Fall 2023

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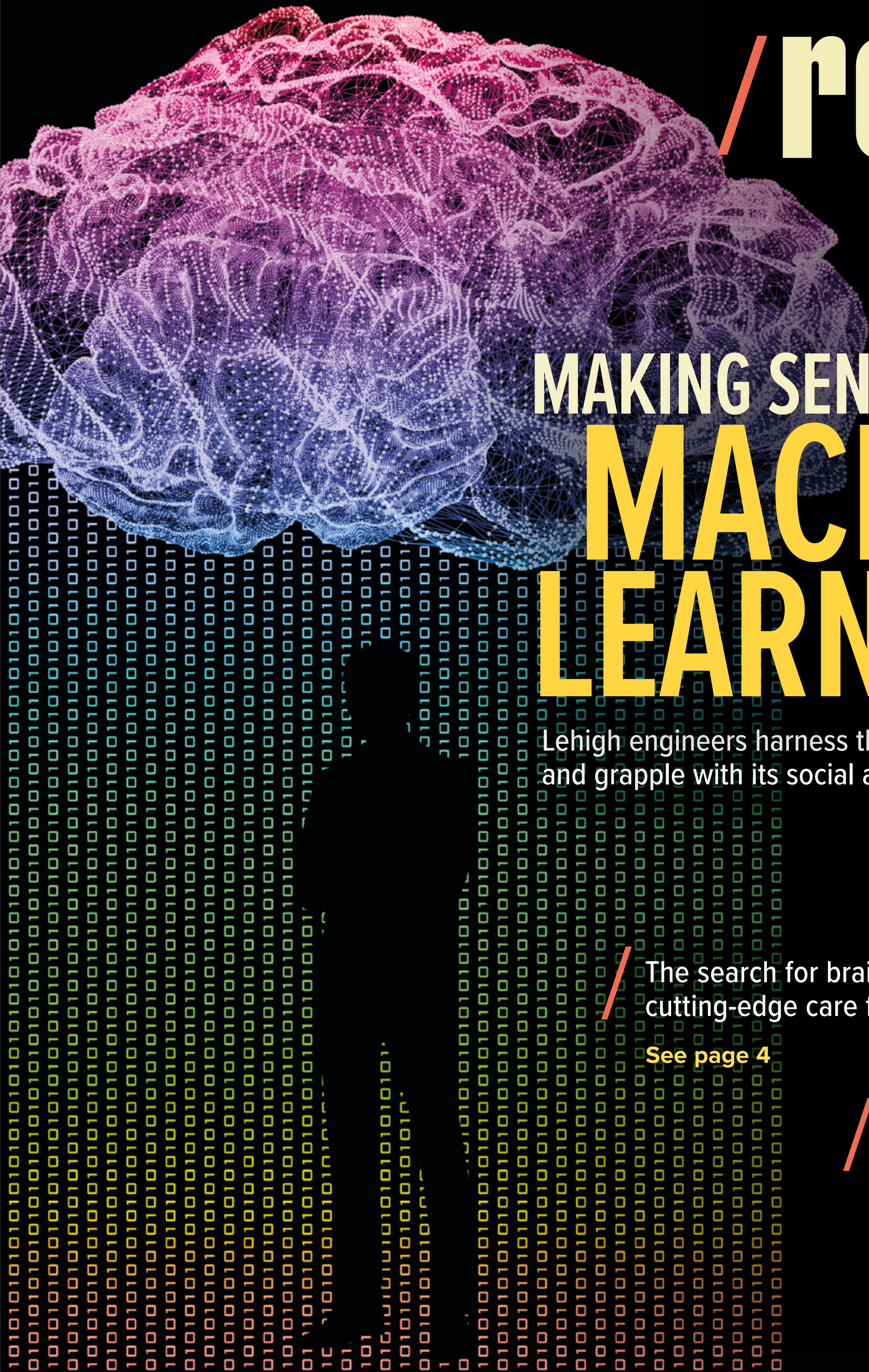

MAKING SENSE OF MACHINE LEARNING

Lehigh engineers harness the power of artificial intelligence and grapple with its social and ethical implications

See page 12

/ The search for brain biomarkers and cutting-edge care for depression

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/ Hot ideas in carbon capture, thermal energy storage

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

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Transforming Mountaintop campus is one of 10 key initiatives outlined in Lehigh's new strategic plan, *Inspiring the Future Makers*.

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LEHIGH UNIVERSITY

OPPOSITE PAGE: MARCUS SMITH '25

LETTER FROM THE DEAN

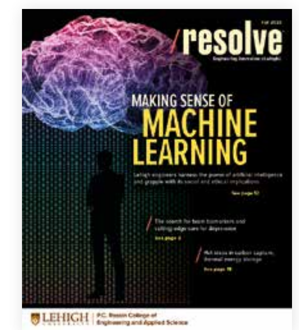
The future is ours for the making

Welcome to the Fall 2023 issue of *Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

This issue of *Resolve* arrives at an exciting moment for our university and for the Rossin College.

Following two semesters of open dialogue among our community of stakeholders, Lehigh released a new strategic plan this summer (see page 2). The themes that emerged through that dialogue, and the specific goals and initiatives now integral to *Inspiring the Future Makers*, resonate deeply within our college. As the plan's initiatives gather momentum, transformational opportunities for Lehigh's engineering community are on the horizon.

Our fall magazine highlights intriguing interdisciplinary projects that align with the plan's emphasis on "high-paced, high-reward research," as well as the strong integration of the plan's key initiatives with our evolving research and educational activities as a college.



Lehigh teams are harnessing the power of artificial intelligence, and specifically machine learning (page 12), to make advances that will revolutionize the way we diagnose diseases, store and distribute energy, and manufacture materials, to name a few examples.

At the same time, the development and incorporation of innovative data science tools and techniques requires careful consideration of how these technologies impact users and our society as a whole. The university's Institute for Data, Intelligent Systems, and Computation (I-DISC) is emerging as a leader in research that champions a holistic, human-centered approach to AI.

On page 18, "Hotbed of Innovation" delves into cutting-edge carbon-reduction technologies developed by Lehigh Engineering faculty: a process that captures and renders dangerous carbon dioxide into harmless baking soda, and a device that efficiently captures and stores renewable energy for large-scale industrial usage.

Also of note is a new $3 million National Science Foundation Research Traineeship (NRT) program grant that will enable graduate students in energy-related fields to lead the energy sector in overcoming its reliance on carbon and in addressing related inequities.

Bringing these themes together is this issue's Rising Star, electrical engineer Javad Khazaei. His work focuses on novel machine-learning approaches to smart energy grid management and the wider integration and distribution of renewable energy.

AS THE STRATEGIC PLAN'S INITIATIVES GATHER MOMENTUM, **TRANSFORMATIONAL OPPORTUNITIES** FOR LEHIGH'S ENGINEERING COMMUNITY ARE ON THE HORIZON.

Our Q&A (page 10) features Jill Seebergh '89, a Principal Senior Technical Fellow at Boeing with a focus in materials and coatings. The chemical engineering alumna has built a reputation as a strategic technical leader and a strong proponent of the value of mentorship and developing talent into interdisciplinary thinkers and leaders: people she calls "π-shaped engineers."

Finally, on page 22, we celebrate the ingenuity and determination of a group of students who have led the Lehigh University Space Initiative (LUSI) to a successful liftoff. The team designed and built Lehigh's first Mars rover and is developing a CubeSat proposal to submit to NASA. These students are indeed shining examples of the Future Makers that Lehigh and the Rossin College seek to train and inspire to shape the world's future.

As always, thank you for your support of Lehigh Engineering and the Rossin College. Please drop me a note with your comments.

Stephen P. DeWeerth, *Professor and Dean*
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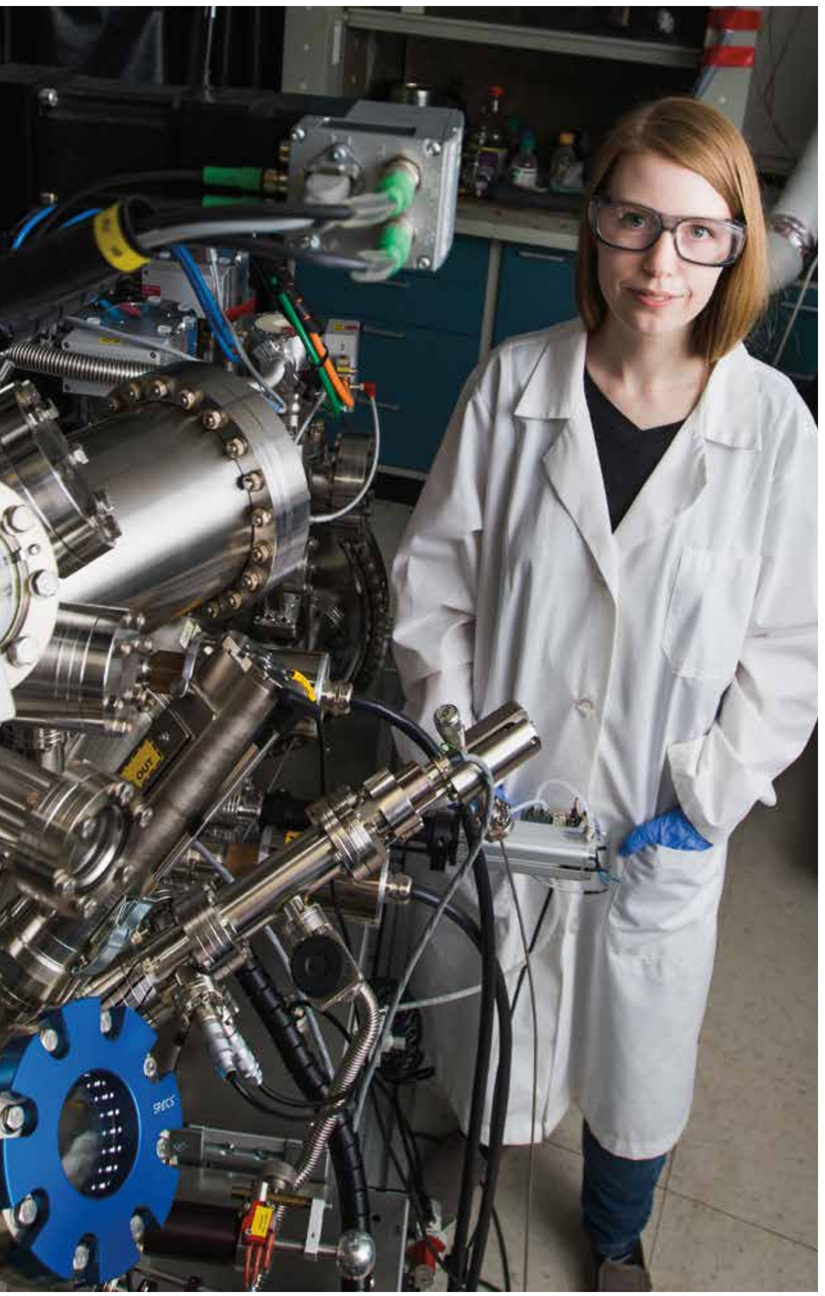
INSPIRING THE FUTURE MAKERS



Future makers are people who are inspired to think deeply and create grounded, pragmatic solutions through research and scholarship, says Lehigh President Joseph J. Helble ’82.

Our new strategic plan, *Inspiring the Future Makers*, provides the foundation for the next 10 years of excellence at Lehigh University. Our community has always sought to inspire deep thinking and address real-world problems, especially through the intersection of technology and humanity. Today, that approach is precisely what our world and future need more than ever.

The plan’s key initiatives, detailed here, define specific projects and actions that will determine where Lehigh will make investments in the Rossin College and throughout the entire university.

KEY INITIATIVES

REDEFINE A DEEPLY INTERDISCIPLINARY EDUCATION

All Lehigh students will be able to participate in boldly interdisciplinary programs and access the educational opportunities available across the university. They will embrace their intellectual curiosity, explore diverse academic programs, and develop both the timely and timeless skills needed for long-term professional and personal success. We will expand inter-college programs for undergraduates. We will transform PhD education to be student-centered and provide specific training relevant to the full range of PhD career pathways.

“Today’s most pressing issues require solutions that defy traditional boundaries and bring together academic disciplines. Students taught to incorporate different modes of addressing and surmounting challenges into an integrated whole—these are Renaissance thinkers for the modern world.”

—Susan Perry, Professor of Practice and Assistant Dean for Academic Affairs

LEFT AND RIGHT: CHRISTA NEU; TOP: TAYLOR STAKES

INVEST IN STRATEGIC INTERDISCIPLINARY RESEARCH

Critical problems require a holistic approach to problem-solving. Lehigh will make key investments in faculty hires, facilities renovation and construction, and support for the development of large grant proposals. We will build an interdisciplinary structure that supports high-paced, high-reward research. We aim to double our research output within 10 years.

“Lehigh is poised to rapidly expand the reach and impact of innovative work conducted across our university’s dynamic research community by focusing our efforts on key areas such as health, sustainability, and related socioeconomic impact, with insight provided by such technologies as data science and machine learning.”

—John Coulter, Professor and Senior Associate Dean for Research and Operations

LEAD IN EDUCATIONAL INNOVATION

Lehigh will apply learning science and “Universal Design for Inquiry” (UDI) to innovate the classroom experience, maximize learning, and personalize education for each student. To institutionalize innovation in academic programs, we will develop an incubator where faculty and staff can focus on creation of the most innovative new programs and approaches to student learning and thriving, in an environment where they are supported and inspired.

“Since Lehigh’s founding, our institution has been known for producing opportunities for active learning that enable deep intellectual connections to form in the minds of students. Novel, data-driven ways of supporting, enhancing, and growing this mindset will find eager partnership and participation across our faculty.

—Kristen Jellison, Professor and Associate Dean for Faculty Development

TRANSFORM MOUNTAINTOP CAMPUS

Lehigh will fully activate the 740-acre Mountaintop campus and transform it into a vital destination and resource for the Lehigh community and beyond. We will use Mountaintop as a location for big and messy work. We will explore the creation of a graduate student and postdoc village, spaces for corporate partnerships, inviting outdoor areas, and retail and community event space.

“Mountaintop’s history is steeped in cutting-edge research—and so is its future. Modern facilities will anchor a vibrant campus that revolves around living, learning, and making. Breakthroughs in areas such as sustainable energy, resilient infrastructure, robotics, and artificial intelligence will happen here.”

—Stephen P. DeWeerth, Professor and Dean

ENHANCE THE SHARED BETHLEHEM EXPERIENCE

Lehigh will expand our partnerships and community engagements throughout Bethlehem’s South Side and the Asa Packer campus, enriching the community and expanding our impact. We will create opportunities for the community to come together and have shared experiences on and off our campus.

“Through our successful CHOICES camps and many faculty-led outreach projects that take place across our college, we are developing an expanding set of programs and modules to spread the joy of STEM to our local community and the greater Lehigh Valley region.”

—Chayah Wilbers, Outreach Program Manager

CULTIVATE A LIFELONG LEHIGH

Lehigh will expand our graduate and professional offerings to be part of the lifelong learning experience. Lehigh will provide learning opportunities for alumni and for others who are seeking to gain new skills and credentials, and advance in their profession and life.

“Lehigh’s legacy of academic excellence shines through at all levels as students pursue their passions and elevate their careers. Our approach emphasizes collaborative study and personal connectivity, building meaningful and lasting relationships within our close-knit alumni community.”

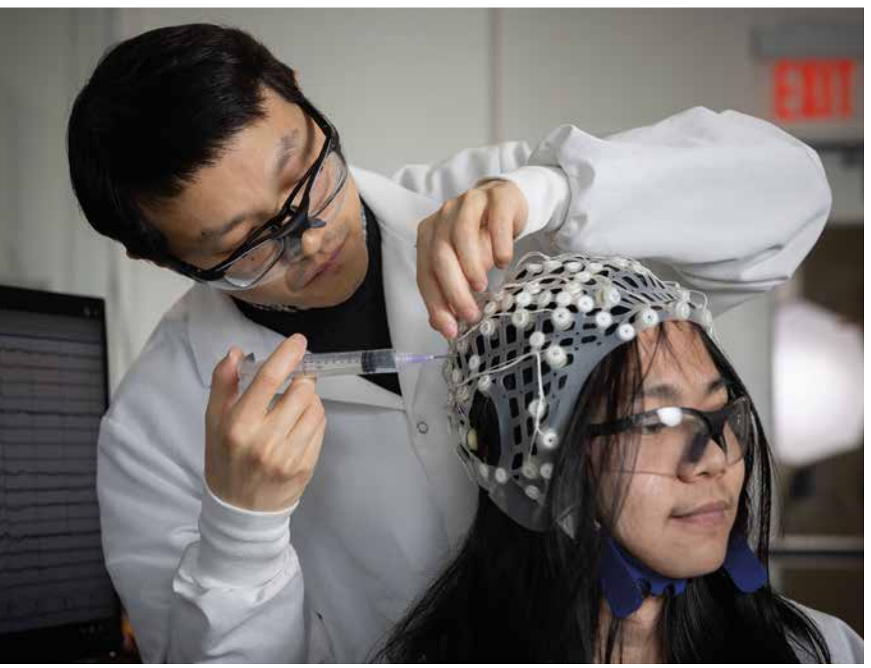
—David Stiles, Director of Development

Read Lehigh’s new strategic plan.

Pursuing a path to precision mental-health care

The study of biomarkers in the brain—powered by cutting-edge machine learning techniques—could redefine the way mental health conditions are categorized and diagnosed and lead to more effective, personalized treatments.

That's the goal of Yu Zhang, an assistant professor of bioengineering and electrical and computer engineering who recently landed major support from the National Institute of Mental Health, a division of the National Institutes of Health. The two grants, which total nearly $4 million, will fund two projects searching for biomarkers using brain imaging and machine learning to improve diagnosis and treatment outcomes for patients with mental health disorders.



Zhang (left) tests his lab's EEG system with PhD student Alex Zhao.

In basic terms, a biomarker is a sign of some type that indicates a medical state and can be measured.

The first study aims to improve the treatment of depression. Antidepressants are the primary form of treatment, but they are effective in only about half of patients who take them, says Zhang, who leads Lehigh's Brain Imaging and Computation Laboratory.

"Traditionally, medical professionals use a combination of behavioral and clinical symptoms to diagnose depression, and those symptoms are fairly subjective and cause substantial heterogeneity in the patients," he says. "Our goal is to build objective biomarkers using brain imaging and machine learning that better capture the brain's dysfunction. Those biomarkers will essentially enable us to predict whether a patient will respond to medication based on their brain circuits, and that will help guide personalized intervention."

Zhang and his team, which includes collaborators from Dell Medical School at the University of Texas at Austin, the Perelman School of Medicine at the University of Pennsylvania, and Stanford University School of Medicine, will utilize data from a double-blind randomized placebo-controlled clinical trial for the biomarker establishment. Those data, including functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) collected from patients prior to treatment, will be used to train a machine learning model to identify biomarkers in the brain.

"Instead of single brain regions, the biomarker we are looking for is characterized by the interaction between different regions and between brain imaging modalities," says Zhang. "We're looking at large-scale brain networks related to a variety of psychiatric disorders, mainly involving cognitive working memory and emotional regulation. We hypothesize that the interaction between these intrinsic brain networks might reveal informative biomarkers that can predict individual-level treatment response."

Essentially, he says, the degree of interaction between the networks may indicate the degree by which a person would respond to medication.

While the team is looking only at selective serotonin reuptake inhibitors, or SSRIs, the ultimate goal, he says, is to fine-tune the model so it can predict a person's response to other compounds.

Their AI-guided biomarker would not only deliver a personalized approach to treatment, he says, but also replace the current trial-and-error treatment strategy that wastes time and money.

"Often, for patients, time is even more important than money," says Zhang. "So combining cutting-edge artificial intelligence with brain imaging could really drive a novel treatment solution that helps people quickly, and gives them greater confidence about their treatment. This could be a form of precision mental-health care that could offer patients real hope."

Zhang's second newly funded study will also use brain-imaging data to identify biomarkers, this time to redefine the classification of mental disorders.

Currently, mental health conditions are grouped according to subjective behavioral and clinical assessments and self-reported questionnaires, says Zhang. The result is that within a single diagnostic category such as autism, the range of symptoms can be vast.

Redefining the classification system could facilitate the development of more effective treatments, says Zhang. Right now, patients diagnosed with a specific disorder are generally treated with a one-size-fits-all approach. Some patients will respond well, but others won't respond at all, and still others may experience adverse reactions. And that's because of the wide variation in how their brains work. If the system could be more fine-tuned, treatments such as medication, psychotherapy, and neuromodulation therapy could be better dialed toward specific needs.

"THIS COULD BE A FORM OF CARE THAT COULD OFFER PATIENTS REAL HOPE."

—Yu Zhang

"Right now, a diagnosis is like a hard label, but explaining these conditions along a spectrum will help us identify subpopulations within a clinical sample," he says. "Once we identify them, we can further study their unique and shared brain abnormalities, and better understand what treatment will be most useful for that specific subtype."

THIS PAGE: DOUGLAS BENEDICT/ACADEMIC IMAGE; OPPOSITE PAGE: TOP: CHRISTA NEU; BOTTOM: ISTOCK/MY PHOTO BUDDY

A boost for tissue engineering

NIH award supports a range of projects over five years

Rather than funding individual research projects, the National Institutes of Health's Maximizing Investigators' Research Award (MIRA) supports labs.

The five-year grant was developed in 2015 to give investigators greater stability and flexibility to increase their efficiency and potential for scientific breakthroughs.

"You can essentially work on anything your lab does," explains Kelly Schultz, an associate professor of chemical and biomolecular engineering, who received a $1.87 million MIRA last year.

For Schultz, that means a variety of tissue engineering endeavors. One of her main focus areas is researching how stem cells interact with synthetic materials. The ultimate goal is to create implantable materials that can deliver stem cells to restart or enhance tissue regeneration, particularly for wound healing.

Since receiving the MIRA, Schultz and her team have made significant progress: They've completed initial characterization of a new material and begun work on a paper for one of the proposed projects. Late last year, she hired two more students.

The award supports work on not only characterization of cell-material interactions but numerous other projects, including studying materials that mimic the reorganization of tissues and how adhesion changes the motility of cells. She will also be able to continue and combine work on stiffness and chemical gradients that was funded by the NSF and the NIH—funding that finishes out this year.

"A wound will secrete different chemicals to essentially tell other cells to come and help," she says. "And there's a gradient there, where the chemical is more concentrated where it's being secreted. The stem cells will react to that and migrate toward higher concentrations. So with the next phase of this work, we'll be combining stiffness gradients with chemical gradients, and looking at ways we can use them together to control the cells."

Learn more about the Schultz Lab in this video.

New approach can predict risk of power line ignition

To prevent power systems from starting wildfires, California electric utilities are authorized to conduct preemptive Public Safety Power Shutoffs (PSPS), which cause blackouts that affect millions of people.

"When preventive Public Safety Power Shutoffs are executed, they cause major issues for businesses in the area," explains Paolo Bocchini, a professor of civil and environmental engineering and founder of Lehigh's Catastrophe Modeling Center. The center was established in 2021 to advance world-class research on the resilience of interdependent infrastructure systems against natural disasters. When Bocchini was approached by a California software company to investigate the policies—and determine if the risk justifies the negative impacts—he saw an opportunity to better understand the mechanical behavior of conductor cables in extreme wind conditions.

When is a PSPS necessary? And can wildfires caused by contact between vegetation and a power system be prevented? New research from Bocchini and doctoral student Xinyue Wang, published in *Scientific Reports* (a *Nature* publication), provides methodology for predicting at what point power line ignition is likely during a storm with high winds. Through a systematic analysis of the conductor dynamic response under strong winds, the researchers found that it is possible to predict the risk of power line ignition. They explain that encroachment probability is highly sensitive to vegetation clearance and wind intensity. And the duration of the wind event must be taken into consideration as well.

"Our study is the first of its kind applying a rigorous probabilistic approach to the problem, including consideration of the mechanical behavior of the conductor cables under strong wind," says Bocchini. "This work can assist decision-makers in determining if a PSPS is warranted, as well as vegetation managers in allocating resources in such a way that effectively minimizes risk."

Previous work mostly used data-driven approaches based on historical ignition records. "In contrast, our research looks at the physical and dynamic interactions between the vegetation and the conductors, in a probabilistic way," says Wang.

The researchers hope to see an impact on policy or practice that goes beyond the wildfire itself. "Since wildfires are closely related to climate change," says Wang, "I think that broader and larger efforts may be needed to fundamentally solve the wildfire problem in California."

Lehigh takes on regional role in expanding energy audits, job training

The Lehigh University Industrial Assessment Center is growing into the Mid-Atlantic Regional IAC Center of Excellence (MARICE) with new funding from the Department of Energy.

Lehigh's IAC was established in 2001 as part of the DOE's nationwide Industrial Assessment Center Program to save energy, reduce waste, and enhance productivity for manufacturing plants in Pennsylvania, New Jersey, and New York.

The center, which was most recently renewed in 2021, is led by two mechanical engineering and mechanics faculty members, Professor Alparslan Oztekin and Professor Emeritus Sudhakar Neti.

The $3.75 million grant stems from the Bipartisan Infrastructure Law. It creates regional IAC centers of excellence to help establish pathways to high-quality jobs, improve manufacturing competitiveness, and reduce industrial emissions. The funding will be split between Lehigh and West Virginia University over the next five years.

"Lehigh's IAC has long provided energy audits for small- to medium-sized plants to make them more competitive while simultaneously providing real-world training for our students in conducting those audits," says mechanical engineering PhD student Abhinay Soanker '15G.

He and fellow mechanical engineering PhD candidate Justin Caspar '19 served as lead students on the Lehigh IAC team and co-wrote the proposal that secured the grant funding. The Lehigh IAC currently supports six PhD students; with this new award, that number will increase by three or more.

"WE'LL BE DEVELOPING A WORKFORCE THAT GOES BEYOND LEHIGH."
—Abhinay Soanker '15G

"One of the major components of our proposal," says Soanker, "was that we wanted to go beyond Lehigh to train the students and professionals who might not have access to resources like these." He says that idea aligns with the federal government's Justice40 Initiative, which addresses historical underinvestment in disadvantaged communities.

Soanker contacted local organizations such as trade schools, community colleges, labor unions, nonprofits, and chambers of commerce for their support. The MARICE team, including Soanker and Caspar, will use the DOE funds in part to conduct training sessions with these groups in areas such as energy efficiency, sustainability, variable frequency drives, HVAC systems, and building management systems. The goal is workforce development in underserved communities.

"We want to train our students to conduct these assessments to provide value and competitiveness to these plants," says Caspar. "The skills they learn can help these companies reduce their operating costs by reducing their energy consumption, and depending on the size of the plant, that can add up to tens of thousands of dollars."

And when those industries are located in disadvantaged areas, the savings can trickle down into the communities themselves, says Soanker.

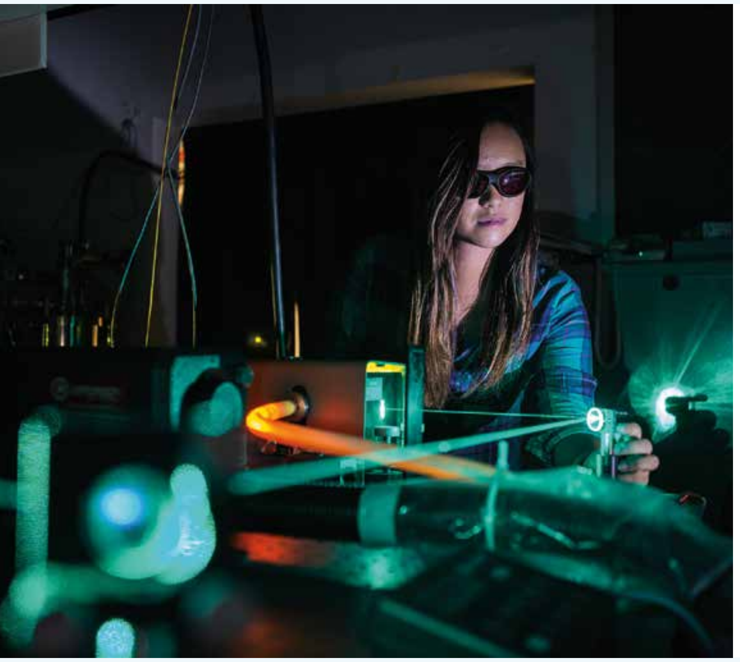
"Lehigh's IAC already has a track record of serving industries in these communities," says Caspar. "They made up about 33 percent of our audit visits last year. So with this grant, that's a metric that we're looking to improve—to enhance the community benefits and the carbon and energy savings associated with the center. "

Partnering with the West Virginia University IAC will enable the two institutions to cover the mid-Atlantic region, strengthening their mutual impact.

The grant will also enable Lehigh's IAC to develop additional tools to measure energy use and calculate savings.

For Soanker and Caspar, who've both been involved with Lehigh's IAC throughout their graduate studies and have conducted nearly 200 assessments between them, the grant has validated the critical work the center has been doing for decades: developing real-world teaching skills, making local industries more efficient, helping communities prosper, and reducing carbon emissions. With the MARICE designation, that impact will grow stronger.

"It means so much to me to know that we will be developing a workforce that goes beyond the university," says Soanker, "and will directly affect communities across the mid-Atlantic."



CREATING OPPORTUNITIES IN PHOTONICS

Lehigh will partner in a regional consortium funded by the National Science Foundation to advance photonics research and workforce development.

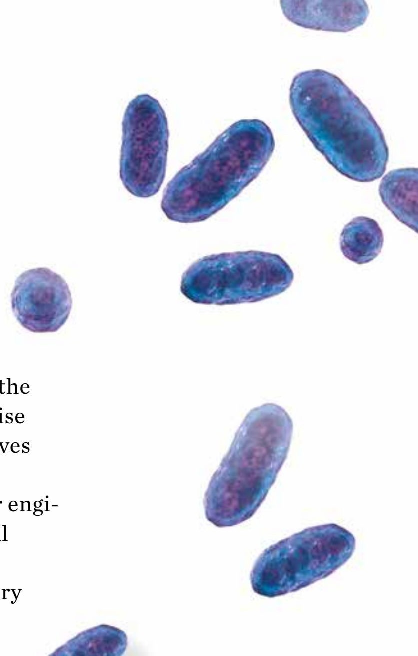
A development grant from the NSF's Regional Innovation Engines program awarded to Princeton University will fund planning for a multistate initiative to advance research in lasers, fiber optics, and other light-based innovations while creating economic, societal, and technological opportunities.

The grant will lay the groundwork for a collaboration called Advancing Photonics Technologies that aims to advance research, transition discoveries into the economy, and build the region's technological workforce.

Lehigh is one of nearly 30 entities from higher education, industry, state economic development agencies, and Entrepreneurial incubators and accelerators collaborating on the effort. Materials Science and Engineering Professor Himanshu Jain, Lehigh's T.L. Diamond Distinguished Chair in Engineering and Applied Science and director of the Institute for Functional Materials and Devices (I-FMD), will co-lead a working group on photonics research and development.

LEFT: CHRISTA NEU; TOP: ISTOCK/CHINAFACE

Filling a need for targeted treatment of gum infections

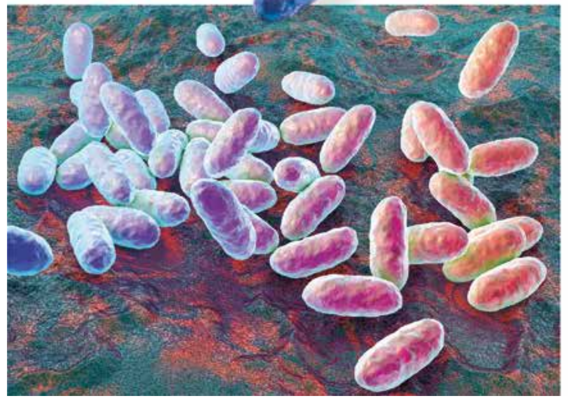


Novel delivery system could help slow the advance of antibiotic resistance

Aggressive periodontitis is a severe type of gum infection that causes the destruction of ligament and bone and can lead to tooth loss in otherwise healthy individuals. The traditional treatment approach usually involves deep cleaning and antibiotics.

Angela Brown, an associate professor of chemical and biomolecular engineering, and her team were recently awarded a grant from the National Institutes of Health to pursue a novel treatment alternative.

The funding supports the development of a nonsurgical drug delivery system that will enable the controlled delivery of antibiotics to treat aggressive periodontitis in adolescents.



"The way these infections are typically treated is by scaling and planing, which essentially means scraping off the bacteria, and then prescribing oral antibiotics," says Brown. "And while that tends to work, sometimes the bacteria come back, and then you have to start the course of antibiotics all over again. The more frequently you take antibiotics, the greater the chances the bacteria will become resistant to them."

Antibiotic resistance is indeed a growing problem. According to the Centers for Disease Control and Prevention, more than 2.8 million antimicrobial-resistant infections occur every year in the U.S., and more than 35,000 people die as a result.

"OUR APPROACH COULD SOLVE PROBLEMS WITH BOTH ANTIBIOTIC RESISTANCE AND DISEASE." —Angela Brown

In previous work, Brown and her team have shown that antibiotics can be encapsulated in liposomes—tiny, round vesicles that contain one or more membranes and can be used as a delivery mechanism. They've also shown that leukotoxin, the toxin released by the periodontitis-causing bacteria, triggers the release of the antibiotics.

"Leukotoxin fights the body's immune response by binding with cholesterol in the membrane of white blood cells, disrupting the membrane and killing the cells," she says. "So we're creating a liposome that has cholesterol, and we're hoping that all or most of the toxin will bind onto the liposome instead of the host cells," says Brown. "When the toxin binds to the liposome, it should cause a release of the antibiotics, killing the disease-causing bacteria."

This grant will support the cell culture work her lab will perform to determine if the approach can protect the host cells from the toxin while simultaneously killing the bacterial cells. They will do this using a "co-culture" model, in which human immune cells and bacterial cells are grown together.

The ultimate goal, she says, is to provide an alternative method of delivering antibiotics to treat aggressive periodontitis.

"We'd also like to continue showing the advantages of using controlled delivery strategies for antibiotics. And because this toxin we're working with is closely related to those that cause diseases like whooping cough and cholera and *E. coli* infections, this approach could be useful against a range of bacteria," she says. "This is our first externally funded project to do this work, and it validates the idea that this technique has a lot of potential to solve problems with both disease and with antibiotic resistance."

Brown discusses her lab's efforts to develop new strategies to fight bacterial infections on the Rossin Connection Podcast.

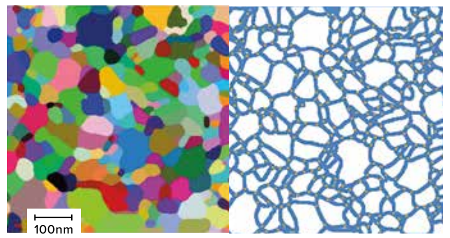
ILLUSTRATION: ISTOCK/DR_MICROBE

Forming a clearer picture of 'grain growth'

Interdisciplinary team tackles hot topic in materials science

Want to make better materials? Read between the lines. Or the "grain boundaries," as they're known in materials science.

The orientations of these infinitesimally small separations between individual "grains" of a polycrystalline material have big effects. In a material such as aluminum, these collections of grains (called microstructures) determine properties such as hardness.



An automated tracing (right) shows grain boundaries and triple junctions corresponding to a representative microstructure for an aluminum film (left).

New research is helping scientists better understand how microstructures change, or undergo "grain growth," at high temperatures.

A team of materials scientists and applied mathematicians developed a mathematical model that more accurately describes such microstructures by integrating data that can be identified from highly magnified images taken during experiments. Their findings are published in *Computational Materials* (a *Nature* publication).

The research team included Jeffrey M. Rickman, Class of '61 Professor of Materials Science and Engineering at Lehigh; Katayun Barmak, Philips Electronics Professor of Applied Physics and Applied Mathematics at Columbia University; Yekaterina Epshteyn, a professor of mathematics at the University of Utah; and Chun Liu, a professor of applied mathematics at the Illinois Institute of Technology.

"Our model is novel because it is given in terms of features that can be identified from experimental micrographs, or photos that reveal the details of these microstructures at a length scale of nanometers to microns," says Rickman. "Because our model can be related to these experimental features, it is a more faithful representation of the actual grain growth process."

The researchers conducted crystal orientation mapping on thin films of aluminum with columnar grains and used a stochastic, marked point process to represent triple junctions, points where three grains and grain boundaries meet in the structure. Their model is the first to integrate data on the interactions and disorientations of these triple junctions to predict grain growth.

Predicting grain growth is key to the creation of new materials and is a pivotal area of study in materials science. As a result, many models of grain growth have been developed. However, the project's direct link between the mathematical model and the experimental micrographs is highly distinctive.

According to Rickman, linking the model directly to features that can be tracked during experiments will benefit computational materials scientists who model the kinetics of grain growth.

"Ultimately, this research provides a way to better understand how grain growth works and how it can be used to inform the development of new materials," Rickman says.

The research was funded by the National Science Foundation's Designing Materials to Revolutionize and Engineer Our Future program.

HYBRID SIMULATION STIRS WINDS OF CHANGE

The Lehigh Real-Time Multi-Directional Hybrid Simulation facility enables researchers to combine physical experiments with computer-based simulations to evaluate the performance of systems subjected to natural hazards—and develop strategies to improve resilience.

In the past, the facility, which is located in Lehigh's ATLSS Engineering Research Center and is part of the NSF-funded Natural Hazards Engineering Research Infrastructure (NHERI) network, has focused on earthquakes. In collaboration with Florida International University (FIU), Lehigh has migrated toward applying real-time hybrid simulations to wind natural hazards that occur under hurricane conditions. "This is going to revolutionize wind-tunnel testing," says James Ricles, the Bruce G. Johnston Professor of Structural Engineering, who leads the NHERI Lehigh Experimental Facility. "It's impossible to bring a skyscraper into the laboratory, so we are linking a structural model in a computer with a physical aeroelastic model in the lab to capture fluid-structure interaction effects in a more accurate manner."

Earlier this year, Lehigh researchers and members of FIU's Wall of Wind facility and Multi-Hazard Engineering Collaboratory on Hybrid Simulation held a two-day workshop in Miami. The focus was on using real-time hybrid simulation to achieve a fuller picture of the impact of high winds on tall buildings. It included a 30-minute live demo of advancements in hybrid simulation to investigate and moderate wind-induced vibrations of a 40-story building. Lehigh participants included Ricles and research scientists Liang Cao and Thomas Marullo.

The workshop at FIU featured a demonstration of real-time aeroelastic hybrid simulation involving a 40-story building subjected to a storm with 170 MPH winds.

OPPOSITE PAGE, TOP: COURTESY OF LEHIGH UNIVERSITY; BOTTOM: LIANG CAO; THIS PAGE, TOP: ISTOCK/JACOB WACKERHAUSEN, BIBICA

Beating osteoarthritis with biomaterials

New technique could lead to breakthroughs in early-stage interventions

Osteoarthritis affects nearly 70 percent of adults over 65. The degenerative joint disease causes pain and reduced joint function. Early intervention is key to maintaining mobility and improving quality of life, says Lesley Chow, an associate professor of bioengineering and materials science and engineering. But currently, early-stage interventions are not effective at regenerating cartilage and delaying or preventing the need for joint replacements. By taking a biomaterials-based approach, Chow hopes to change this.

Earlier this year, Chow and Dr. Gregory Carolan of St. Luke's University Health Network (SLUHN) received a grant from the National Institutes of Health to engineer biomaterials that promote cartilage tissue regeneration to prevent the onset of osteoarthritis.

Chow, building on previous research, is combining her expertise in 3D printing and biomaterials design to develop scaffolds for tissue repair. With this work, the researchers aim to make a scaffold that's simple enough to implant using tools and procedures that are currently used by orthopedic surgeons.

Cartilage cannot regenerate on its own, explains Chow, and medical intervention is necessary to mimic the same properties as native tissue.

"WE'RE THANKFUL TO THOSE WHO PAVED THE WAY FOR US TO DESIGN NEW BIOMATERIALS."

—Lesley Chow

The scaffolds will be designed with specialized chemistries that enable the spatial and temporal delivery of bioactive peptides designed to mimic growth factors, or proteins that stimulate cell behavior. The team hopes that these scaffolds will promote cartilage regeneration to restore joint function.

"This project takes advantage of click chemistry, which allows us to attach bioactive molecules to our scaffolds at different times and in specific locations in the presence of cells. We can therefore simulate dynamic changes that the cells would have experienced during development to direct native-like cartilage formation," explains Chow, noting that chemists Carolyn Bertozzi, Morten Meldal, and K. Barry Sharpless were awarded the 2022 Nobel Prize in Chemistry for developing click chemistry and bioorthogonal chemistry. "We are very thankful to these pioneers who paved the way for us to design new and exciting biomaterials."

Partners in the project include Carolan, who is section chief of orthopedic sports medicine and shoulder surgery at SLUHN; Félix Gerardo Ortega Oviedo, a PhD student in the Chow Lab; and undergraduate student Fenet Demissie '24.

"Effective treatment options for articular cartilage injuries have been a major topic of research and innovation in orthopedic surgery for decades," says Carolan. "Despite this focus, the treatment options currently available are unable to reproduce the pre-injury state of the damaged articular cartilage and as such, surgeons are not able to provide our patients with the outcomes that they wish to achieve. This project uses a novel approach of 3D-printing technology to manage these challenging injuries."

The research team hopes this development will lead to breakthroughs in early-stage interventions, improving the quality of life early on for those affected by osteoarthritis.

"This project has the potential to completely change how we address and treat these debilitating injuries and may finally provide surgeons the ability to truly 'repair' articular cartilage," Carolan says. "This would be a major advancement in patient care and would be applicable to millions of patients with these injuries in the United States of America alone."

In this video, Chow explains how her lab is helping people move better.

INTERVIEW BY KATIE KACKENMEISTER

AERIAL VIEW

From the upper echelon of R&D at Boeing, chemical engineer Dr. Jill Seebergh ’89 propels materials innovation and fosters a culture of mentorship

As a Principal Senior Technical Fellow, Jill Seebergh ’89 ranks among the top members of Boeing’s executive technical leadership. Over her 26-year career at the global aerospace giant, Seebergh has applied her expertise in adhesion and interface science, multifunctional coatings, and nanomaterials to make safer, more efficient aircraft and improve manufacturing processes in support of the company’s wide-ranging sustainability goals. She also provides strategic technical leadership while placing particular emphasis on mentoring colleagues across the corporate enterprise. “We’re in a moment when there are big disruptors driving a lot of exciting technology development in aerospace,” says the Lehigh chemical engineering alumna, who holds nine U.S. patents and a PhD and master’s degree from the University of Washington. “I bring a chemical technology perspective to the table, but interdisciplinarity is the name of the game. Approaching big problems requires lots of different skills and people from different backgrounds working together.”

Q: What are some of the applications of your research?

A: Most of my career has been focused on developing new coating materials and processes and implementing them on products that Boeing makes across its commercial aviation and defense and space units. I’ve worked on environmentally preferred surface treatments and coatings—reducing the amount of solvents used, eliminating hazardous materials, and focusing on using less water and energy.

Other applications of my research relate to the durability of materials, for example, more durable exterior coating systems for airplanes, like the paint used in the decorative designs. We’ve extended the service life of those materials by two to three times. Now airlines don’t have to repaint as often or do as much maintenance.

I have also worked on coatings that reduce the buildup of ice on surfaces. It’s a passive means of ice protection that saves energy and doesn’t add much weight on the aircraft. And then with the pandemic, there has been an increased focus on “healthy travel” by designing aircraft cabins with features like antimicrobial coatings and other technologies that help protect passengers from communicable diseases.

Q: What is the Boeing Technical Fellowship?

A: The Fellowship provides a career pathway for technical experts who have demonstrated innovation and problem-solving skills, as well as an aptitude for leadership, mentoring, and teaching—and who have a technical vision of the future. When I joined Boeing, I worked alongside and was mentored by Fellows and saw them doing projects with universities, serving on industry committees, and going to conferences to give technical presentations. I saw them being engaged outside of Boeing, while also leading the technology projects and setting a lot of the strategic direction. That inspired me to pursue the same career path. Now, having reached the executive level of the Fellowship, I have responsibility for helping to set technical strategy and working with programs and senior leaders across the company.

Q: What role does mentorship play in your position?

A: I’ve come to appreciate how vital mentoring is at every stage of education and career level. I definitely had mentors at Lehigh who gave me advice and the chance to conduct research, and who coached me on giving presentations and putting together research reports. In my career, I’ve mentored everyone from the interns and new employees up through experienced people who are Fellows and managers. And I have mentors as well, because even after 26 years, you always need people to bounce ideas off of.

Mentoring goes beyond giving people advice on going back to school or career-life balance. It includes providing practical help like reviewing an abstract or a conference presentation, but it’s more than just that. You have to actively find opportunities for people. It’s not enough to schedule a weekly half-hour meeting to dispense wisdom.

At this stage in my career, I am in a better position to see opportunities for others and take action. I recently nominated one of my mentees to attend a National Academy of Engineering symposium. It wasn’t even on her horizon. But she got accepted. Doing things like that is so important. A lot of people talk about training the next generation, and that is truly needed. But I’m also interested in helping people find their passion.

Q: How does the growing emphasis on sustainability influence your work?

A: Sustainability has become a big focus everywhere in the past three to five years or so, but I’ve been working on some aspects of it for as long as I’ve been at Boeing. The aviation industry has set the ambitious goal of achieving net-zero carbon emissions by 2050. We are working on sustainable aviation fuels, which is a first step toward decarbonizing the aerospace industry because for large commercial airplanes, the technologies for electrification and hydrogen are not there yet and may take decades.

But sustainability is not just about reducing CO_2 emissions when airplanes fly. It’s a life-cycle approach. That means thinking about sustainability in the design of the aircraft, its parts, and its technologies. We need sustainable manufacturing operations and maintenance approaches, and then at the end of the life of the aircraft, recycling and reuse, to drive circularity.

Future aircraft designs will incorporate more lightweight materials, including new metal alloys and thermoplastic composites, and more additively-manufactured parts. The resins and fibers that are used to make composites and coatings and sealants will start to be made from non-petroleum feedstocks. It’s going to be a big transition, not just in the aerospace industry, but in every industry connected to the manufacture of airplanes.

A lot of my work has been aimed at reducing hazardous waste by developing new primers and surface treatments that don’t contain, for instance, hexavalent chromium, which is a very good corrosion inhibitor but is also very toxic. We want to reformulate those materials to eliminate the hazardous chemicals and implement processes that are friendlier to people. For example, we sand a lot of surfaces to prepare them for painting and sealing and bonding. People do that work. We’re trying to eliminate or automate sanding processes so that the work is more ergonomic and safer.

We are also focused on reducing the amount of water and energy used in manufacturing processes. For example, coatings and sealants that cure at ambient temperature instead of elevated temperatures, or cure in seconds or minutes instead of hours, so that we’re not heating up giant parts in energy-intensive ovens or paint hangars. All of these things impact the whole sustainable life cycle.

> “Today’s engineers need to be π-shaped, rather than T-shaped. A π-shaped engineer has an additional ‘leg’ that represents proficiency in data science and machine learning.”

There is a lot of R&D that goes into solving those problems. It’s an incredible challenge, but also one that the whole world is getting behind.

Q: What advice would you give to engineering students and early-career professionals?

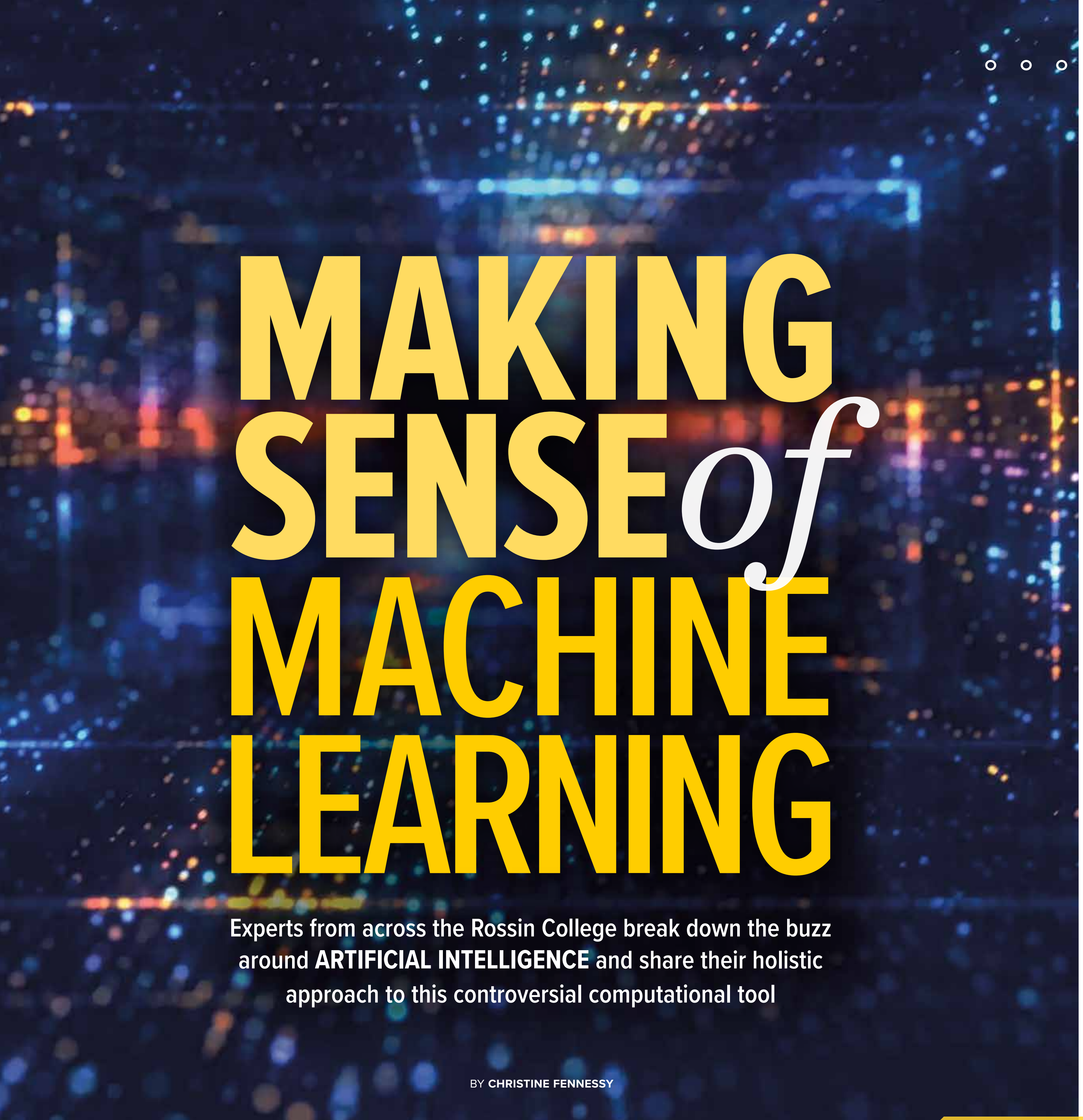
A: Choosing a major seemed like such a big decision, but in practice, the boundaries on what you can do with a given engineering degree are very wide. Some of the work I do could also be done by a materials scientist or a chemist. There’s not a wrong decision if students are struggling between, say, choosing mechanical or civil or environmental engineering, because there’s a lot of overlap of what backgrounds you can bring in to do certain jobs.

Today’s engineers need to be π-shaped, rather than T-shaped. The idea is that a T-shaped engineer has deep expertise in a single field (represented by the vertical line) combined with knowledge in other engineering fields and the ability to collaborate across disciplines (represented by the horizontal line). A π-shaped engineer has an additional “leg” that represents proficiency in data science and machine learning. It’s not enough to be “just” an engineer, and in my case, a chemical engineer—you also need skills in collaboration, communication, and analytics.

My work at Boeing supports chemical technologies, but I don’t just work with chemical engineers and chemists. There are also materials scientists, physicists, applied mathematicians, and mechanical engineers on my team, and we collaborate with experts in other fields, for example, structural engineering and flight sciences. We work with our intellectual property team. We work with our supply chain team. You need that diversity of disciplines and cross-functional teamwork to find innovative solutions.

Anti-icing coatings developed by Seebergh’s team were tested on the 2014 Boeing ecoDemonstrator, a 787-8 Dreamliner.

PHOTOS COURTESY OF BOEING



MAKING SENSE *of* MACHINE LEARNING

Experts from across the Rossin College break down the buzz around **ARTIFICIAL INTELLIGENCE** and share their holistic approach to this controversial computational tool

BY **CHRISTINE FENNESSY**

There's recently been a surge of media coverage around machine learning and artificial intelligence (AI). And you would be forgiven for thinking they're essentially the same thing, as the terms are often used interchangeably.

"They overlap, but for those of us who work in this space, they are distinct," says professor Brian Davison, chair of the Department of Computer Science and Engineering (CSE). "AI is an umbrella term that encompasses any computing technique that seems intelligent, and one technique under that umbrella is machine learning."

More specifically, artificial intelligence is the development of systems that are capable of mimicking human intelligence to perform tasks such as image, speech, and facial recognition; decision-making; and language translation. These systems are capable of iterating to improve their performance. Programmers and developers build them with tools that include machine learning, deep learning, neural networks, computer vision, and natural language processing—all of which allow the systems to simulate the reasoning humans use to learn, problem-solve, and make decisions.

As a subfield of AI, machine learning employs algorithms to enable computers to learn from data to identify patterns and then do something with that recognition, such as make a prediction, a decision, or a recommendation. Examples of artificial intelligence that uses machine learning are vast and include virtual assistants, navigational systems, recommendation systems (think Netflix), and chatbots like ChatGPT.

To some, however, words like *intelligent* and *learning* can be fraught.

"The machine is *not* learning," says professor Larry Snyder, Harvey E. Wagner Endowed Chair in the Department of Industrial and Systems Engineering (ISE) and Lehigh's Deputy Provost for Faculty Affairs. "What it's doing is meant to emulate what a human brain does, but the machine is not intelligent. It's not smart. If we had called it something like 'algorithmic methods for prediction,' it would sound a lot less sci-fi—and a lot more accurate."

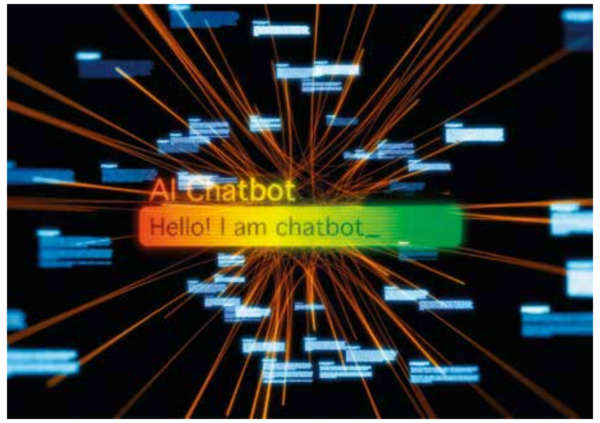
The distinction is important, especially in the era of ChatGPT, the large language model, or LLM, that uses deep-learning algorithms and enormous datasets to recognize, summarize, translate, predict, and generate content based on user prompts.

Two months after it launched last November, ChatGPT reached 100 million monthly active users, making it the fastest-growing consumer application in history, according to a UBS study. Just as fast came the backlash and concern, in particular over issues of privacy, security, intellectual property, disinformation, bias, education, and employment (see "Clouded Judgment," page 17).

In May, employees of ChatGPT's creator, OpenAI—including its CEO Sam Altman—joined journalists, lecturers, and other domain experts in signing a one-sentence "Statement of AI Risk." It reads: "Mitigating the risk of extinction from AI should be a global priority alongside other societal-scale risks such as pandemics and nuclear war."

Such a warning, however, may also be misleading.

"There are certainly reasons to worry about ChatGPT and other technologies like facial recognition, but we are very far off from a Terminator-type event where the systems of the world unite and turn against their creators," says Davison. "Almost all of the very cool things that we see today are about being able to do a specific thing. They aren't self-aware, they don't understand what they're doing, and they can't reason about what they're doing. Something like ChatGPT runs through patterns, then generates something, but it doesn't know that it generated anything. I'm a sci-fi person. I watch those movies, and I think those ideas are worth thinking about. But I don't think they're worth panicking about."



Davison says that tech companies will undoubtedly respond to the criticism, and ChatGPT and similar technologies (like Google's Bard and Microsoft's Bing) will only get better over time.

"We're going to be able to talk to our systems in ways that we haven't been able to do before, and for the most part, I think that will be an advantage, and an improvement over the way the world has been," he says.

> "If we had called machine learning something like 'algorithmic methods for prediction,' it would sound a lot less sci-fi—and a lot more accurate." —Larry Snyder

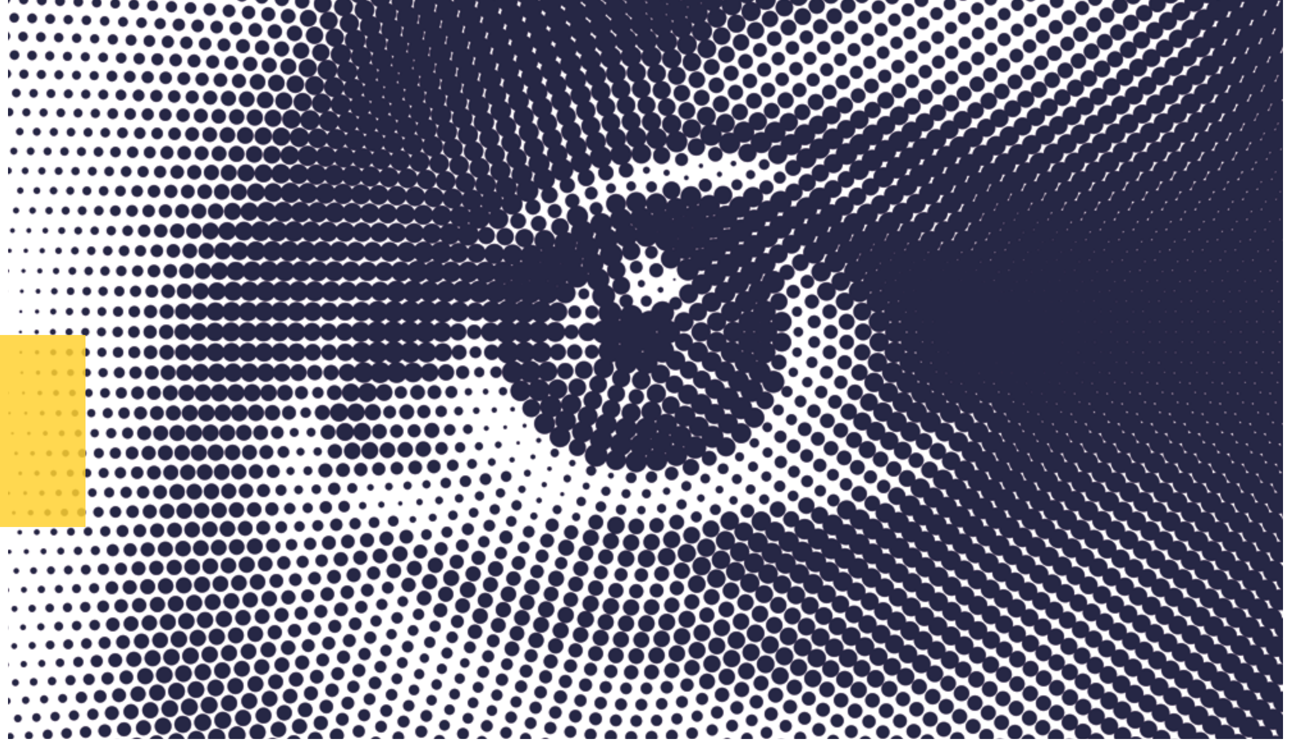
Improving the world, of course, is at the heart of the research ethos at Lehigh. Machine learning has been a tool of researchers here for decades and is a key focus area in Lehigh's Institute for Data, Intelligent Systems, and Computation (I-DISC). With advances in computational techniques and computer hardware, the potential for both discovery into the fundamentals of machine learning and applications of it are seemingly limitless. The projects showcased here are just a sample of the range of innovative work on campus, but they reflect the moment we're in: a world and a reality that is increasingly powered by AI, and that demands a more holistic approach to ensure a future that serves and protects all users.

LEFT: ISTOCK/BAHADIR EROGLU; RIGHT: ISTOCK/DEM10

THERE'S MORE TO THE STORY...

Continue reading online to get a wider picture of Rossin College research into the fundamentals of machine learning and how the technology is being used in fields such as manufacturing, medicine, finance, and renewable energy.

Scan the code or head to **engineering.lehigh.edu/ML** for the full story.



Lehigh researchers studying computer vision could help solve the problem of online visual misinformation.

DESIGNING FAIR ALGORITHMS

In machine learning, algorithms make the magic happen. Through a series of complex mathematical operations, algorithms train the model to essentially say, 'Okay, this input goes to that output.' Give it enough pictures of a cat (input), assign those pictures a label, "cat" (output), and eventually, the connection is made. You can feed the model images of felines it's never seen before, and it will accurately predict—i.e., identify—what animal it's "seeing." (Computers don't actually "see" the image, but rather numbers associated with pixels that mathematically translate into "cat" or "dog," or whatever it's being trained to recognize.)

"When we're born, our brains don't have all the connections that tell us how to identify a cat," says Frank E. Curtis, a professor of industrial and systems engineering. "We learn over time, through observation, through making mistakes, through people telling us, 'This is a cat.' Learning to make that connection is essentially an algorithm that we follow as people."

Taking learning to walk, for example. Our brains' algorithm tells us to move forward in a certain way. If we don't fall, we know we did something right, and we're ready to take the next step. If we trip, we try to correct what we did wrong so we don't fall the next time. The process continues until we've mastered the skill. "The algorithm is just a process of updating the model over and over again," says Curtis, "and trying to move it toward getting a higher percentage of correct predictions based on the data you have."

Curtis's research focuses on the design of algorithms—how to make them faster, more accurate, and more transferable across tasks, like a single algorithm that can do speech recognition across multiple languages. He's also started studying how to make them more fair. In other words, how to design them to make predictions that aren't influenced by bias in the data.

"There isn't going to be a perfect algorithm because there isn't going to be a perfect sense of what's fair and what's not," he says. "It's also important to remember that humans don't always do the best job either in making fair decisions."

The ramifications of bias are real. Take an algorithm designed to determine who gets a loan. The model is fed data that contain features, essentially bits of information. When it comes to fairness, Curtis says, the goal is to ensure that certain features aren't overly influencing the model's prediction. So, let's say race is scraped from the data. The model is then trained on data that might include other information, such as home addresses that correspond with certain populations.

"Even though you took the specific feature of race out," he says, "there still might be other features in the data that are correlated with race that could lead to a biased outcome as to who gets a loan and who doesn't."

Curtis wants to figure out how to guide algorithms to better balance the objectives of accuracy and fairness when building machine learning models. This notion of "balance" is essential because as long as bias of any amount exists in the data, he says, there's no way to build a model that's both fair *and* accurate. To do that would require incorporating fairness measures that are within socially acceptable amounts, a move that would require regulation of the algorithms themselves.

"Most governments haven't done that yet, but that would give us a guideline to work with," he says. "I can't tell you what the prescribed amount of bias should be—that's the job of policymakers. But if someone could tell me, I could design the algorithm to get us there."

EXPOSING FAKES

As you scroll through social media feeds, are you sure what you're seeing is real?

"The human visual system is very advanced, and we can easily recognize real-world objects," says Aparna Bharati, an assistant professor of computer science and engineering. "But online, we can very easily be fooled by high-quality fakes, and sometimes, even by the low-quality ones."

Bharati researches computer vision, an interdisciplinary field that enables computers to understand the visual world through photographs and videos. Specifically, she's developing algorithms for the detection and profiling of fake content to solve the problem of visual misinformation. As our use of social media has expanded, so have the tools and algorithms to edit, filter, and generate misleading or fabricated images.

"Those images can be used to support false narratives, or erode trust in the information ecosystem," says Bharati. "The goal of our research is to help restore that trust so people can make more-informed decisions."

She says the operations that users employ to create artificial content leave behind telltale signs, or "statistical fingerprints." Her team will use a range of deep-learning techniques to analyze volumes of images, including real ones and their artificially edited variants. They'll train the model to not only distinguish between the authentic and the fake, but with the latter images, which regions within them are spurious. In other words, the algorithm will pick up and highlight all those little details we miss as we casually scroll through our feeds.

"Developing algorithms that can inform users about the history of the content, with respect to how it was edited or generated, can reduce misinformation for online users," says Bharati. "Well-informed citizens are the backbone of any democratic or economic system, and in order to take actions for the betterment of ourselves and the world, we need to know what is real."

SOLVING THE AMBIGUITY PROBLEM

"For robots to achieve true autonomy in the future, they must be able to assess risks before making decisions," says Nader Motee, a professor of mechanical engineering and mechanics.

We humans conduct risk analysis all the time—from how we drive to what we say and how we say it. That analysis allows us to make a decision—slow down, say "I'm sorry," maybe not use all caps in that text message. At this moment, robots can't do this kind of analysis, which means they can't make decisions on their own (a relief to most of us, no doubt). But a world with autonomous robots could be a world in which we humans get a lot of meaningful assistance from machines—more help with disaster recovery, for instance.

However, to do risk analysis robots first require quantifying the ambiguity of perception. "In humans, our perception is based on what we've learned in the past," says Motee. "But the number of samples that a robot, or a human, can be fed of any given object is limited. So there's always ambiguity and uncertainty about what the robot is seeing. *Is it a stop sign?* On top of that, if there's noise in the environment, like rain or fog or darkness, there's uncertainty about the object itself. *Is it even a sign at all?* So there is uncertainty about not only the object, but also the identity of that object inside that class. So the ambiguity is the uncertainty of the uncertainty."

Ambiguous perception in a robot is dangerous—consider, for example, the consequences of a self-driving car perceiving a stop sign as a speed limit sign.

It's a real problem to solve, and Motee and his team are tackling it by quantifying the sources of uncertainty. Essentially, they want to go inside the black box of a range of perception modules—machine learning models that use visual sensing—to better understand how the models are perceiving the environment.

"The relationship between the input, which are the images, and the output, which are the labels (like *traffic sign*) is very complex," he says. "But to quantify the ambiguity and the output of perception, I have to analyze these models and the relationships between these two quantities. Then I can compute if I have some uncertainty on the output, how that would be transferred to the output."

That's the first step.

Ambiguous perception in robots can be dangerous, like when a self-driving car misinterprets a road or traffic sign.

"Once we quantify the ambiguity," he says, "we could use risk measures for decision-making purposes."

A robot capable of assessing risk could, in theory, make a safe decision on its next course of action. A team of robots could communicate effectively. They could also perceive the actions of the humans around them and infer how they could best assist them.

"But they have to assess risk first to determine if their next course of action is actually going to help the humans, or make their work even harder. They'll have to do a lot of analysis."

And so will Motee and his team. But he finds the prospect of a future where perception modules work as a connected network exciting. They could perceive information about our health, our transportation system, and our security.

"These modules would collaborate with each other," he says, "and hopefully create a smart society that could improve our health and our lifestyles."

LEFT: ISTOCK/CUNDRA; RIGHT: ISTOCK/CREISINGER

TWEAKING THE TOOLS

A lot of us depend (heavily) on GPS to get around. But what if there's a hurricane or a wildfire and we have to immediately evacuate? Could we safely rely on those navigation systems?

“Apps like Google Maps use predictive models that are trained heavily on non-disaster-event-type patterns, so when you deploy them in extreme events, when patterns are unique and unforeseen, the models might not predict as well,” says Parv Venkitasubramaniam, a professor of electrical and computer engineering who directs the college's Data Science program.

Machine learning may help preserve endangered languages, which contribute to cultural diversity and identity.

On top of that, he says, the machine learning models powering these systems can have more than half a million parameters, so it's impossible to say why they're making certain predictions regarding traffic speed, flow, and volume. That opaqueness is especially problematic during extreme events.

“Human beings are making critical decisions regarding evacuation and emergency response, so you can't say, ‘The black box says, do this.’ You need to give first responders something that's more transparent and explainable as to why the model is making a prediction.”

Venkitasubramaniam is part of an interdisciplinary research group (within Lehigh's I-DISC) called Explainable Graph Learning that is exploring this problem. The researchers are taking knowledge from the domain of transportation engineering—the study of the interactions between travelers and infrastructure—to build machine learning models. For example, he says, science dictates that traffic will diffuse a certain way if there's congestion versus a free flow of vehicles. That information can be captured by equations that can then be used to build more effective models.

“And what we've found is that these domain-informed models with far fewer parameters perform better when you have unexpected or unforeseen patterns of traffic,” he says.

Venkitasubramaniam is also part of a separate interdisciplinary team working to solve a well-known privacy issue with machine learning, called membership inference. It happens when sensitive information from training data, such as the health information of individuals, is revealed when adversarial queries are asked of a model.

He says that developers try to ensure privacy by adding noise to either the input data or output inference, or, more typically, by adding randomness to the training process where “you keep making things a little fuzzy.” The problem, however, is that noise compromises the quality of the output.

Venkitasubramaniam and his colleagues believe they have the solution that strikes a balance between privacy and noise. They hypothesize that the reason models reveal their information is because they're overspecified, meaning they have so many parameters that the models can store a huge amount of—potentially revealing—information about the data. The solution, they say, is to reduce the dimensionality of the model by compressing it, rather than obfuscating it with noise.

“When you compress it, all you're saying is, ‘I don't want a rich model. I just want the model to be good enough to make the inference,’” he says. “And because I'm starving the model, I'm getting the privacy I desire.”

The team has been able to show that a compression algorithm they've developed does better than some of the state-of-the-art obfuscation methods.

“We need to explore this principle further, but ultimately, this could be applied to anything that involves sensitive data, especially in healthcare. Our approach here is more fundamental. We're changing the tool to suit the needs of the problem.”

PROTECTING DIVERSITY

“Saving and revitalizing endangered languages is important for maintaining cultural diversity,” says Maryam Rahnemoonfar, an associate professor in the Department of Computer Science and Engineering and the Department of Civil and Environmental Engineering. “Language loss is equal to losing identity, memory, culture, and knowledge, and can even affect the mental health of Indigenous people.”

Rahnemoonfar serves as the faculty mentor for a project in Lehigh's Mountaintop Summer Experience program that is using machine learning to revive the languages of Native Americans. However, a major hurdle in the project is the lack of resources featuring these languages that are available to feed the deep learning algorithms. Comparable sources in English, Spanish, French, or German are plentiful.

“That scarcity results in very low accuracy when applied to Indigenous languages,” she says. “To tackle this issue, we will collect a large set of text and audio resources in collaboration with local communities, develop novel machine learning techniques that combine deep learning algorithms with rule-based methods that add constraints in the learning process about language morphology, and create reinforcement learning algorithms that integrate the feedback of native speakers.”

While the final product for these tools is still being conceived, Rahnemoonfar hopes the team's work will enable younger generations to learn and speak their native language and better connect with their elders and their culture.

READ MORE ONLINE

LEFT: ISTOCK/THEPALMER; RIGHT: ISTOCK/DEVRIMB

CLOUDED JUDGEMENT

Ethics, bias, and fairness in the age of AI

Why did so many of the experts who signed the “Statement of AI Risk” call their life's work an “existential threat”? In part, it may be because they've released something into the world without fully understanding how it works.

“When you look at large language models (LLMs), like what powers ChatGPT, there are billions of parameters,” says CSE associate professor Eric Baumer. “Once the model is trained, it's so complex that it becomes difficult to interrogate and understand why any one of those billions of parameters influences the output.”

So while the creators of these systems are knowledgeable about algorithms and the training process, he says, they don't have a complete understanding. “And I think that's what leads to these claims about them being an existential threat.”

Baumer's concerns, however, don't quite rise to that level. He's much more worried about how this lack of understanding can lead to bias in these systems.

“Because of our inability to interrogate, inspect, and understand the models, we're not going to know what biases are being ingested or how they will manifest until they actually do,” he says. “I don't know that this technology is going to destroy humanity, but it might destroy our ability to be humane to one another.”

“I don't know that this technology is going to **destroy humanity**, but it might destroy our ability to be humane to one another.”

—Eric Baumer

ISE professor Larry Snyder agrees. It's not the prospect of living in *The Matrix* that worries him—but the potential for serious harm if generative AI technologies are “running rampant.” Generative AI (e.g., ChatGPT and Bard) refers to the algorithms that can create new content, including text, code, images, audio, video, and simulations.

“Deep fakes, online trolling, misinformation, increasingly hostile rhetoric about minoritized groups—basically all the bad stuff on the internet and in the world of computing—just gets accelerated and magnified now because of these technologies,” he says.

They also infringe on intellectual property. Because the systems are trained on what's available across the internet, when they generate art, for example, the images are based on the work of others—artists who have not consented to having their intellectual property train an algorithm. What's more, the training data for ChatGPT and similar technologies hardly represents all corners of the web; instead, the dataset pulls from the most easily accessible parts of the internet, such as Wikipedia and Reddit, says Snyder, pointing out that those sources are primarily written by white men.

“So the outputs are reflecting only that slice,” he says. “And they can't necessarily make the training data more diverse because that content is less prevalent on the internet for all the systemic, historical reasons why white men are overrepresented on the internet to begin with.”

But it's not just LLMs that are problematic, of course. AI, machine learning, and computing more broadly are replete with issues of ethics, bias, and fairness. The examples given by Lehigh researchers are seemingly endless:

- ▶ Many of the algorithms that power search engines are trained on biased data that perpetuate and create stereotypes about certain groups of people. Such systems also reflect the biases of those who *create* the data, such as the tendency among English speakers to refer to doctors as men, which creates bias around gender and occupation.
- ▶ Smart appliances trained on data that don't represent all potential users haven't functioned properly for people with certain skin colors.
- ▶ On social media platforms, algorithms continually feed us what we want, which essentially puts us inside an echo chamber that lacks diversity of thoughts and ideas and exacerbates polarization.
- ▶ Algorithms used to predict criminal recidivism have been found to be inherently unfair, performing worse for certain racial categories. When facial recognition was found to be more accurate for white male faces than for other demographic groups, the response was to train the model on more people with darker skin, which posed complicated ethical questions around which groups of people are having their likeness used—without consent—to train models used by police.

“We have so many examples of systems that were created to do something cool, innovative, and groundbreaking, yet were built without consideration of the ethical or societal impact,” says CSE chair Brian Davison. “It's no longer enough to be a highly skilled, technical person. You also need to understand society and how the technology you're designing will impact it.”

There is a real effort to address these societal impacts. Baumer, who calls himself a “hopeful skeptic” when it comes to our ability to fix such issues, points to the Association for Computing Machinery's Conference on Fairness, Accountability, and Transparency (ACM FAccT). This annual meeting brings together researchers and practitioners across a range of professions who are interested in addressing and reducing the harms inherent in algorithmic systems. Increasingly, corporations and corporate researchers are developing AI design guidelines around best practices to accompany trained models.

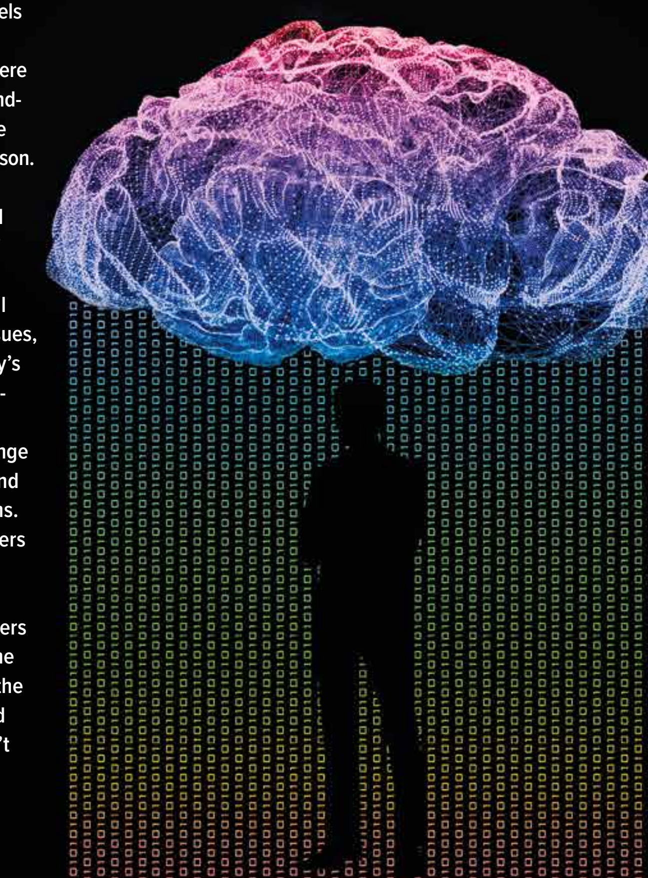
And there's even a move to embed philosophers trained in ethics within computer science teams, he says, “so you have someone who can go beyond the what-if question and who knows the literature and how to reason about these problems. We shouldn't assume that every computer or data scientist is also going to become an ethicist, but we should help them become familiar enough with such considerations to converse meaningfully and productively with ethicists.”

At Lehigh, new and revised courses for both undergraduate and graduate students are preparing the next generation of professionals to do just that. Snyder and Suzanne Edwards, an associate professor of English and Women, Gender, and Sexuality Studies in Lehigh's College of Arts and Sciences, developed and co-taught Algorithms and Social Justice, an interdisciplinary class for engineers and humanists that was offered for the first time last fall (and wrapped up as ChatGPT was starting to take off). It's being offered again this fall.

“This generation of students is well aware of the societal harm baked into these technologies,” says Snyder. “It's not an afterthought to them. They're thinking about the ethical pieces in ways that are natural and inherent, and that's encouraging.”

Baumer teaches ethics to both undergraduates and master's students. He gives programming assignments to the latter that demonstrate the difficulty in trying to optimize multiple metrics simultaneously.

“They learn that it's mathematically and practically speaking, impossible,” he says. “And then it's like, ‘Okay, you built this model that's biased—now what do you do?’ Part of the benefit of having an ethics course is for students to make mistakes in a safe environment where you don't have people, for example, denied parole. These classes prepare them to make decisions when they're creating real-world models, so they can avoid those very real consequences.”



HOTBED OF INNOVATION

Lehigh researchers rise to the challenges of the CO_2 crisis with breakthroughs in energy storage technologies and direct air capture

Lehigh Thermal Battery

SUPPORTING RENEWABLES THROUGH CUTTING-EDGE ENERGY STORAGE

In the ramp-up to more widespread renewable energy use, Thermal Energy Storage (TES) has become one of the options for enabling power grids to respond to variable supply and demand conditions. TES systems are like batteries that use temperature shifts to store energy for later use or for use at another location. Such systems capture energy in different ways, and the most commonly used techniques are based on latent and sensible heat transfer.

> "This concept is unique and new among utility-scale thermal energy storage ideas."
>
> —Carlos Romero

The latent heat method involves using the amount of thermal energy needed for a phase change—which is a change in physical state, such as from solid to liquid, or liquid to gas—without altering a material's temperature. Sensible heat storage uses the thermal energy provided to raise the temperature of a material without causing any phase transitions.

Researchers at Lehigh, with support from the Department of Energy, have developed a new thermal energy storage system, the Lehigh Thermal Battery, that combines the best of both techniques. The technology consists of engineered cementitious materials and thermosiphons in a combination that enables fast and efficient thermal performance at low cost. It is also capable of operating with heat or electricity as the charging energy input.

Earlier this year the team announced that, after three years of R&D, the technology is scalable and prototype-ready.

The project is a collaboration among Lehigh's Energy Research Center (ERC), Lehigh's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center, and Advanced Cooling Technologies, a Pennsylvania-based thermal management solutions company.

"The concrete plus thermosiphon concept is unique and new among utility-scale thermal energy storage ideas," says ERC Director and Research Professor Carlos Romero, who is one of the project leaders. "The technology offers the potential for adaptation over a broad range of temperatures and heat transfer media and operating conditions. This makes it suitable for decarbonization opportunities in industry, flexibilization of conventional power plants, and advancements and penetration of concentrated solar power."

The Lehigh Thermal Battery technology is innovative because it is modular and designed for independent energy input/output streams during charging/discharging, which is feasible with the help of the thermosiphons. "And the two-phase change process inside the thermosiphon tubes allows rapid isothermal heat transfer to and from the storage media at very high heat transfer coefficients and heat rates," says Sudhakar Neti, a professor emeritus in the Department of Mechanics and Mechanical Engineering who co-leads the project.

In addition to Romero and Neti, the team includes civil and environmental engineering faculty members Clay Naito, Spencer Quiel, and Muhannad Suleiman; ERC Principal Research Scientist Zheng Yao; and Chien-Hua Chen, Devon Jensen, Yue Xiao, and Daksh Adhikari from Advanced Cooling Technologies. Also involved were Lehigh graduate students Ahmed Abdulridha '22 PhD, Julio Bravo '23 PhD, Dominic Matrone '23G, and Shuoyu Arnold Wang '24 PhD.

"The design physically separates the flows of energy into and out of the system," says Naito. "Charging takes place by allowing a heat transfer fluid or electrical energy at a bottom plenum to activate the evaporator-charging section of the thermosiphon. A two-phase fluid inside the thermosiphons allows for rapid, uniform, and isothermal distribution of heat into the cementitious storage media." *—Lori Friedman*

Read more about the innovative TES technology behind the Lehigh Thermal Battery and the wide range of potential applications.

OPPOSITE PAGE: HOLLY FASCHING; THIS PAGE: DOUGLAS BENEDICT/ACADEMIC IMAGE

TRAINING FUTURE ENERGY LEADERS

An interdisciplinary team led by Arindam Banerjee, professor and chair of the Department of Mechanical Engineering and Mechanics, has been awarded nearly $3 million from the National Science Foundation to train a diverse group of future energy-sector leaders across academia, industry, government, and policy organizations.

The five-year award will allow Lehigh to establish a SEED (Stakeholder Engaged, Equitable, Decarbonized) Energy Futures Training Program to provide graduate students with the skills needed to explore, collaborate, and pioneer solutions to the society's reliance on carbon-based energy sources and energy inequities. The program will provide training to PhD students, as well as to those pursuing a Master of Science or Master of Arts.

"We will be training graduate students to work at the intersection of energy-related problems," says Banerjee. "The training would be holistic because the students would also be trained on aspects around policy—bringing in stakeholders early in their research program, so that the types of solutions that they are working on are stakeholder-informed or stakeholder-engaged."

Co-leading the effort are Shalinee Kishore, Iacocca Chair Professor of Electrical and Computer Engineering and director of Lehigh's Institute for Cyber Physical Infrastructure and Energy (I-CPIE); Karen Beck Pooley, a professor of practice of political science (College of Arts and Sciences); and Alberto Lamadrid, an associate professor of economics (Lehigh Business). Rossin College faculty members Carlos Romero and Farrah Moazeni are among the extended team of collaborators.

In seeking the funding from the NSF Research Traineeship (NRT) program, the Lehigh team expressed a need for the energy sector to innovate and overcome two key impeding legacies—carbon reliance and energy inequities. To that end, the team says, engineers and policymakers will both need to have the skill set to drive solutions.

"Climate change is upon us," Kishore says. "There's a major transformation in our energy systems that's needed to mitigate its effects on society and the environment. And that transformation requires us to think about new types of sustainable energy solutions and how they can be adopted across wide cross sections of society.

"To get to those solutions being commonplace in our energy sector, we need to have engineers who are trained to understand that these solutions need to impact society equitably. They need to be beneficial in terms of environmental and health impact to everyone."

The team expects to train a cohort of 8 to 10 graduate students each year once the program is fully launched. Banerjee and Kishore say it's important for students to understand the relevance of an equitable, decarbonized energy future.

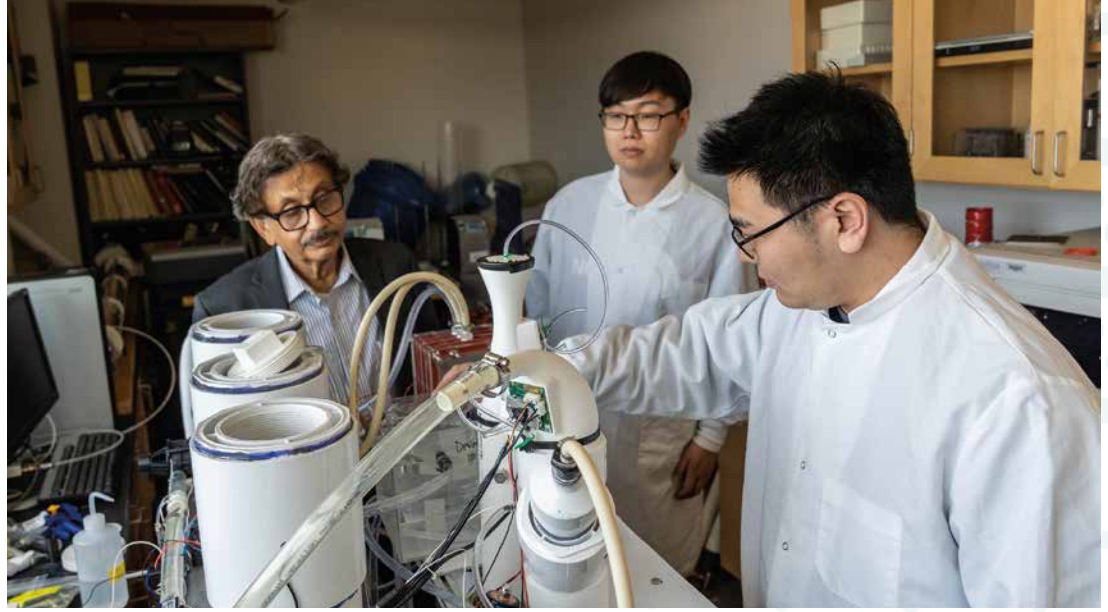
"Certain communities benefit from technological growth in the energy space, and certain communities do not," Kishore says. That's true, she says for example, when locations are chosen for renewable resources or carbon capture solutions. Who will environmentally benefit?

"So when we do think about future solar farms, and we think about future solutions, we're addressing the things that didn't happen in the past, where the coal plants were put up right next to disadvantaged communities, which further suffered from the environmental and health impact of having coal facilities next to them."

Also at issue is the lack of diversity in the energy workforce itself, Banerjee and Kishore say. The program aims to ensure a future workforce that is diverse and reflective of society.

The effort will have seven pillars: coursework on stakeholder engagement that culminates in an annual student-led workshop; a required course on ethics and equity in technology; multidisciplinary engineering, policy, environmental science, economics, and population health graduate coursework and certificate program; participation in interdisciplinary research teams; policy-focused internships; community building; and a professional development and leadership seminar series to introduce students to roles in the energy sector.

Stakeholder partners include the City of Bethlehem, Lehigh Valley Planning Commission, Nurture Nature Center, Pennsylvania Environmental Council, Pennsylvania Department of Environmental Protection, Philadelphia Solar Energy Association, ClearPath, NASDAQ, GTI Energy, and the National Renewable Energy Laboratory. ***—Mary Ellen Alu***



From left, SenGupta, Zhongyu Shi '23G, and Xinkai Wu '23G in SenGupta's lab.

DeCarbonHIX

A POTENTIAL SEA CHANGE IN CARBON CAPTURE

Professor Arup SenGupta has developed a novel way to capture carbon dioxide and store it in the "infinite sink" of the ocean.

The approach uses an innovative copper-containing polymeric filter and essentially converts CO_2 into sodium bicarbonate—aka baking soda—that can be released harmlessly into the ocean. This hybrid material, or filter, is called DeCarbonHIX (i.e., decarbonization through hybrid ion exchange material), and is described in a paper published in *Science Advances*.

The research, which demonstrated a 300 percent increase in the amount of carbon captured compared with existing direct air capture methods, has garnered attention from media outlets like the BBC and CNN and organizations such as the American Chemical Society. SenGupta has been fielding interest in the tech from companies based in Brazil, Ireland, and the Middle East.

"The climate crisis is an international problem," says SenGupta, a faculty member in chemical and biomolecular engineering and civil and environmental engineering. "I believe we have a responsibility to build direct air capture technology in a way that it can be implemented by people and countries around the world. Anyone who can operate a cell phone should be able to operate this process. This is not technology for making money. It's for saving the world."

The invention stemmed from an ongoing CO_2-driven wastewater desalination project funded by the Bureau of Reclamation. SenGupta and his students were on the lookout for a supply of carbon dioxide that would be reliable even in remote locations. That quest led the way to the field of direct air capture (DAC) and the creation of DeCarbonHIX (inset photo, blue sample).

There are three ways to reduce CO_2, he says. The first—government action—can reduce emissions, but that won't address what's already in the air. "The second way is removing it from point sources, places like chimneys where carbon dioxide is being emitted in huge amounts," he says. "The good thing about that is you can remove it at very high concentrations, but it only targets emissions from specific sources."

"This is not technology for making money. It's for saving the world."

—Arup SenGupta

The newest method is called direct air capture, which, he says, "allows you to remove CO_2 from anywhere."

With DAC, chemical processes remove CO_2 from the atmosphere, after which it's typically stored underground. However, says SenGupta, the technology is limited by its capacity. It can't capture enough CO_2 to overcome the energy cost of running the process.

"If you're capturing carbon dioxide from a chimney at a plant, the amount of CO_2 in the air can be upwards of 100,000 parts per million," he says. "At that concentration, it's easy to remove. But generally speaking, the CO_2 level in the air is around 400 ppm. That's very high from a climate change point of view, but for removal purposes, we consider that ultra-dilute. Current filter materials just can't collect enough of it."

Another challenge is storage. After the CO_2 is captured, it's dissolved, put under pressure, liquefied, and typically stored miles underground. A DAC operation must be located in an area with enough geological storage—and stability. A country like Japan can't pump carbon dioxide underground because the area is prone to earthquakes.

SenGupta has developed a DAC method that overcomes both the capture problem and the issue of storage.

DeCarbonHIX is a mechanically strong, chemically stable sorbent (a material used to absorb liquids or gasses). It contains copper, which changes an intrinsic property of the parent polymer material and substantially enhances the capturing capacity, he says. "We showed that for direct air capture with 400 ppm of CO_2, we achieve capacity, meaning capacity is no longer a function of how much carbon dioxide is in the air. The filter will get saturated completely at any concentration, which means you can perform DAC in your backyard, in the middle of the desert, or in the middle of the ocean."

The ocean is actually SenGupta's solution to the storage problem.

His DAC process starts with air blowing through the filter to capture CO_2. Once the filter is saturated with gas molecules, seawater is passed through the filter. The seawater converts the carbon dioxide to sodium bicarbonate. The solution is then released directly into the ocean, what SenGupta calls "an infinite sink."

"And it has no adverse impact on the ocean whatsoever," says SenGupta.

In fact, he says, the sodium bicarbonate, which is slightly alkaline, may improve the health of the ocean. That's because elevated levels of CO_2 in the atmosphere have gradually reduced the pH of the ocean, causing acidification. More acidic waters harm the growth and reproduction of marine life such as corals and plankton and can create catastrophic collapses in the food chain.

"Sodium bicarbonate may reverse that lowering of pH," he says.

The third part of SenGupta's method involves conditioning the filter, essentially restoring it to the state in which it can begin capturing CO_2 again. The process requires passing a diluted solution of sodium hydroxide through the filter.

"Now the question is, where will this sodium hydroxide come from? In many places, it's likely already a waste material, but sodium hydroxide can also be made using seawater, and the energy required to make it can come from renewable sources like solar and wind. If the goal is to remove CO_2, you should be emitting as little CO_2 in the process as possible. The goal is net-zero direct air capture."

SenGupta envisions an offshore platform hosting the operation. As the air blows, the filter would capture carbon dioxide until it's saturated, at which point seawater would convert the gas to a sodium bicarbonate solution, and sodium hydroxide created from seawater would restore the filter to operational status. Energy from waves, wind, and/or the sun would power it all. Such platforms would be spread far and wide in a universal attempt to capture 100 million tons of CO_2 in five to seven years.

It will be a huge engineering challenge to build the technology to the level of true global impact, and it will require expertise and partnership across a wide range of disciplines—and of course, funding.

"This is not magic," he says. "There will be many problems to solve along the way. But I believe it has the potential to be a very economical process."

—*Christine Fennessy*

CONSIDERING 'CARBON COST'

"Concrete is the No. 1 produced material in the world, and it has a huge carbon cost," says Spencer Smith '24G. "That's because mining the limestone that makes Portland cement used in concrete mix creates tons of emissions."

Smith, a master's student in the Department of Civil and Environmental Engineering, is working with associate professor John T. Fox on life-cycle analysis of concrete made using fly ash—a by-product of coal-burning power plants—as replacement for Portland cement. The project is looking at how much carbon it takes to make a pound of the fly-ash alternative concrete versus a pound of the traditional product.

"Anything we can do to reduce the levels of limestone in concrete will reduce those emissions," says Smith, who has been interested in environmental engineering and sustainability since high school.

In November 2022, he attended COP 27, the most recent Conference of the Parties to the United Nations Framework Convention on Climate Change, in Sharm El-Sheikh, Egypt, as an ambassador for the American Chemical Society (ACS) and for the United States.

"The big thing that's happening in carbon capture right now is this idea of the carbon market, which puts a value on keeping carbon out of the atmosphere," he says. "At COP 27, people were talking about how they can utilize the carbon market to live more sustainably, but also, potentially, to elevate their standard of living."

This was Smith's second trip to COP as an ACS ambassador, having traveled to Glasgow, Scotland, in 2021 as an undergraduate at York College of Pennsylvania.

"We went to Capitol Hill and got delegate training from members of the State Department and other government officials on how to talk to politicians and business leaders," he says.

As a delegate in Egypt, Smith was able to access events, exhibitions, and talks in the Green Zone, where he spoke with fellow students from 1PointFive, a Texas-based company building one of the country's first direct air capture plants with the goal of capturing excess carbon in the atmosphere. He also had access to the Blue Zone, a UN-managed space for attendees accredited by the organization, where he spoke to a wide swath of people, including Indigenous leaders, fellow engineers, and artists about their various approaches to sustainability. He also heard talks on the use of carbon capture in the production of sustainable fuels in the aerospace industry, as well as how Japan is working with a carbon capture plant to use calcium carbonate—created from captured carbon—to replace limestone in their own replacement concrete.

"My goal is to make connections," he says. "It's easy for me to sit in a lab and say carbon capture is going to change the world. But COP offers an amazing opportunity to talk with people who are already doing this work, who have already found solutions, or who are willing to partner up and work with you on different approaches to solving the emissions problem. We here in the U.S. have a lot to learn from the rest of the world, and so I'm using my experiences at COP to inform my work in the lab and, hopefully, to my eventual job site. For me, these conferences have completely changed my life." —*Christine Fennessy*

A METEORIC RISE

After completing its first mission—building a Mars rover—the student-led Lehigh University Space Initiative sets a course to join NASA's CubeSat Launch Initiative.

BY **CHRISTINE FENNESSY**

It didn't exist when he came to Lehigh, but Zemichael Gebeyehu '24 had little doubt he could start a club for students interested in space. It was, after all, the university's commitment to experiential learning that brought him here in the first place.

"I wanted to major in aerospace engineering, but that degree isn't offered in Ethiopia," says Gebeyehu. "So I was looking at schools in the U.S., and Lehigh stood out because it emphasized doing stuff *outside* of class. And I really wanted hands-on experience building things related to space."

Once he got on campus, Gebeyehu, a mechanical engineering major, joined several clubs, including Formula SAE and the Aerospace Club. He also found a group of similarly space-obsessed students.

"I said to myself, *Okay, I need to make this happen.* I wanted to bring everyone together into one club where we could get hands-on experience related to designing, building, and testing space vehicles."

He and his peers formed an executive board and applied for club status, and in the Fall 2021 semester, the Lehigh University Space Initiative (LUSI) was born. Today, the club has approximately 25 members representing a range of disciplines, including mechanical and software engineering as well as business, biology, and chemistry.

LUSI has three main goals, says Gebeyehu (pictured, center): growing a community of like-minded people, providing technical training (in CAD programs like SolidWorks, simulation software like Ansys, and space mission design), and providing opportunities to design and build. The group created Lehigh's first Mars rover and entered it in the 2023 University Rover Challenge, an international competition sponsored annually by the Mars Society.

The challenge asks student teams to build a remotely operated vehicle that can accomplish four missions that simulate assisting astronauts on Mars—autonomous navigation, equipment servicing, extreme delivery, and conducting a science mission, which includes collecting and *in situ* analysis of a soil sample.

To secure an invitation to compete in the finals at the Mars Desert Research Station in Utah, LUSI submitted a written report and video detailing the design and operation of their rover. The team's inaugural entry scored well but didn't make the cut.

"The goal is to modify our current rover and enter it again next spring," says Gebeyehu. "So this fall, we'll be doing a lot of iterating and testing, because it's all about autonomous navigation and the software aspect is very intricate."

The club's other project objective—to secure a contract with NASA's CubeSat Launch Initiative—is longer term and very ambitious. A CubeSat (artist's rendering, bottom right) is a nanosatellite capable of performing research in space. NASA's initiative gives students the chance to design, develop, and build flight-ready spacecraft while simultaneously collecting data from those spacecraft during an actual mission.

LUSI is outlining their design, research objectives, and funding stream in a proposal they'll submit in November. If it's accepted, NASA will fund the cost of launching the CubeSat on a future mission.

The team has been focused on the proposal for more than a year. "We have students working on the chassis of the satellite, the power systems, the solar arrays—and we're designing it to study B stars and massive stars," says Gebeyehu. "If we get accepted, we'll be able to start development of the hardware, and maybe by 2027 or 2028, the next group of LUSI students will be ready to launch it into space."

It's a big if, of course, as the competition will be stiff, and the team needs to show they've got the financial support to cover the extremely expensive, space-resistant materials they'll need. But it wouldn't surprise mechanical engineering and mechanics professor Terry Hart '68 one bit if they're able to pull it off.

"I keep coming back to the fact that this club is an initiative that the students came up with on their own, and they made it happen," says Hart, a former NASA astronaut and one of LUSI's advisors. "They are very, very self-motivated with everything they've done, launching these two projects, competing on a national level with their rover, putting stickers on their rover like they do in NASCAR to raise funds. They are more than just technically clever with everything they do."

ILLUSTRATION: NASA/JPL-CALTECH; PHOTOS: CHRISTA NEU (2)

Indeed, it is more than technical experience that has attracted students to the club. Michael Baron '26 is a second-year student in the IDEAS (Integrated Degree in Engineering, Arts and Sciences) honors program who heads LUSI's software team. He first heard about the group at the annual club fair, and came in with extensive experience building software for embedded systems, like those that can power a model rocket.

"I wanted to get experience working in a group," says Baron. "So I came to the club hoping to not only work with other very talented individuals, but also to get some leadership experience."

For the past year, he's led the team that helped design the architecture for the software that drives the rover's cameras and motors, as well as the ground station laptop that controls the vehicle. For the CubeSat proposal, he's been outlining the components they'll need to handle all the data coming from the satellite's sensors and antennas.

Not every student has Baron's background with such complex systems, and so he's learned how to quickly assess his teammates' understanding and guide them to ensure everyone is contributing.

"It's been great practice for whatever I end up doing after I graduate," he says. "It's one thing to be able to do a project by yourself, but if you can lead other people, and delegate responsibilities, that's how the really big projects get done."

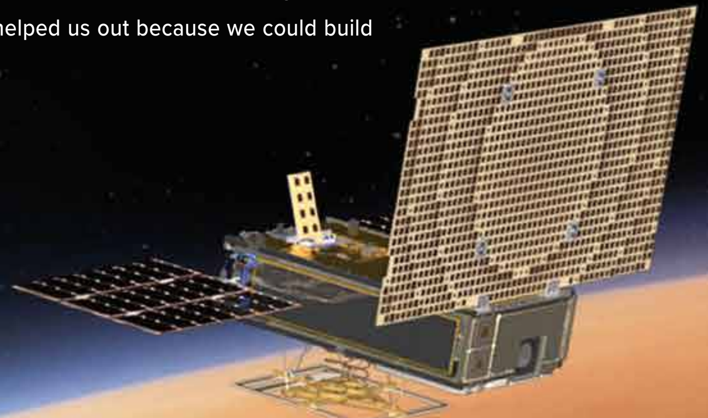
And the LUSI projects are really big. Gebeyehu says the team pulled a string of all-nighters at Wilbur Powerhouse to make the rover submission deadline. "We lived at Wilbur," he says with a laugh. "We love that place. It has everything we need—CNC machines, a water-jet laser cutter, 3D printers. The additive manufacturing process really helped us out because we could build something quickly, iterate, print it, and test it. We couldn't have done it without Wilbur."

Like Baron, Gebeyehu has learned as much about the power of so-called soft skills as he has the intricacies of designing spacecraft.

"Communication is so important," he says. "We have a lot of people with different interests and backgrounds, and you have to be able to manage them, but you also have to inspire them because the time commitments are intense. If I'm saying, 'Hey, we're going to pull an all-nighter to fix this,' I have to be there. I have to be an example."

Perhaps one of the best examples both Gebeyehu and Baron could set as leaders is demonstrating the possibilities of where all that hard work can lead. This past summer, Baron interned at SpaceX, and Gebeyehu, at Apple. Both say their interviews for the positions focused heavily on the experiential learning they did through LUSI.

"Leading the software team for LUSI was a big reason I got that internship," says Baron. "At SpaceX, they want to see what you can actually do. And so having that experience of leading other students and building stuff was exactly what they wanted to see. Because that's what you'll be doing in the real world."



Watch a video of the LUSI Mars rover in action.

A matter of (power system) control

Javad Khazaei takes a data-driven modeling approach to better integrate renewable energy into the grid

Khazaei directs the Integrated, Resilient, and Intelligent Energy Systems Laboratory (below) at Lehigh.

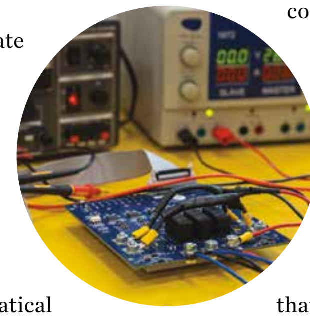
"Nearly every aspect of our daily lives depends on energy," says Javad Khazaei, an assistant professor of electrical and computer engineering. "It runs pretty much all of our infrastructure—our buildings, our water, our transportation. So if the energy system isn't resilient, the operation of all those sectors is in jeopardy."

Our current power system consists of distributed generation units—such as renewables, conventional power plants, and energy storage units—that produce electricity, and transmission and distribution systems that deliver energy to consumers. It's a complex cyber-physical system with a lot of parts that all need to be controlled in real-time to ensure the lights (and just about everything else) go on and stay on. It's also a system that's increasingly subject to instability issues as more renewable energy resources, such as solar and wind power, are added to the grid.

"My work focuses on how we can utilize data-driven approaches and machine learning techniques to improve our understanding for modeling and control of resources in a smart power system, such as renewable energy sources, power plants, battery storage devices, or electric vehicles,"

says Khazaei, whose research has been funded by the National Science Foundation and the Department of Defense. "And once we have a good model, we look at how we can control the components of systems that range from small-scale, such as microgrids, to large-scale systems with multiple power plants and large-scale renewable energy generation units such as distribution grids and transmission systems."

For instance, if you want a microgrid facility that powers a building to operate standalone when grid outages happen, he says, you need to design an appropriate controller, and for a robust control design, you need an accurate model of your microgrid assets.



"If you have a mathematical model of the microgrid system, then you can design a controller that, no matter what, guarantees that you'll be able to deliver that amount of power. So accurate models enable you to design controllers, which allow you to guarantee performance, but existing models are often obtained by several assumptions and might not be accurate enough when uncertainties and nonlinearities exist. For instance, the intermittent nature of renewable energy is an uncertainty that is often ignored in the modeling studies."

To build those models, Khazaei and his team use a statistical machine learning technique called sparse regression. They collect measurements from distributed energy resources within the power system (such as voltage, current, frequency, generator rotor speed, solar radiation, or a battery's state of charge) and identify mathematical models of these resources using sparse regression techniques.

The challenge in modeling these systems lies in that the data he and his team use is often siloed or inaccessible. For example, he says, numerous firms develop renewable energy technologies, all of which connect to the main electricity grid through a power electronics converter. However, converter parameters and topology often vary by company and are rarely open-source.

"We don't know all the parameters that have been used to build it, so our knowledge of these devices and the system is limited," he says. "Using the measurements that we do have access to, we're working on how we can develop models that accurately represent these systems. Once we have the model, and despite those uncertain parameters, we're looking at how we can design controllers that guarantee performance."

Controllers help avert instabilities within a system: For instance, when a generation unit is lost in the power grid, the frequency drops significantly. This can trip renewable energy sources that often are synchronized to the main electricity grid and cannot operate below certain frequencies.

An example of such a failure was a temporary loss of 1000 megawatts of solar photovoltaic generation in California in July 2020 as a result of grid failure. Typically, a reclosing system quickly trips the breakers back and restores the system, says Khazaei. "But most of these renewable energy sources don't have that capacity to bring the system back. My research focuses on designing various control techniques from classical model-based approaches to advanced data-driven and machine-learning-based controllers such as deep learning to solve these issues. My recent work involves developing deep-learning-based controllers for naval ships' power and energy systems, which are usually microgrids."

Developing these tools will ultimately help in the country's transition toward using more renewables to power the grid and enhance our national security. So it's both timely and urgent work. It's also very hands-on, he says, as his lab's hardware-in-the-loop microgrid facility allows students the opportunity to design and control microgrids with solar and wind energy systems. And that experience is giving those students a serious edge in the job market.

"Both my undergraduate and graduate students are now getting job offers months before they graduate," he says. "The power and energy field is booming right now, and our students are leaving Lehigh with the kind of experience that will help them make a real impact."

CHRISTA NEU (2)

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RISING TO THE CHALLENGE

Zemichael Gebeyehu ’24 (left) and Nathaniel Dudko ’26 work on the Lehigh University Space Initiative’s Mars rover.

See page 22