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

See page 4

Hot ideas in carbon capture, thermal energy storage

See page 18
This issue of Resolve arrives at an exciting moment for our university and for the Rossin 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.

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.

On page 18, “Hothed 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 $83 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.

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. 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
P.C. Rossin College of Engineering and Applied Science
steve.deweerth@lehigh.edu
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 bold 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

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 Jelison, 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 events.

“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

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INSPRIING THE FUTURE MAKERS
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.

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 the Stanford University School of Medicine, will utilize data from a double-blinded, placebo-controlled clinical trial for the biomarker establishment. Those data, including functional magnetic resonance imaging (fMRI) and electrophysiology (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’re 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, many of which involve working memory and emotional regulation. We hypothesize that the interaction among these intrinsic brain networks might reveal informative biomarkers that could predict individual 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 SSRI, the ultimate goal, he says, is to fine-tune the model so it can predict a person’s response to other compounds. “Our AI-aided 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.”

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 drugs work 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 network that controls one fine-tuned, treatments such as medication, psychotherapy, and neurostimulation therapy could be better dialed toward specific needs.

Zhang and his team will also use brain-imaging data to identify biomarkers, this time to refine their understanding of how brain networks relate to behaviors. 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 drugs work 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 network that controls one

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 freedom to pursue their research. Currently, Zhang’s newly funded study will use brain-imaging data to identify biomarkers, this time to refine understanding of how brain networks relate to behaviors.

Current research on the resilience of interdependent infrastructure systems against natural disasters, when Bocchini was approached by a California software company in 2015 to give investigators greater freedom to pursue their research. Currently, Zhang’s newly funded study will use brain-imaging data to identify biomarkers, this time to refine understanding of how brain networks relate to behaviors.

New approach can predict risk of power line ignition

In this video.

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

—Yu Zhang

To prevent power systems from starting wildfires, California utility companies are authorized to conduct preventive 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 address world-class issues that industry and society are facing in the assessment of loss due to 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.

“What is a PSPS mechanism? And can wildfires cause contact between vegetation and a power system be prevented?”

New research from Bocchini and doctoral student Kayya 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 responses under strong winds, the researchers found that it is possible to predict the risk of power line ignition. They explain that unanchored probability is highly sensitive to vegetation clearance and wind intensity. 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 this 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,” they say, “we think that broader and larger efforts may be needed to fundamentally solve the wildfire problem in California.”

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. Last year, she hired two more students.

The awards support 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 mobility 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 secretes different chemicals to essentially tell other cells what’s going on, and there’s a gradient there, where the chemical is more concentrated where it’s acting. And then the gradient is moving toward lower 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 cell’s wound healing.”
Lehightakes onregionalrolein expandingenergy audits,job training 

TheLehighUniversityIndustrial Assessment Center is growing into theMid-Atlantic Regional IAC Center ofExcellence (MARICE) with new funding from theDepartment of Energy.

Lehightook ona regional role in expanding energy audits, job training, and high-quality jobs, improve manufacturing competitiveness, and reduce industrial emissions. The funding will be split between Lehight and West Virginia University over the next five years.

TheLehigh 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 Ph.D. student Abhinay Soanker ’15G.

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

“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 those.” He says that idea aligns with the federal government’s Just40 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 those groups in areas such as energy efficiency, sustainability, variable frequency drives, HVAC systems, and building management systems. The goal is to work with local communities to conduct those assessments to provide value and competitiveness to those plants,” says Caspar. “The skills they learn can help these companies reduce their operating costs by reducing their energy use, which, 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.

“Lehight’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 Lehight’s IAC to develop additional tools to measure energy use and calculate savings.

For Soanker and Caspar, who’ve both been involved with Lehight’s IAC throughout their graduate studies and have conducted nearly 200 assessments, the proposal is both academic and technological opportunities.

Grant will lay 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.

Lehight 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, Lehight’s T.L. Diamond Distinguished Chair in Engineering and Applied Science and director of the Institute for Functional Materials and Devices (IFMD), will co-lead a working group on photonics research and development.

CREATING OPPORTUNITIES IN PHOTONICS

Lehight 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 Engine Program awarded to Princeton University will fund planning for a multi-state initiative to advance research in lasers, fiber optics, and other light-based innovations while creating opportunities to shape the region’s future.

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.

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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 non-surgical drug delivery system that will enable the delivered of antibiotics to treat aggressive periodontitis in adolescents.

“We hope that these infections are typically treated by scaling and planing, which essentially means scraping off the bacteria, and then prescribing oral antibiotics,” says Brown.

“We know that the pili—these structures of the bacteria—some times the bacteria come back, and then you have to start the course of antibiotics all over again. The more frequently you take antibiot -ics, the greater the chances this bacteria will become resistant to the drugs. Antibiotic resistance is indeed a growing problem. According to the Centers for Disease Control and Prevention (CDC), infections occur every year in the U.S., and more than 35,000 people die as a result.

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 leukotixin, the toxin released by the periodontitis-causing bacteria, triggers the release of the antibiotics.

“Leukotxin fights the body’s immune response by binding with cholester -ol 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 working on how to get the molecule into the liposome instead of the host cells,” says Brown. “When the toxin binds to the liposome, it should cause a release of the antibiotic, 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 toxins simultaneously killing the bacterial cells. They will use 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 studying the advantages of using controlled delivery strategies for antibiotics. And because this toxin we’re working with is closely related to those that cause disease like whooping cough and cholera and E. coli infections, this approach could be useful against a range of bacte ria,” she says. “This is our first externally funded project to do this work, and it validates that this technique has the potential to solve problems with both disease and with antibiotic resistance.”

“Ourapproach could solve problems with both antibiotic resistance and disease.” —Angela Brown
Forming a clearer picture of ‘grain growth’

Interdisciplinary team tackles hot topic in materials science

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 ATLS 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, says Rickman, who is leading this effort. “As a result, many models of grain growth have been developed. However, the project’s direct link between the mathematical model and the experimental micrograph is highly distinctive. According to Rickman, linking the model directly to five-point data can track the evolution of 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.

Want to make better materials? Read between the lines. Or at least the microstructures 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.

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 ’84 Professor of Materials Science and Engineering at Lehigh; Kataryn Burnak, Philips Electronics Professor of Applied Physics and Applied Mathematics at Columbia University; Yuketania Epiphany, a professor of mathematics at the University of Utah; and Chan 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 those 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 those 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 micrograph is highly distinctive.

According to Rickman, linking the model directly to five-point data can track the evolution of 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.

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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 bioscience, materials science and engineering.

Current 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 (ELUHN) 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.

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The scaffolds will be designed with specialized chemistries that enable the spatial and temporal delivery of bioactive molecules 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, Morton Meldal, and R. Barry Sharpless were awarded the 2022 Nobel Prize in Chemistry for developing click chemistry and bioorthogonal chemistry. “We are very thankful to those pioneers who paved the way for us to design new and exciting biomaterials.”

“WE’RE THANKFUL TO THOSE WHO PAVED THE WAY FOR US TO DESIGN NEW BIOMATERIALS.”

—Lesley Chow

Partners in the project include Carolan, who is section chief of orthopedic surgery and shoulder surgery at SLUHN; Felix Gerardo Ortega Orozco, a PhD student in the Chow Lab; and undergraduate student Fonte Domenico ’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 AS THEY’RE KNOWN TO HAVE IN THE PAST.”

—Lesley Chow

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, as they’re known to have in the past,” says Carolan. “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.”

By creating a flow of new cartilage on the surface of the existing cartilage, Chow’s scaffolds could bestow patients with the ability to truly ‘repair’ tissue damage. “We’re thankful to these pioneers who paved the way for us to design new and exciting biomaterials.”

ODESSA MILLER in this video, Chow explains how her lab is helping people move better.

Osteoarthritis is a chronic disease that affects the joint cartilage and the bone underneath. It occurs when the cartilage wears down or is damaged. Osteoarthritis is the most common type of arthritis and affects millions of people worldwide. It most commonly affects the joints of the hands, knees, hips, and spine. The condition can cause pain, stiffness, and swelling in the affected joint. It is a major public health issue, particularly in older populations. The cause of osteoarthritis is not fully understood, but it is thought to be related to a combination of factors, including genetics, age, obesity, and joint injury. There is currently no cure for osteoarthritis, but there are treatments available to help manage symptoms and improve function. These include medication, physical therapy, and surgery. Addressing the needs of patients with osteoarthritis is an important area of research, and the work of the Chow Lab and others in the field is contributing to our understanding of how to best treat this condition.
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 parts in energy-intensive ovens or do as much maintenance. 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 those 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 mentorship is at every stage of an education and career level. I definitely had mentors at Lehigh who gave me advice and the chance to conduct research. There is a lot of overlap because there’s a lot of crossover between physics and chemistry, so I was able to speak with people in both fields. I’ve worked on environmental and preferred surface treatments and coatings—reducing the amount of solvents used, eliminating hazardous materials, and focusing on using less water and energy.

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. Boeing makes across the commercial aviation and defense and space units. I’ve worked on environmental preferred surface treatments and coatings—reducing the amount of solvents used, eliminating hazardous materials, and focusing on using less water and energy.

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

**Making Sense of Machine Learning**

**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 AIUB 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.

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 Computing (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.

“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

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

In machine learning, algorithms make the most happen. Through a series of complex mathematical operations, algorithms train the model to essentially say: “Okay, this input looks like 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 felinos 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.”

“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 taking actions. “For robots to achieve true autonomy in the future, they must be able to assess risks before taking actions.” says Neil Morin, a professor of mechanical engineering and mechanics. “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, stop, 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. “Perceivers, in our perception, is based on what we’ve learned in the past,” says Morin. “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 or if it’s a stop sign.”

On top of that, if there’s noise in the environment, like rain or fog or darkness, then there’s ambiguity about the object. Is it a stop sign or not? 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.

“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.”

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 many languages. He’s also studied trimming that data so robots can make them more fair. In other words, how to design them to make predictions that aren’t influenced by bias in the data.

“Sequential perception is a good 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 their decisions.”

The ramifications of bias are real. Take an algorithm designed to determine who gets a loan. The model is fed data that contains 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 look 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 “black box” 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? Artificial intelligence has become 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 and interpret the visual world through photographs and videos. Specifically, she’s developing algorithms that can differentiate fact from fiction and neutral content from fake content to solve the problem of visual misinformation. As our use of social media has expanded, so have the tools and algorithms to with,filter, and generate misleading or fabricated images. “These 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 restores that trust so people can make more-informed decisions.”

She says the operations that users employ to create artifactual 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 aporous. In other words, the algorithm will pick out 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.”

**DESIGNING FAIR ALGORITHMS**

Over the next few years, Aparna Bharati hopes her researchers can help solve the problem of online visual misinformation.
Clouded Judgement, bias, and fairness in the age of AI

Why did so many of the experts who signed the "Statement of AI & Blue" call their ilk an "existential threat"? In part, it may be because they've seen commercial models, like attention models, break down in the world without fully understanding how it works. "When you look at large language models (LLMs), like those from research universities or tech compa-

ties," says CSE associate professor Eric Baumer. "Once the model is trained, it's not complex enough to become transparent and understandable why one of 100 of these parameters influences the output."

So while the creation of these systems is "knowledgeable about algorithms and the training process, he says, they don't have the skills to interpret the output. "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

"Saving and reviving endangered lan-
guages is important for maintaining cultural diversity," says Maryam Rahnemoonfar, an associate professor in the Department of Computer Science and Engineering. She is the Department of Civil and Environmental Engineering: "Language loss is equal to losing identity, memory, culture, and knowledge, and our environment is affected by this loss."

Rahnemoonfar serves as the faculty mentor for a project at Lehigh's Mountaintop Summer Experience program that is using machine learning to recover 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 models. 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 tech-
niques that can complement the data-scarce methods that add constraints to the learning process about language maintenance learning algorithms that integrate the feedback of native speakers."

While the final product for these tools is still being con-
vected, 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.

CLOUDED JUDGEMENT

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HOTBED OF INNOVATION

Lehigh researchers rise to the challenges of the CO2 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 a key to unlocking the options for 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 storage.

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 storage media in order to raise the temperature. Sensible heat storage systems are commonly used in industrial processes and the most energy-intensive industrial processes. Sensible heat storage systems are commonly used in industrial processes and the most energy-intensive industrial processes.

Lehigh Thermal Battery technology is innovative because it is modular and designed for independent energy input/output streams and 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 Nett, a professor emeritus in the Department of Mechanical and Mechanical Engineering who co-leads the project.

In addition to Romero and Nett, the team includes civil and environmental engineering faculty members Clay Naito, Spencer Quisl, and Muhammad Saleem, ERC Principal Research Scientist Zheng Yao, and Chien- Hua Chen. Devon Jensen, Yue Xiao, and Daishik Adhikari from Advanced Cooling Technologies. Also involved were Lehigh graduate students Ahmed Abdulrahma ‘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.” —Loe Friedman

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

Lehigh’s Advanced Technology for Large Structures (ATLLS) Engineering Research Center, and Advanced Cooling Technologies, a Pennsylvania-based thermal management solutions company. “The core concept of the 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.”

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

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, I-CPIE Chair Professor of Electrical and Computer Engineering and director of Lehigh’s Institute for Cyber Physical Infrastructure and Energy (I-CPE); 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 Moezzi 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.

“So to get those solutions being common-place in our energy sector, we need to have engineers who are trained to understand what these solutions need to impact society equitably. They need to be beneficial in terms of economic and 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.


—Mary Ellen Ali

Rossin College
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 CO₂ into sodium bicarbonate—aka baking soda—that can be released harmlessly into the ocean. This process is not technology for making money. It’s for saving the world.

The invention stemmed from an ongoing CO₂-driven wastewater desalination project funded by the Bureau of Reclamation. SenGupta and his students were on the lookout for a solution to carbon dioxide that would be reliable even in remote locations. That quest led them to the field of direct air capture (DAC) and the creation of DeCarbonHIX (inset photo, blue samples).

There are three ways to reduce CO₂, 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.”

The new method is called direct air capture, which, he says, “allows you to remove CO₂ from anywhere.” With DAC, chemical processes remove CO₂ from the atmosphere, after which it’s typically stored underground. However, says SenGupta, the technology is limited by its capacity. “If you’re capturing carbon dioxide from a chimney at a plant, the amount of CO₂ 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 CO₂ 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 CO₂ 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 (material used to absorb liquids or gasess). It contains copper, which changes an intrinsic property of the parent polymeric material and substantially enhances the capturing capacity, he says. “We showed that for direct air capture from 400 ppm of CO₂, 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, in the middle of the ocean. It can’t capture enough CO₂ to overcome the energy cost of running the process.”

The DAC process starts with air blowing through the filter to capture CO₂. Once the filter is saturated with gas molecules, seawater is passed through the filter. The seawater can reduce 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 CO₂ 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.

The third part of SenGupta’s method involves conditioning the filter, essentially restoring it to the state in which it can again capture CO₂. The process requires passing a diluted solution of sodium hydroxide through the filter.

“The second thing 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 CO₂, you should be aiming as little CO₂ 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 CO₂ in five to seven years.

“It will be a huge engineering challenge to build the technology to the level of global impact, and it will require expertise and partnerships across a wide range of disciplines.”

“This is not magic,” he says. “There will be many problems to solve along the way. But I believe we will have to work very hard 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 costs tons of emissions.”

So, when Smith, a master’s student in the Department of Civil and Environmental Engineering, was 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 a 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.

“All we can do is 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. “It will be a huge engineering challenge to build the technology to the level of global impact, and it will require expertise and partnerships across a wide range of disciplines.”

Smith attended COP 27 to learn from others who are already doing this work, who have already found solutions, or who are willing to partner and work with you on different approaches to solving the emissions problem. “I hope to bring the 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 or 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 world’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 had 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’re 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

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From left, SenGupta, Zheng Hu; Shi Z., and Xiwen Mu; X. in SenGupta’s lab.

Rossin College 21
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 Space Initiative sets a course.

BY CHRISTINE FENNESSY

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.

The club has approximately 25 members, including Formula SAE and the mechanical engineering major, joined several clubs, including Formula SAE and the Aerospace Club. He also found a group of similarly space-obsessed students.

“Rossin College 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 experimental 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.”

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A matter of (power system) control

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

“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 of 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 the model, 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 those systems lies in that data by and team use is often siloed or inaccessible. For example, he says, numerous firms develop renewable energy technologies, all of which connect to the main electric 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 those 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 guarantees performance.

Controllers help avert instabilities within a system: For instance, if 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 those 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 those 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 experiment 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 students are leaving Lehigh with the kind of experience that will help them make a real impact.”

Lehigh’s new strategic plan, Inspiring the Future Makers, will cultivate and support an environment where every mind can thrive and reimagine how we educate, innovate, conduct research, and work collaboratively to create a better future.

GO Beyond: The Campaign for Future Makers invites alumni and friends to play a critical role in achieving the plan. Your engagement and philanthropy support the initiatives designed to help Lehigh and the Rossin College lead in what we do best.

Scan the code or visit engineering.lehigh.edu/give to learn how you can support existing initiatives and stay informed about exciting new opportunities to make an impact as we shape our future together.
RISING TO THE CHALLENGE

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

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