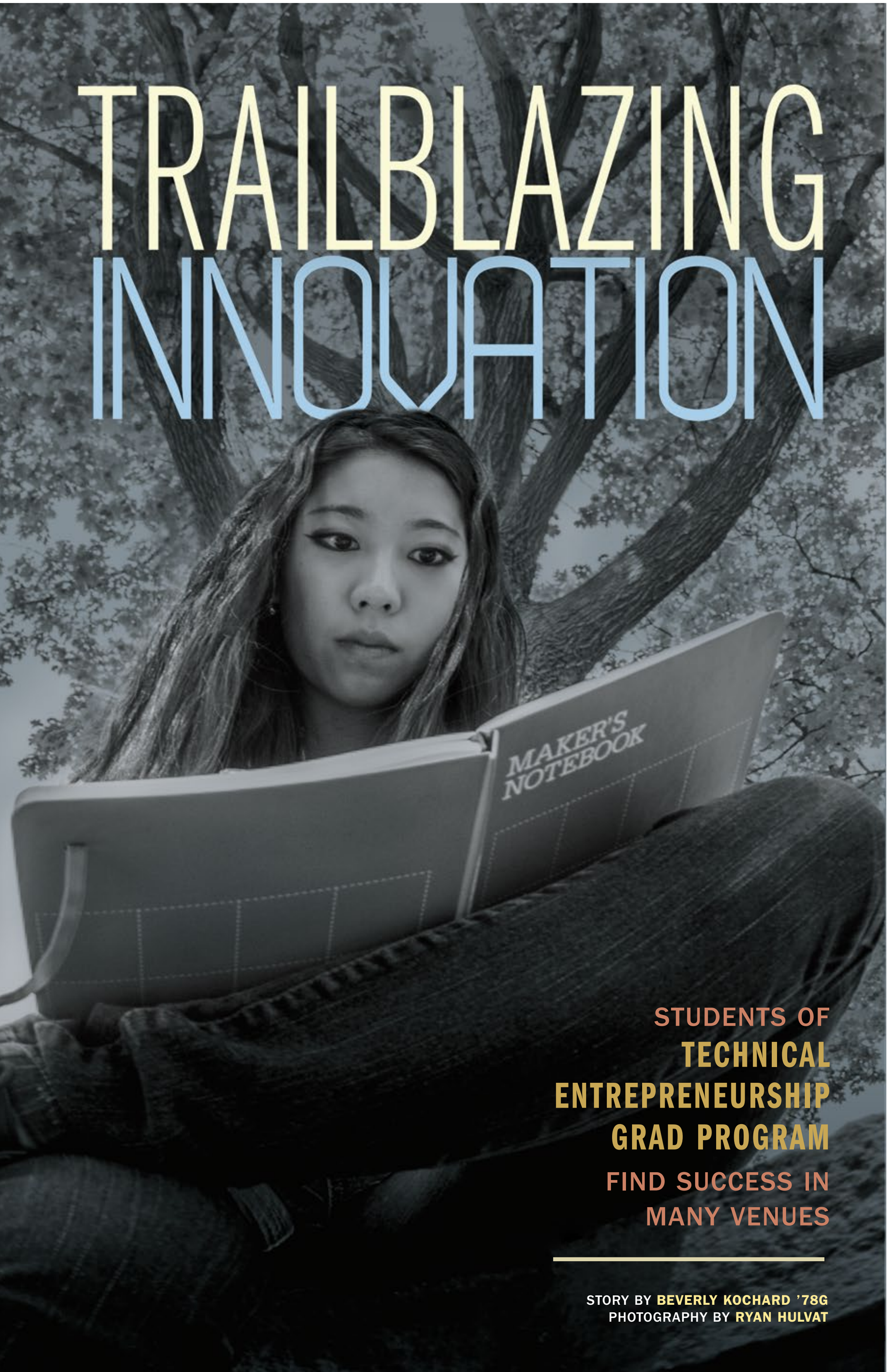
TRAILBLAZING INNOVATION



STUDENTS OF TECHNICAL ENTREPRENEURSHIP GRAD PROGRAM FIND SUCCESS IN MANY VENUES

STORY BY **BEVERLY KOCHARD '78G**
PHOTOGRAPHY BY **RYAN HULVAT**

KNOWN FOR INNOVATING IN THE WORLD OF ENTREPRENEURIAL EDUCATION, Lehigh University launched its own startup, of sorts, in the summer of 2012.

This startup, Lehigh's Professional Master's program in Technical Entrepreneurship (TE), combines graduate-level engineering skills with real life application to provide training in the art and practice of creating new ventures—producing entrepreneurs who are cross-trained to innovate across multiple disciplines.

Students travel through TE as a cohort of 20 to 30. Dedicated faculty manage the program and deliver 12 courses offered only to TE students. The program operates in its own space; students also have access to the adjacent Creativity and Innovation Lab and resources for 3D printing, electronics, and prototyping.

Now in its fifth year, TE attracts from a wide variety of disciplines, from bio, mechanical and chemical engineering to physics, supply chain and journalism.

"The melting pot of knowledge and skills in the TE cohort fuels the innovation process," says Michael Lehman, professor of practice in TE.

Since its inception, the full-time, twelve-month, residential program has graduated close to 90 budding entrepreneurs.

"Four distinctive career paths have evolved," Lehman continues. "As the program launches successive waves of innovators, we're hearing more and more impressive stories that illustrate the value of the TE degree."

LAUNCH

A COMPANY

Creativity, passion, knowledge, skills, support, and opportunity—when present at the same time in the same space—can turn a dream into a reality.

Take Jessie Garcia ’12, ’13G, for example.

Garcia founded Tozuda, LLC, after earning her TE degree at Lehigh. The patent-pending technology that forms the underpinning of her first product was developed during the year she spent in the program.

“Having an idea is one thing, she says, “but translating it into a product is something else entirely. That’s where the TE program comes in.”

Her experience playing rugby at Lehigh as an undergraduate global studies major, combined with today’s national spotlight on head injuries, inspired her to create a sensor that attaches to a construction worker’s hardhat and detects potentially dangerous levels of force to the head. She’s also developing two additional sensors for use in athletics and the shipping industry.

TE graduates have also launched startups in the toy industry, digital media and marketing, management consulting, fashion, jewelry, athletic equipment, and product development and manufacturing.

LEAD

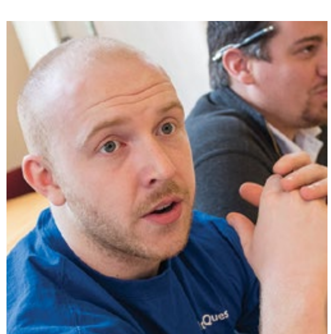
AN ENTREPRENEURIAL TEAM

Brandon Evanko ’15G always planned to join the family business, BRUNS-PAK (BP). Founded by Brandon’s father, Lehigh alumnus Mark Evanko ’79, BP offers datacenter services including consulting, design, and construction.

After earning his B.A. in economics at Franklin and Marshall College, Brandon enrolled in Lehigh’s TE program. He was brought on board at BP as a project engineer after completing his master’s degree, and he eventually hopes to run the company.

“All of my educational choices have been shaped by the idea that I might one day be able to take over the reins and do a great job,” he says. “Getting my TE degree was the best academic decision I’ve ever made.”

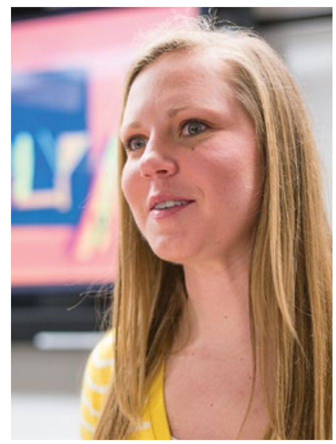
TE grads have affiliated with entrepreneurial endeavors focused on logistics and supply chain management, transit technology, fine art, marketing, venture technology and support, and business intelligence solutions.



CATALYZE

EMERGING ENTREPRENEURS

Some who are passionate about entrepreneurism find their calling in sharing their knowledge and skills to help others succeed in the field.



As Katelyn Noderer ’09, ’13G observes, “entrepreneurship education is really about teaching students a new way of problem solving and empowering them to go out and change the world.”

Noderer graduated from Lehigh with a B.A. in psychology and design arts, served two years with the Peace Corps in Ukraine, and earned her M.Eng. in TE in 2013. As associate director of the Center for Entrepreneurial Studies at Stanford Graduate School of Business, she has the opportunity to make a difference in the lives of hundreds of students each year. She derives tremendous satisfaction from teaching them a process that can be leveraged to solve problems, make life decisions, and achieve goals.

“I never would have had the skills and, perhaps most importantly, the passion for this position,” she says, “if I hadn’t gone through the TE program.”

Other grads are teaching, mentoring, and guiding emerging entrepreneurs in such fields as software, product development, and startup management.

INNOVATE

WITHIN A CORPORATION

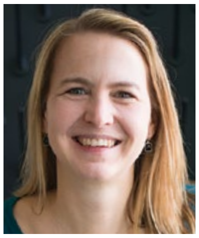
Kris Lynch ’14, ’15G, who earned both his B.S. in mechanical engineering and his M.Eng. in TE at Lehigh, used TE’s unique blend of product design and business acumen to land a position with IBM.

In his role with Big Blue, Lynch’s work takes place at the intersection of technology and business. Many of his responsibilities fall in the areas of project management, marketing, and user experience design, allowing him to maximize use of his graduate education.

“The skills I learned and the relationships I established while in the TE program truly changed my life,” Lynch says.

Cassie Tian ’13, ’14G, who holds a both a B.S. in bioengineering and an M. Eng. in TE from Lehigh, was hired by Catalent Pharma Solutions. “Going through the TE program was the transition point of my life,” she notes. “I discovered talents I never knew I had.”

SEE LONGER ARTICLE @ **lehigh.edu/resolve**



Angela Brown (above) seeks to block "bad" bacteria from attaching their outer membrane vesicles to healthy cells (below).

Making bacteria an unwelcome guest

The best way to fight disease, says researcher, is to block it from taking hold

Bacterial infection takes hold in the body when a pathogenic microorganism delivers toxins to healthy cells. One way bacteria accomplish this is by releasing vesicles, which act as tiny envelopes transporting toxins and other virulence factors to host cells. These toxins allow the bacteria to "make themselves at home" in cells.

In the search for alternatives to antibiotics, researchers are exploring untraditional infection treatments that focus on these virulence factors as prime targets.

Angela Brown, a P.C. Rossin Assistant Professor of chemical and biomolecular engineering at Lehigh, describes the alternative route this way: "Instead of killing bacteria, we make them really uncomfortable, giving the immune system time to mount a strong response."

Brown, who joined Lehigh in January 2014 after a postdoctoral appointment at the University of Pennsylvania's School of Dental Medicine, is pioneering a unique approach that, unlike previous methods targeting virulence factors, has the potential to apply to a broad range of pathogens. She and her team are focused on a novel target: outer membrane vesicles (OMVs). These are regularly shed by Gram negative bacteria, among the most challenging type of bacteria to treat.

Her work has caught the attention of the National Science Foundation, which recently awarded her an NSF CAREER grant to fund the development of this transformative approach. The prestigious $500,000 grant supports untenured faculty pursuing solutions to major challenges through research and teaching.

During the five-year grant period, Brown and her team will identify shared delivery mechanisms common among Gram negative bacteria in order to develop broad-range antibacterial molecules that will radically change the way the medical practitioners fight pathogenic bacteria.

Both the United States Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) have identified antibiotic resistance as a significant health threat, and Brown's work addresses the urgent need to develop new antibiotic strategies. She will begin by systematically characterizing the toxin association of outer membrane vesicles—building on her previous work, which confirmed that the composition of bacteria's OMVs plays a significant role in the toxin's ability to bind with the vesicle.

Brown and her team will identify the specific lipid components and membrane properties that facilitate the binding of toxins to the vesicle and then investigate the role of those toxins in the vesicles' ability to deliver vesicles to a healthy cell.

The third and final goal of the project will be to inhibit a toxin's ability to associate with the OMV surface and block it from binding with a host cell—treating the bacteria like an unwelcome guest.

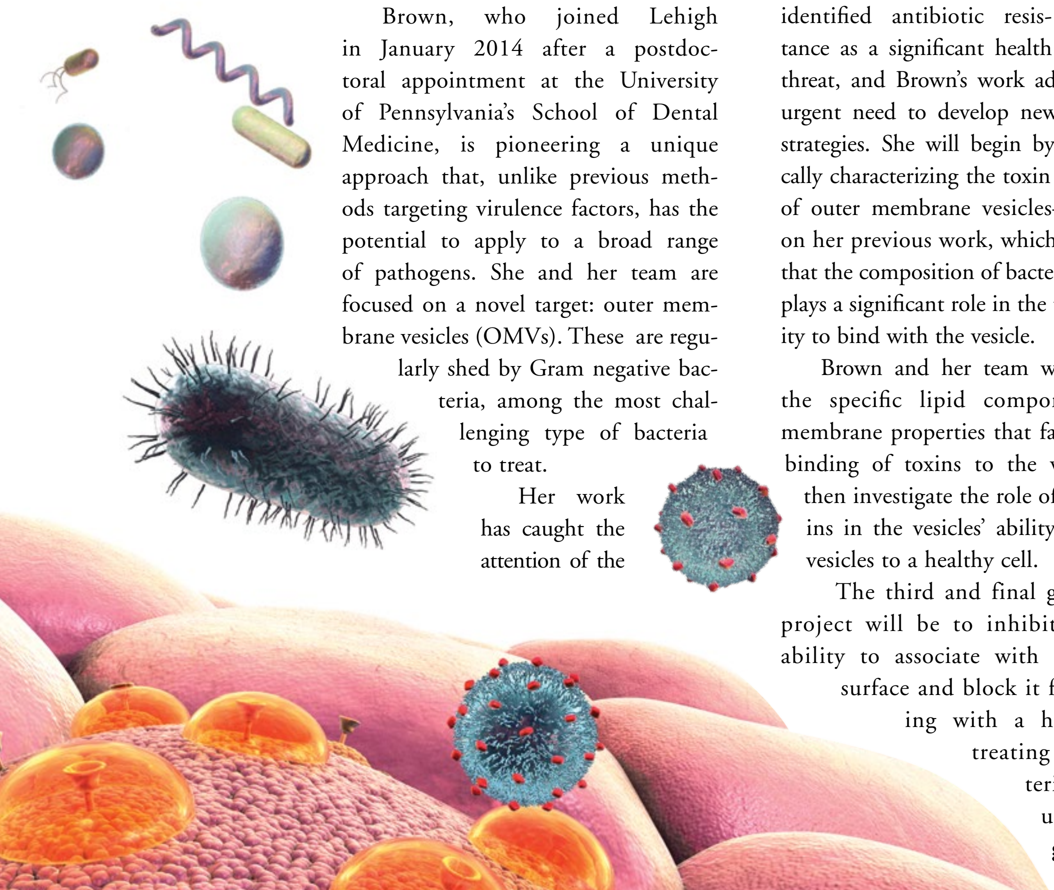
PROFILE VIDEO ONLINE @ lehigh.edu/resolve

For the past seven years, Brown has been working with a bacterial leukotoxin produced by the oral pathogen *Aggregatibacter actinomycetemcomitans*. This toxin has been demonstrated to be enriched in the OMVs produced by *A. actinomycetemcomitans*. She plans to build on the preliminary evidence she has collected—some of which were published recently in *Molecular Oral Microbiology*—to investigate her hypothesis using three representative organisms. This will identify shared mechanisms that could be used as targets for the development of broad-range treatment options.

In addition to her research, Brown seeks to address urgent challenges the country faces related to training an adaptable STEM workforce and improving the numbers of females entering and remaining in it.

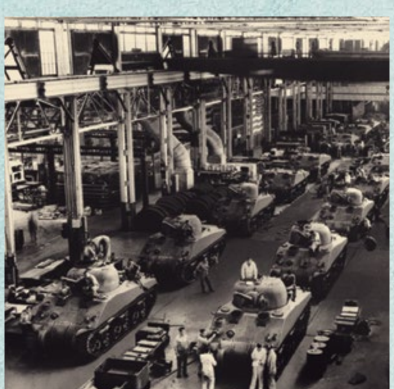
As more women become primary earners for their families, STEM careers become particularly important to our country's economic health. Women in these careers earn about 30 percent more than women in other careers. Although the numbers of women and underrepresented minorities pursuing these careers has increased over the past four decades, problems remain.

Brown aims to contribute to the solution by increasing the number of female chemical engineering degrees (to closer to 50 percent) and facilitating the long-term STEM careers of engineering graduates by helping her students see the broader impact of their studies and their research. She is also committed to employing female and underrepresented minority students, both undergraduate and graduate, in her lab.



THE LOEWY INSTITUTE at Lehigh is named after a prominent Jewish family that fled Nazi Germany in the 1930s. Once established in the U.S., they contributed mightily to the Allied victory in World War II, transformed the aerospace industry, and shaped much of modern manufacturing.

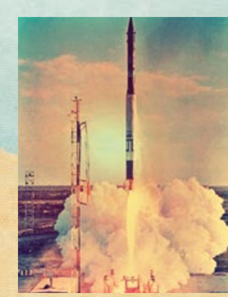
Designers of massive tools, mills, and presses, Ludwig (1887-1942) and Erwin (1897-1959) Loewy's imprint on modern life is everywhere. Their expertise transformed commercial and military technology, and their legacy made possible some of the 20th century's greatest feats of industrial and technological progress.

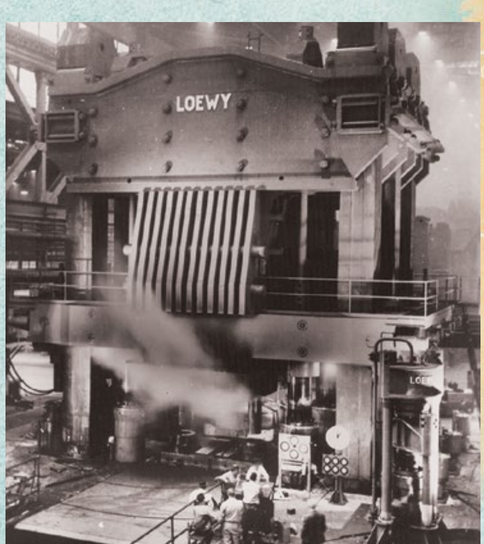


After the family's escape through Western Europe and England, the Loewy-Hydropress company was **established in the U.S. in 1940**. The firm quickly ignited the American industrial response to French and British war efforts, and soon bolstered direct U.S. involvement.

At the outbreak of war, Erwin lobbied the Advisory Committee to the President for National Defense to mobilize the U.S. aircraft industry by building 100 huge extrusion presses. By 1943, the number of Loewy presses supporting the effort **far exceeded the initial estimate**.

Erwin was active in helping German Jewish engineers emigrate pre- and post-war. His team helped develop the first motion simulator for the **Polaris Missile**, as well as the launch pad for the **Vanguard Rocket**.





The Loewy-Hydropress massive **50,000-ton machine "Major"** (shown left), was integral to the development of iconic craft such as the B-52 and the Boeing 707. Still in operation, it has fabricated parts for virtually every airplane in the skies today.

THE LOEWY FAMILY FOUNDATION IS A LONGTIME SUPPORTER OF LEHIGH RESEARCH, FIRST THROUGH THE INSTITUTE FOR METAL FORMING AND NOW THROUGH THE RECENTLY-DEDICATED LOEWY INSTITUTE.

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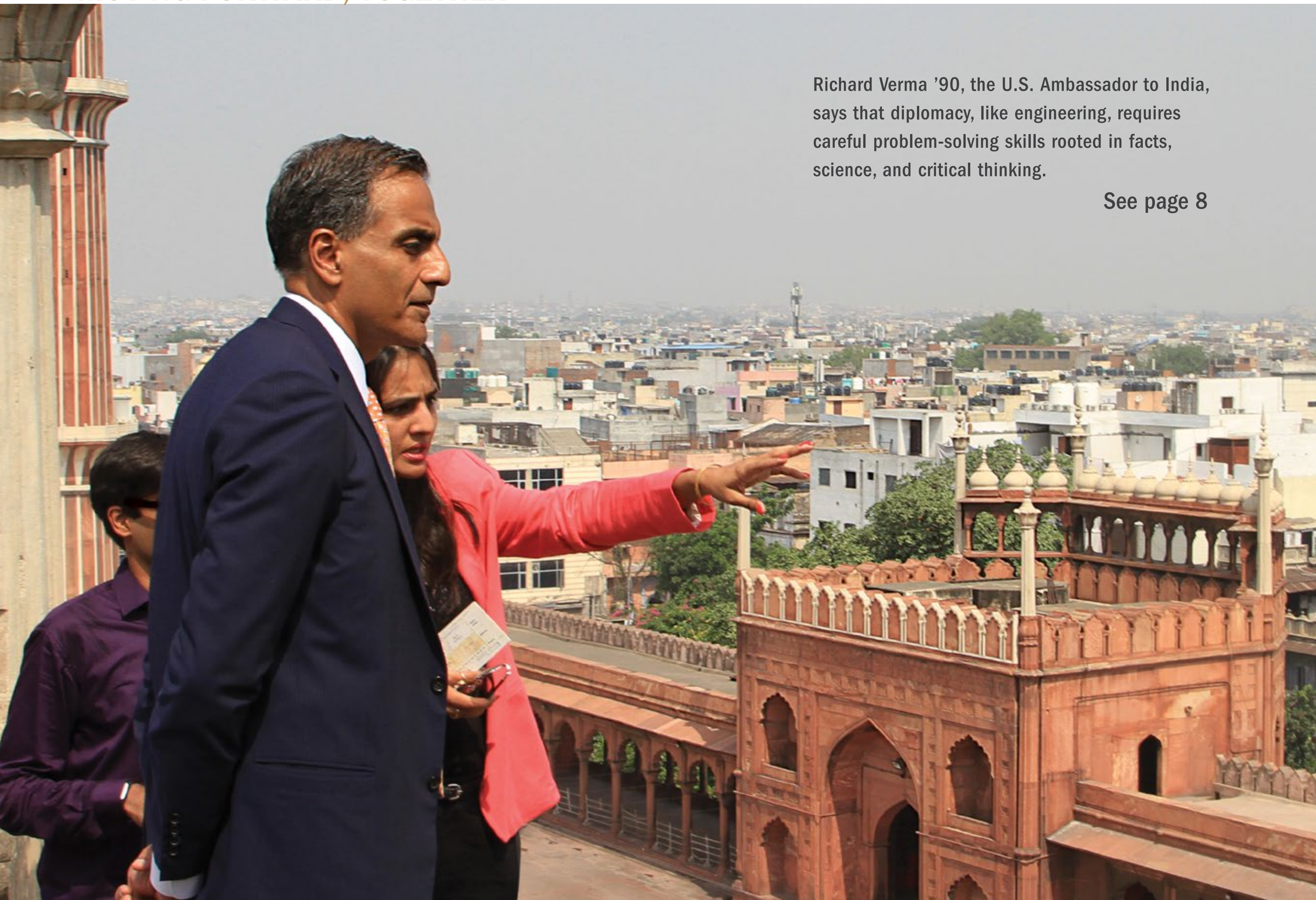
MOVING FORWARD, TOGETHER



Richard Verma '90, the U.S. Ambassador to India, says that diplomacy, like engineering, requires careful problem-solving skills rooted in facts, science, and critical thinking.

See page 8