helluva engineer

FALL 2024

GEORGIA TECH COLLEGE OF ENGINEERING

OUR SUSTAINABLE FUTURE

... IN ENERGY
Engineers are advancing batteries, fuel, and manufacturing **PAGE 10**

... IN AGRICULTURE
Feeding a growing world in a changing climate **PAGE 20**

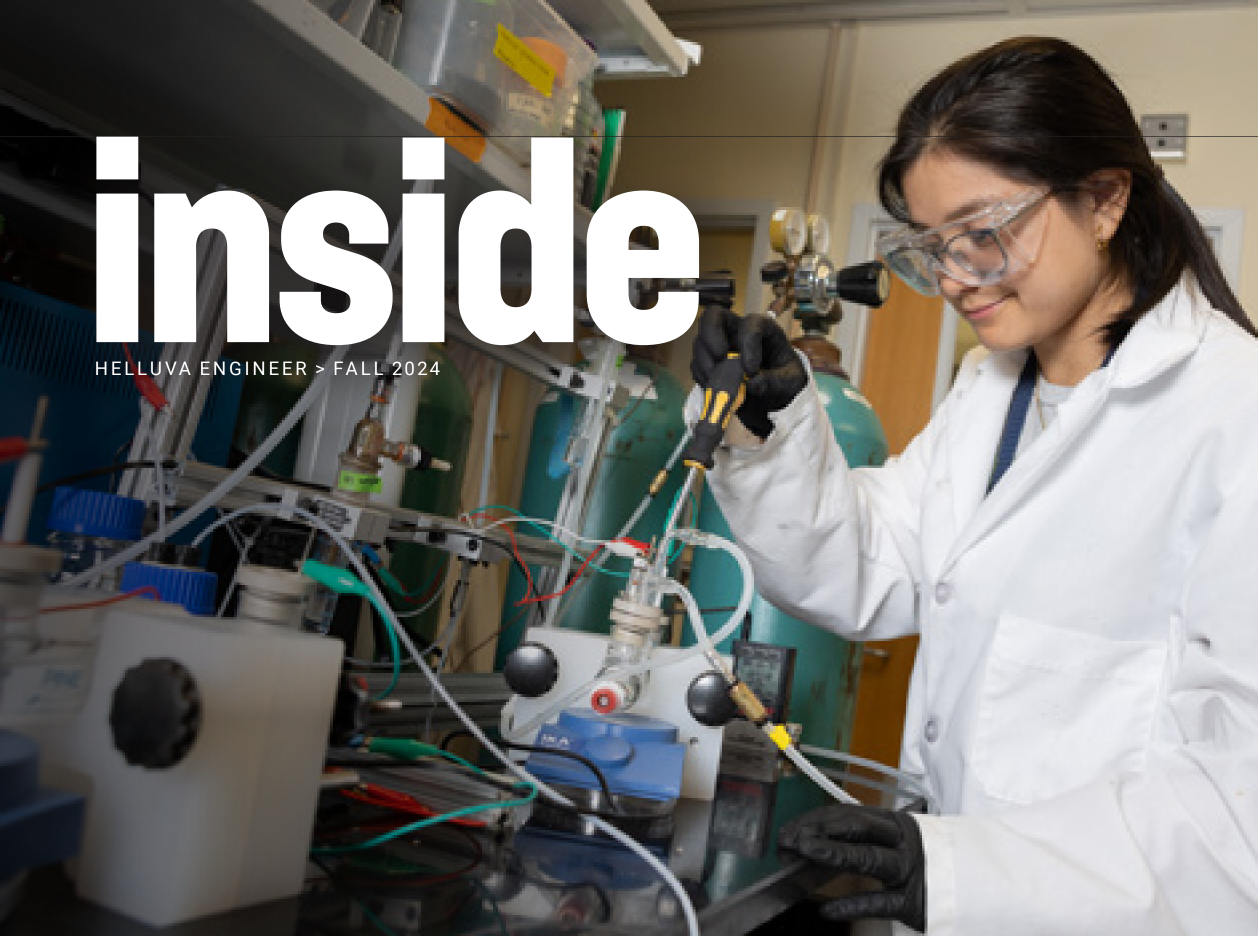
... IN RECYCLING
New methods and materials to reduce waste and recycle more **PAGE 28**


ENERGY

ALLISON CARTER

Increasing numbers of electric vehicles are adding stress to the nation's already strained power grid. Engineering researchers Kartik Sastry (pictured, left), David Taylor, and Michael Leamy have built a smarter EV charger to help. Their approach optimizes charging to reduce demand on the grid and gives owners a suite of customization options, such as charging when power rates are lowest or prioritizing charging when carbon-free power is available.

▶ **MORE ENERGY INNOVATIONS FOR A SUSTAINABLE FUTURE, PAGE 10**



inside

HELLUVA ENGINEER > FALL 2024

FEATURES

WE ARE

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HELLUVA ENGINEER
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Dear Friends,

In all the ways you might define it, advancing sustainability has never been more critical — and more exciting. That's why it's our focus in this issue of *Helluva Engineer*.

Consider: The Georgia Department of Economic Development projects that renewable bioenergy will put more than $5 billion into the state's economy in the next decade. Meanwhile, electric vehicle, battery, and solar power manufacturing is taking off in Georgia, with billions of dollars in investments announced in the last few years. This is in addition to Southern Company opening two new nuclear reactors at Plant Vogtle in Waynesboro.

These pursuits and initiatives have made Georgia one of the nation's leaders in clean energy resources. And Georgia Tech is right at the vanguard. In the College of Engineering, our researchers are focused on many facets of energy technology: wind, nuclear, solar, aviation fuels, batteries, and beyond.

Meanwhile, we're also working on sustainability technology and innovation that will benefit another heavy-hitting Georgia industry: agriculture and agribusiness. Engineers are developing techniques to reduce fertilizer runoff and find new ways to recycle waste into useful nutrients for growing crops. Their efforts will be key in helping keep our oceans and waterways clean while feeding a growing, and increasingly urban, population here and around the world.

Our engineers also are dreaming up materials that could reduce the growing piles of electronic waste and reuse the plastics that have infiltrated every corner of our planet. And it's not just paving the pathway to greater sustainability through creation of new products and technologies. Georgia Tech's research community is making great strides in advancing *how* those technologies are created, too.

Now, there's no question the advancements made by humankind are remarkable. But as I tell our students frequently, it's no longer enough *just* to advance. Engineers are taught to focus on traditional constraints such as safety, cost, size, and performance. Along with those, we must also ensure that the solutions we develop to society's problems serve all people. For example, as our researchers develop a process to reclaim and reuse fertilizer runoff, they're also mindful that the process must be realistically implemented by the growers who would benefit. Another engineer is investigating how a switch to electric vehicles — and its important benefits for climate change — will impact the communities where the lithium for vehicle batteries is mined.

We call this equity-centered engineering, and you'll read more in these pages about how we're advancing that principle.

I'm tremendously proud of the energy and sustainability advancements our faculty, students, and alumni are developing. We are excited to share some of them with you in this issue.

Have a great holiday season, and my best wishes for a happy and healthy 2025.

Sincerely,

Raheem Beyah
Dean and Southern Company Chair

CANDLER HOBBS

2

in the field

AE Breaks Ground on New Hangar

The Daniel Guggenheim School of Aerospace Engineering has begun construction of a 10,000 square-foot hangar facility dedicated to research in advanced air mobility.

The Hangar will house an electric powertrain laboratory, a propulsion system test cell, an avionics lab, composite fabrication areas, and an area for integrating prototype aircraft with wing spans up to 20 feet. In particular, work in the facility will focus on electric vertical takeoff and landing (eVTOL) aircraft and other novel types of electric aircraft.

Completion is slated for fall 2025.

"The Hangar represents the beginning of an ecosystem of flight research related to advanced air mobility that we will grow with projects focused not just on core technologies but also on integrating large-scale prototype aircraft," said Brian German, professor and co-director of Georgia Tech's Center for Urban and Regional Air Mobility. "We hope that our work in The Hangar will be a major enabler for bringing business activity and a new advanced air mobility workforce to Georgia."

Two NASA-supported eVTOL projects and a solar electric airplane technology demonstration effort already are on tap for the research space.

▶ MONIQUE WADDELL

Above: A rendering of The Hangar.

Inset: AE Professor Brian German and William R.T. Oakes, Jr. School Chair Mitchell Walker sign a beam that will be installed in the facility.

RENDERING: PERKINS & WILL; INSET: CANDLER HOBBS

3

With mRNA and Gene Editing Tools, a Promising Dengue Virus Treatment

A team of researchers led by biomedical engineer Phil Santangelo has developed a breakthrough therapy to target and kill the virus that causes dengue, a painful and sometimes fatal infection spread by mosquitoes.

Typically found in tropical countries, the virus is spreading as climate change pushes disease-carrying mosquitoes into new places and raises the risk of infection for billions of people. No effective antiviral treatment exists, in part because there are four serotypes of the dengue virus, creating four different targets for a vaccine.

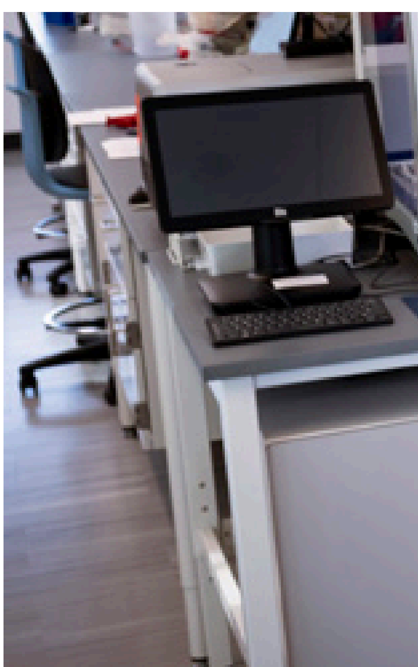
Using messenger RNA (mRNA) and the gene editing tool CRISPR, Santangelo's team eliminated the virus in mice. They encoded a custom mRNA molecule with instructions to create Cas13a, a CRISPR protein that can cut viral RNA, and guides to direct the Cas13a to the viral RNA to be cut. When the encoded mRNA is delivered to infected cells, they execute the instructions and degrade the virus.

A single dose of the treatment was given to mice infected with lethal doses of two serotypes of dengue virus. All the treated mice survived with no unintended damage to their RNA. Santangelo's team now is testing their approach on dengue's other serotypes and will study the treatment in other viruses.

"We're very interested in trying these kinds of approaches to go after as many viruses as we can with one, potent treatment," Santangelo said. "We're trying to find the most efficient way to kill these viruses. We're not quite there yet, but we're going to get there."

The approach, published in *Nature Microbiology*, is the first time an mRNA-based CRISPR treatment has worked against systemic viral infections in animal models.

▶ **JERRY GRILLO**



JACK KEARSE

Anna Erickson

Nuclear Nonproliferation Consortium Wins Another $25M

Georgia Tech researchers will lead a group of 12 universities and 12 national labs as part of a $25 million U.S. Department of Energy National Nuclear Security Administration (NNSA) award.

The Consortium for Enabling Technologies and Innovation 2.0 will advance technologies across three core disciplines: data science and digital technologies in nuclear security and nonproliferation, precision environmental analysis for enhanced nuclear nonproliferation vigilance and emergency response, and emerging technologies.

They will be advanced by research projects in novel radiation detectors, algorithms, testbeds, and digital twins.

This is the second time Georgia Tech has won this award and led research and development efforts to aid NNSA's nonproliferation, nuclear science, and security endeavors.

"What we're trying to do is bring those emergent technologies that are not implemented right now to fruition," said Anna Erickson, Woodruff Professor and associate chair for research in the George W. Woodruff School of Mechanical Engineering, who leads both grants. "We want to understand what's ahead in the future for both the technology and the threats, which will help us determine how we can address it today."

▶ **TESS MALONE**

NUCLEAR ENERGY
Why nuclear energy will be an important part of a clean-energy future, page 17

Expanding Access to Microorganism Research

Researchers in the School of Chemical and Biomolecular Engineering have developed an inexpensive, easy-to-assemble, autonomous tracking microscope. Costing just $400 in parts, the DIY "Trackoscope" is a frugal-science innovation that makes studying microorganisms more accessible to a wide range of users, from high school laboratories to research environments with limited resources.

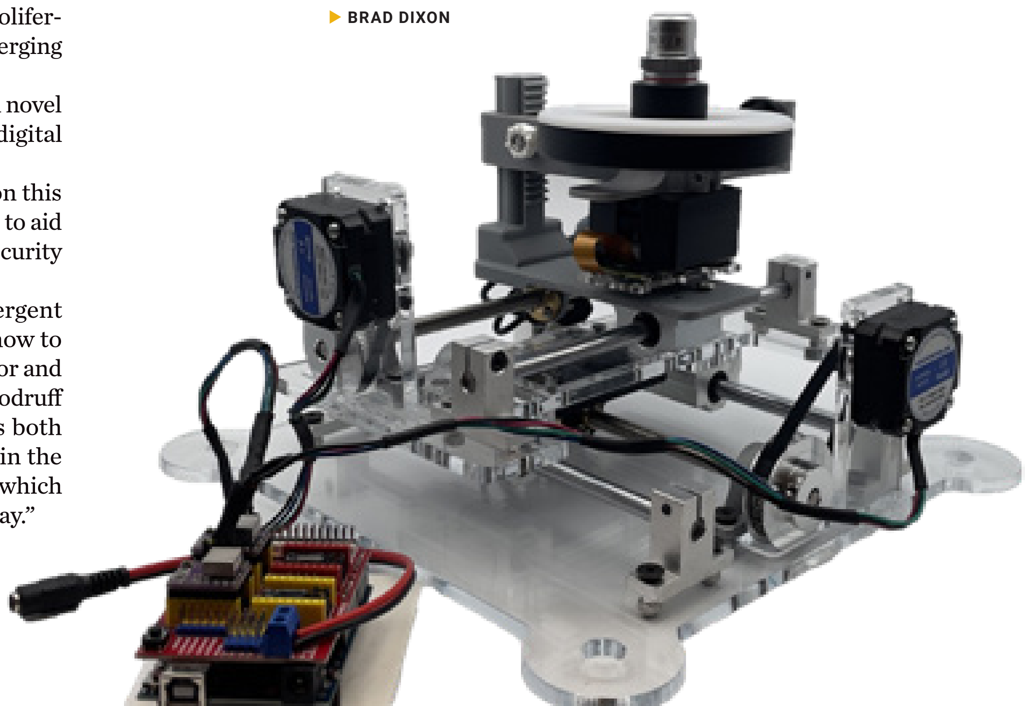
Studying the complex motility patterns of cells and microorganisms is key to understanding their behaviors and biomechanics. However, many conventional microscopes have fixed lenses and can't track organisms over extended periods without manual intervention. Trackoscope overcomes those limitations.

The idea of mechanical engineering major Priya Soneji, the device came to life in the lab of Associate Professor Saad Bhamla.

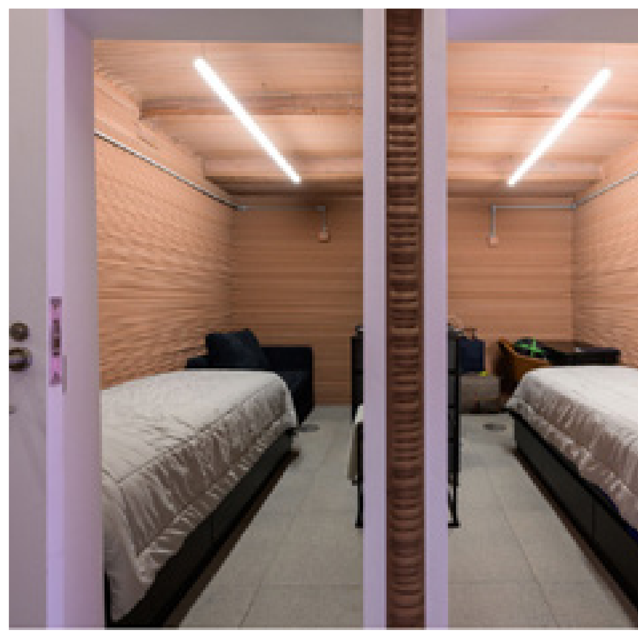
The versatile microscope is capable of monitoring organisms while minimizing the risk that they will collide with container walls, preserving their natural behaviors and enabling experiments involving predator-prey dynamics.

Existing tracking solutions can cost $1,000 to $5,000, putting them out of reach in resource-constrained environments. The modular design of Trackoscope facilitates customization and adaptation to specific research needs. Its construction involves straightforward assembly using materials like wood or acrylic, plus laser-cut and 3D-printed components.

▶ **BRAD DIXON**



ERICKSON: JOYA CHAPMAN; TRACKOSCOPE: BHAMLA LAB



A Yellow Jacket on 'Mars'

This summer, civil engineering graduate Ross Brockwell returned from his mission on Mars. Or at least the first effort to see how astronauts might live and work on the Red Planet.

A year ago, Brockwell stepped into NASA's Mars Dune Alpha habitat at Johnson Space Center in Houston with three other crew members for a 378-day simulation designed to gain insights into the challenges of deep space exploration and its effects on human health and performance.

During the mission, the crew performed robotic operations, habitat maintenance, agricultural activities, and simulated surface walks in the "sandbox" with the assistance of virtual reality. They endured intentional resource limitations, isolation, and confinement. Just like on Mars, communication "back" to Earth took about 20 minutes.

"Sometimes, you get chances in your lifetime. If I don't get a chance to actually go to Mars and I can take this chance to help us get there as a planet, I'm honored," said Brockwell, a structural engineer by day who always has dreamed of space travel.

Brockwell's role as the mission's flight engineer focused on infrastructure, building design, and organizational leadership. As much as he learned throughout the mission, like anticipating possible failure points and contingency planning, NASA learned even more through physical and cognitive monitoring.

"There was a lot of science, and some of it was focused on us as the participants — our physiology and our performance — to make the mission as realistic as possible," he said.

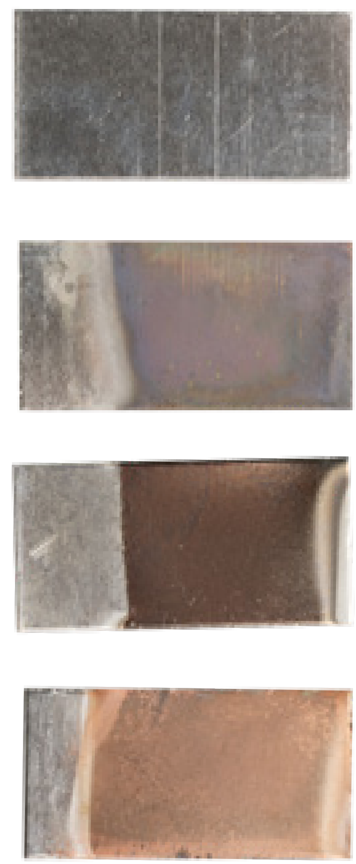
▶ **STEVEN GAGLIANO**

Top: Ross Brockwell speaks after the crew exits the Mars Dune Alpha habitat at NASA's Johnson Space Center in Houston, Texas.

Inset: A look inside the Mars habitat.

NASA/CHAPEA

Modified Stainless Steel Could Kill Bacteria Without Antibiotics or Chemicals



Top: Anuja Tripathi examines a sample of stainless steel after an electrochemical etching process.

Right: Four samples of stainless steel show the different stages of Tripathi's process. An unmodified sample at the top, and after the electrochemical etching process. The third and fourth samples are after copper ion deposition — four minutes and 15 minutes respectively.

CANDLER HOBBS

An electrochemical process developed in the School of Chemical and Biomolecular Engineering could offer new protection against bacterial infections without contributing to growing antibiotic resistance.

The approach capitalizes on the natural antibacterial properties of copper and creates incredibly small needle-like structures on the surface of stainless steel to kill harmful bacteria like E. coli and Staphylococcus. It's convenient and inexpensive, and it could reduce the need for chemicals and antibiotics in hospitals, kitchens, and other settings where surface contamination can lead to serious illness.

It also could save lives: A global study of drug-resistant infections found they directly killed 1.27 million people in 2019 and contributed to nearly 5 million other deaths — making these infections one of the leading causes of death for every age group.

Led by postdoctoral scholar Anuja Tripathi, the team first developed an electrochemical method to etch the surface of stainless steel, creating nano-sized needle-like structures on the surface that can puncture bacteria's cell membranes. Then, with a second electrochemical process, the researchers deposited copper ions on the steel's surface. The copper interacts with the cell membranes and ultimately compromises them.

Despite copper's known antibacterial properties, it's not widely used to fight surface contamination because it's expensive. Tripathi's approach deposits only a thin layer of copper ions on the stainless steel, so it's cost-effective without compromising the material's antibacterial activity.

Together, the dual attacks resulted in 97% reduction of Gram-negative E. coli and 99% reduction in Gram-positive Staphylococcus epidermis bacteria in the group's study.

▶ JOSHUA STEWART

CEE Team Wins National Sustainability Competition

Georgia Tech students won first place at the American Society of Civil Engineers (ASCE) 2024 Sustainable Solutions Competition — their second consecutive top finish.

"To say we are elated is an understatement," said team captain Mary Helvie, a fourth-year civil engineering student. "A lot of us felt a lot of pressure from winning the previous year. We had big shoes to fill. We spent countless hours working together on this project and it's something we are extremely proud of."

The Sustainable Solutions Competition challenges college students to address real-world issues with creative engineering solutions. This year, students were asked to revitalize and redevelop a fictional abandoned industrial waterfront area in a flood plain. Their winning proposal included:

- A stormwater park to minimize flooding and increase water infiltration, inspired by Atlanta's Rodney Cook Sr. Park and the Georgia Tech EcoCommons.
- A five-story multiuse building with housing units, a grocery store, clinic, gym, bike repair shop, and more.
- An education center, restaurant, and community garden. All of the buildings in this parcel had solar panels and were elevated for flood proofing.

The national competition featured winners of 17 regional contests.

▶ MELISSA FRALICK

COURTESY: SUSTAINABLE SOLUTIONS TEAM

$5M Challenge Grant to Boost CEE Graduate Fellowships

Anonymous donors have created a $5 million giving challenge to create new graduate student fellowships in the School of Civil and Environmental Engineering (CEE).

Through the end of 2024, the pool of funds will match gifts dollar-for-dollar when donors commit to establishing a new fellowship endowment. It's an effort to increase the support available to the School's faculty when they're competing for the nation's top civil and environmental engineering Ph.D. students.

"Our excellent academics and research enterprise would not be possible without the ability to recruit and retain the best graduate students in the nation," said Karen and John Huff School Chair Don Webster. "Expanding graduate fellowship endowments will have a huge impact on the future of civil and environmental engineering at Georgia Tech."

In addition to their own studies, grad students are the backbone of CEE's academic programs. They teach undergraduates, assist faculty with critical research, and provide a meaningful metric for the School's national rankings.

The most in-demand prospective graduate students often entertain generous financial offers from several top institutions. According to school leaders, CEE has not always been able to adequately compete with those offers.

For more information on the graduate fellowship challenge, contact CEE Director of Development Patricia White at patricia.white@ce.gatech.edu.

▶ MELISSA FRALICK

Transforming Tomorrow: The Campaign for Georgia Tech is the Institute's most ambitious comprehensive fundraising campaign, with a goal of more than $2 billion to advance the Institute and its impact — on people's lives, the way we work together to create innovative solutions, and our world — for decades to come.

STEM Fest, Summer Camps Introduce Thousands of Young Students to Engineering and Science

More than 2,000 K-12 students attended the College of Engineering's first STEM Fest in September, filling McCamish Pavilion with the excited chatter of young people discovering new ideas. They explored 60 or so interactive stations, exhibits, and activities designed to teach students about science, technology, engineering, and math (STEM) concepts.

"It's fantastic to see all these kids from every corner of our city, and beyond, learning about STEM and having a great time," said Damon Williams, the College's associate dean for inclusive excellence. "We have a responsibility to ensure that K-12 students in metro Atlanta are introduced to STEM concepts and what Georgia Tech has to offer. Today is the next step toward achieving that."

STEM Fest marked the beginning of a partnership between the College and STEM Global Action. The New Orleans-based organization is led by Calvin Mackie, a three-time graduate of the George W. Woodruff School of Mechanical Engineering. Since 2013, Mackie and his team have organized STEM learning events for more than 160,000 students around the nation.

The festival capped a busy summer and early fall of engineering outreach activities organized by the College. Among them:

- A partnership with STEM Gems for a summer camp aimed at rising 9th and 10th grade girls. They spent a week on campus participating in hands-on STEM activities, exploring careers, and learning about Georgia Tech research.
- The Summer Engineering Institute, a weeklong intensive camp for older high school students blending engineering and insider information on college admissions to hook students on STEM majors.

JASON MADERER

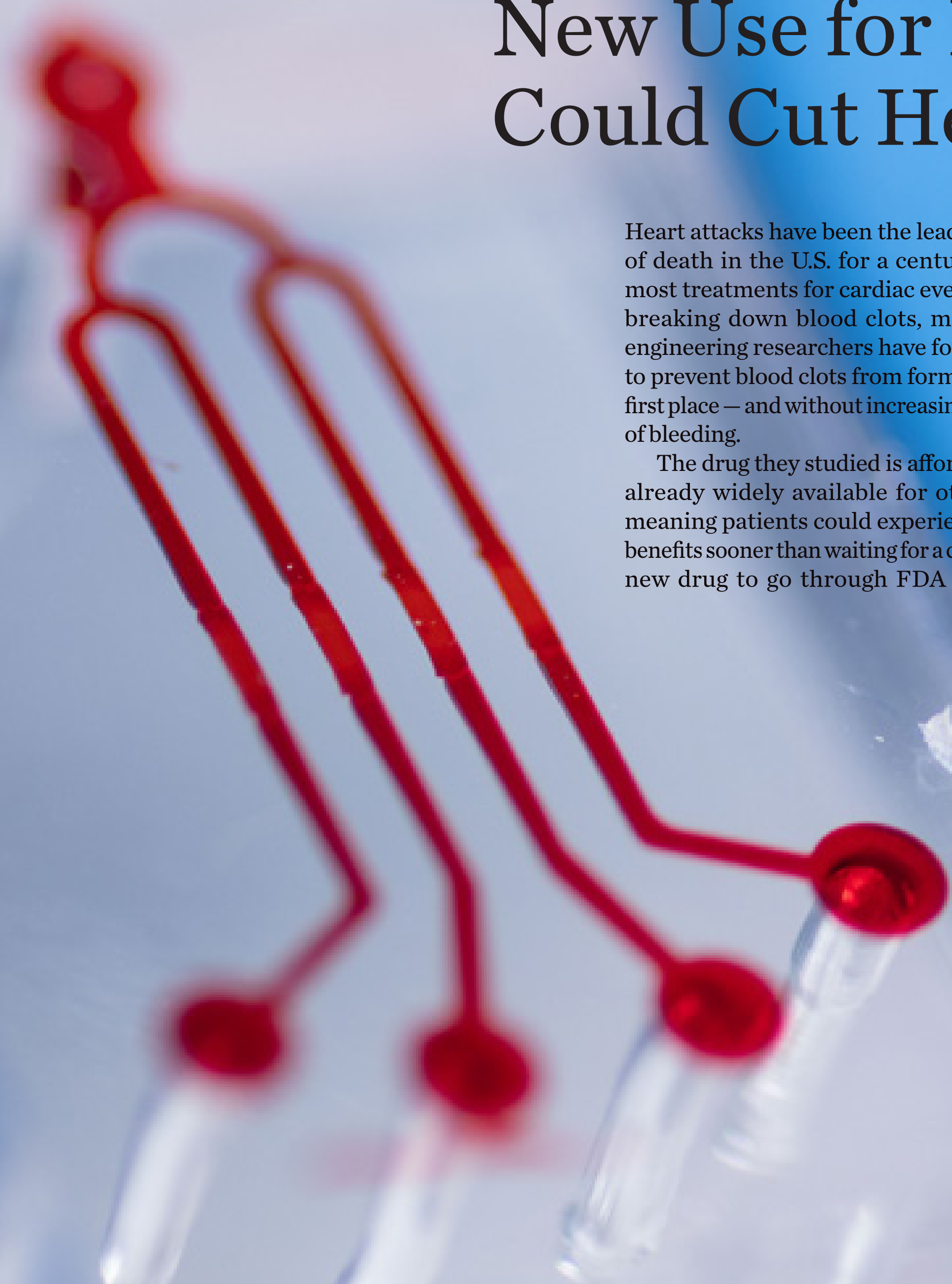
Top left: Summer Engineering Institute campers toured the Student Competition Center and heard from team members about the vehicles they designed and built.

Top right: Fourth grader Grayson Thomas learned about pulleys and balance at STEM Fest.

Above: STEM Gems campers built a water filtration system out of everyday materials — soda bottles and cotton balls.

STEM GEMS: MALCOLM DAVIE; SUMMER ENGINEERING INSTITUTE: LIZ KELLY; STEM FEST: KEMI GRIFFIN

New Use for Existing Drug Could Cut Heart Attack Risk



In this lab model of an artery, blood comes in from the top and splits into four channels that can be observed separately. The middle region is where the channel narrows to mimic an atherosclerotic plaque.

ROB FELT

Heart attacks have been the leading cause of death in the U.S. for a century. While most treatments for cardiac events target breaking down blood clots, mechanical engineering researchers have found a way to prevent blood clots from forming in the first place — and without increasing the risks of bleeding.

The drug they studied is affordable and already widely available for other uses, meaning patients could experience these benefits sooner than waiting for a completely new drug to go through FDA approval. Eventually, the drug could be used to prevent second heart attacks for high-risk patients or even primary heart attacks, strokes, and other complications caused by blood clots.

Most existing preventive treatments for clots involve anti-platelet drugs that also can cause bleeding. Instead of targeting clots, the Georgia Tech researchers went after a protein called von Willebrand factor (VWF) that holds clots together.

Led by David Ku, Lawrence P. Huang Endowed Chair for Engineering Entrepreneurship and Regents' Professor, the team sought to break down VWF proteins using N-acetyl cysteine (NAC), a drug typically used to treat acetaminophen overdose. Earlier researchers had tried using NAC to break down clots after formation, but Ku's team wanted to stop clots before they even started.

In their study, NAC completely prevented a clot from forming in an artificial model artery and subsequently in a mouse model. Even better, NAC's benefits lasted six hours after it left the bloodstream, keeping arteries clear for longer.

The researchers envision the drug will be most useful if a patient has already had a heart attack but is at risk for a second one soon after. An IV injection of NAC could lower that immediate risk. Eventually, NAC derivatives could be taken as a daily pill to reduce heart attack risk.

▸ TESS MALONE


E
V

BY JASON MADERER

11

POWERING UP

OUR RESEARCHERS ARE CREATING NEW TECHNOLOGIES THAT POLLUTE LESS AND STORE MORE ENERGY — WHILE ALSO ENSURING THE MANUFACTURING PROCESS IS CLEAN.

Clockwise from top: Anna Erickson, Matt McDowell, Juan-Pablo Correa-Baena, Adam Steinberg, Valerie Thomas, Wenting Sun, Tequila Harris

For 20 years, Georgia Tech's Strategic Energy Institute (SEI) has brought together campus researchers who collectively develop better ways to meet the energy needs of today and tomorrow.

These days, that amounts to more than 1,000 people. Georgia Tech faculty are creating advanced communications and information systems, sensing and control approaches, and transmission and energy storage technologies that will make the nation's power distribution systems more efficient and cost-effective. Their research also focuses on integrating renewable energy sources and electric vehicles.

"As the nation's largest technologically focused university, Georgia Tech is playing an integral role in developing solutions that enable more equitable, lower cost, and cleaner generation, storage, distribution, and utilization of energy," said Tim Lieuwen, Georgia Tech's interim executive vice president for research. Lieuwen knows SEI better than anyone: he had been its executive director since 2012 until stepping in this summer as interim leader of Tech's entire research enterprise.

"Georgia Tech researchers are not just helping to create cleaner, more efficient fuel options or mitigate the environmental impact of conventional energy supplies. They also are creating better performing, more economically viable energy options," he said.

Tim Lieuwen in the Carbon Neutral Energy Solutions Laboratory Building.

CHRIS MCKENNEY

The work at SEI and across Georgia Tech has helped make the state of Georgia one of the nation's leaders in clean energy, battery technology, and energy sustainability. It's attracting numerous companies to invest in research and development in the state, including Hyundai, SK Battery America, and solar panel maker Qcells.

Lieuwen, himself a two-time mechanical engineering alumnus, is one of many engineering professors with an eye on energy sustainability. Some are finding new ways — and new materials — to improve batteries. Others are working on solar energy, nuclear power, and sustainable aviation fuels. And some are focused less on the final product and more on how to streamline manufacturing processes to increase sustainability.

They're all driven by an ideal that Lieuwen said was born on campus about a decade ago and persists today.

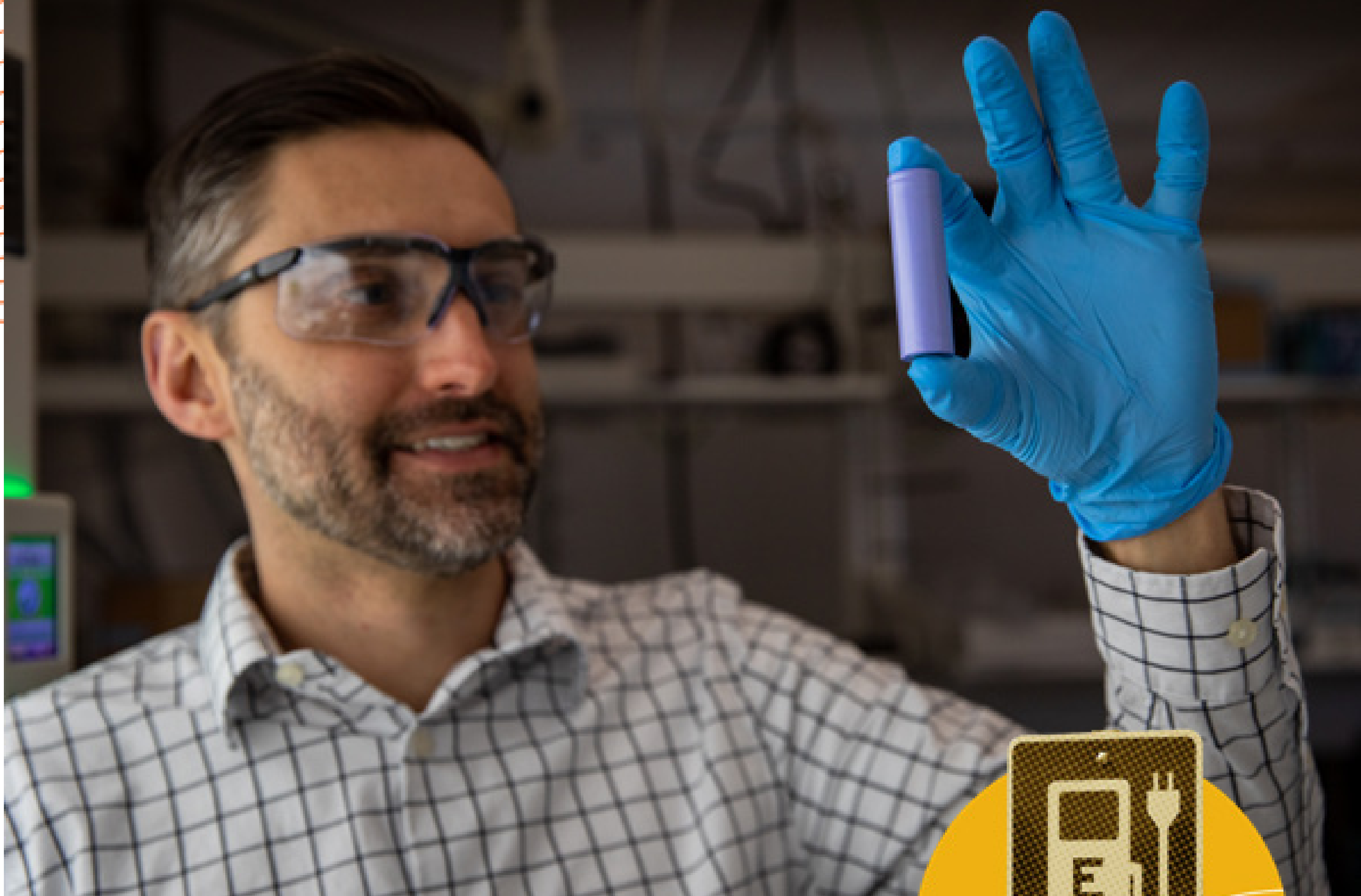
"At Georgia Tech, we insist that it's not enough to only create new energy technologies," he said. "Our leadership has instilled a responsibility to also focus on how those technologies are created. By focusing on both the manufacturing process and the final product, we can create more sustainable materials at scale. And with our state as the petri dish, it allows Tech to help create green energy jobs that benefit all corners of Georgia."

LEADING THE CHARGE

MATT MCDOWELL IS TRANSFORMING BATTERY TECHNOLOGY FROM THE LAB TO THE MARKET

Matt McDowell is a matchmaker. As co-director of the Georgia Tech Advanced Battery Center, McDowell supports the state's $30 billion investment in battery technology by connecting companies to Georgia Tech for research and development. He and co-director Gleb Yushin promote the campus's unique facilities to foster relationships between Tech and global partners to create new battery technologies for electric vehicles, grid energy storage, electric aviation, and more.

Within his own lab in the George W. Woodruff School of Mechanical Engineering, McDowell focuses on



reinventing batteries and other energy storage devices by researching how battery materials transform during use.

"Lithium-ion batteries, which are rechargeable and ubiquitous in computers and cell phones, won't be replaced for a while, if ever," said McDowell, Carter N. Paden, Jr. Distinguished Chair and associate professor. "However, there are a number of new technologies on the horizon. We're looking for ways to create solid-state batteries that could be safer and potentially have even greater storage capacity."

Lithium-ion batteries were commercialized in 1991. When they went into the first electric vehicles in 2008, they cost more than 10 times what they do today. The price continues to fall, and they are trending to soon be as inexpensive as an internal combustion engine.

One of the remaining problems, McDowell said, is safety. The liquid electrolytes they contain are flammable, making solid-state batteries a compelling alternative.

"Next-generation batteries require materials with higher charge storage capacity, or they require the development of new materials for entirely new battery systems beyond lithium-ion," McDowell said. "For example, sodium-ion batteries have a lower density, could be cheaper to make, and could provide back-up power and renewable energy for the grid."

Sodium is also more plentiful than lithium and more geographically friendly. Instead of mining in limited areas around the world for lithium, sodium is widely available, including by extraction from the oceans. Sodium-ion batteries also use hard carbon instead of graphite, the main component in lithium-ion batteries.

"Graphite is a great material, but most of it comes from overseas. Scientists can make it, but it takes a lot of energy and high temperatures. Sodium is more sustainable," McDowell said.

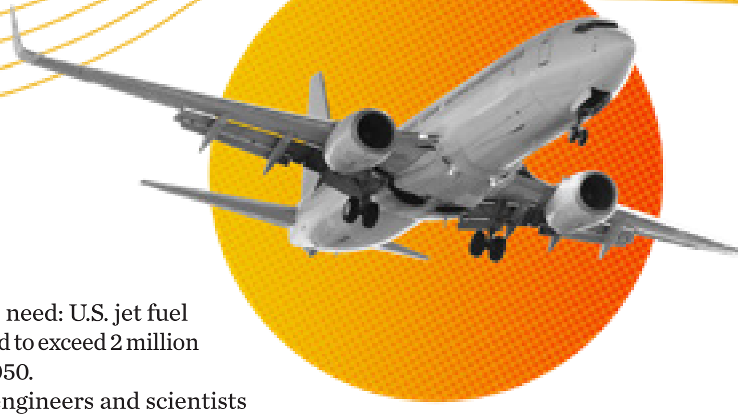
McDowell sees a future — one that isn't that far away — where electric vehicles are widely available, including at costs less than $30,000. The only way that happens is by bringing down the cost of batteries with new technologies. That's the goal of the Advanced Battery Center. In addition to McDowell, Yushin, and approximately 20 other faculty members, the center represents battery R&D activities at Tech that includes 150 or so graduate students and postdoctoral researchers.

They're already looking forward to the next step and deepening Georgia Tech's impact on the state and nation.

"An important effort within the Advanced Battery Center is the creation and development of a new pilot-scale battery manufacturing laboratory facility on campus," McDowell said. "This facility will enable translation of new energy storage innovations to commercial scales, and it will be a key resource for Georgia Tech and the broader region."

Matt McDowell's research focuses on materials for next-generation batteries that are safer and more sustainable alternatives to lithium-ion batteries.

ASHLEY RITCHIE



SAME FLIGHT, LESS CARBON

RESEARCHERS ARE CREATING AND TESTING SUSTAINABLE AVIATION FUELS FOR CLEANER TRAVEL

According to the International Energy Agency, aviation contributes 3% of all global carbon dioxide emissions. Although only a small portion of the world's population currently travels by air, more people will travel as incomes grow: the industry expects passenger-miles to double by 2050. Facing this prospect of high and growing emissions, the international aviation industry has pledged to eliminate its carbon emissions by 2050.

The best bet to get there is rethinking what fuels are used in aviation. Instead of using petroleum, sustainable aviation fuels (SAFs) — or, more technically, low-carbon fuels — can be produced from a range of feedstocks, including agricultural residues, waste oils and fats, energy crops, and municipal waste.

Many airlines have signed agreements with SAF producers, and some of the fuel is in use. The U.S. Department of Energy reported that nearly 400,000 commercial flights have used SAFs at approximately 50 worldwide airports. Meanwhile, the U.S. Energy Information Administration projects daily production of 50,000 barrels of SAFs in 2025. That's still a long way from meeting the need: U.S. jet fuel demand is expected to exceed 2 million barrels a day by 2050.

Even though engineers and scientists know how to make SAFs, there are reasons why it's currently in such short supply. And those used today, aerospace engineering professor Adam Steinberg said, need to be blended with fossil fuels to fly safely.

"So far, no commercial flights have used a 100% SAF. Other than test flights, today's SAFs are only certified to fly when blended with at least 50% petroleum-based fuel," said Steinberg, Pratt & Whitney Chair and professor in the Daniel Guggenheim School of Aerospace Engineering (AE). "SAFs don't have the exact same chemical components as current jet fuel, which leads to unintended engine complications. A 100% SAF is currently too big a safety risk."

Many of the engines in current airplanes were designed decades ago. Steinberg said those old machines rely on the makeup of petroleum-based fuels to function. For example, SAFs usually don't contain the aromatic

Adam Steinberg (left) works with students in the Ben T. Zinn Combustion Laboratory.

CANDLER HOBBS

hydrocarbons molecules that are found in traditional fuels. Getting rid of aromatics may be good for sustainability, but they're needed to swell seals in current engines.

"The engines leak if the fuel doesn't contain aromatics. That's one reason the industry is blending SAF with fossil fuel," Steinberg said.

Addressing those issues is one of Steinberg's goals as director of Georgia Tech's Ben T. Zinn Combustion Laboratory. It's among the world's largest academic combustion research facilities. The Zinn Lab allows Steinberg and other researchers to test fuels and their impacts on engines.

"As we design better engines, the machines become more complicated. And that could reveal sensitivities not seen in simpler engines," Steinberg said. "For instance, if you change to SAFs and the engine goes out at 30,000 feet, does the difference in fuel properties make it harder or easier to relight the engine?"

Wenting Sun also works in the lab. The AE associate professor oversees a Federal Aviation Administration (FAA)-funded project simulating engine conditions and modeling combustion to measure emissions and see what is produced at engine-relevant high temperature and pressure conditions.

"We investigate the combustion processes of both conventional jet fuel and SAFs and compare their differences. Then we examine what we can modify to minimize emissions from both fuels," Sun said. "This past April, the FAA released a final rule to regulate particle emissions. Our research will likely inform policymakers regarding regulations on future engines and fuels."

Sun's goal is to burn fuels as cleanly as possible. One of his favorite ways to explain clean burning is comparing a candle to a natural-gas stove. The smoke coming off a candle flame is the emission, and the orange color is proof that many particles are present. A stove's flame is blue, which means it's cleaner and nearly free of particles.

"Our goal is to develop technologies that increase efficiency and simultaneously decrease emissions of sustainable aviation fuels," Sun said.

Work at Georgia Tech on SAFs extends beyond aerospace engineers. Industrial engineer Valerie Thomas performs environmental lifecycle assessments of low-carbon transportation fuels, including those for aviation. She's nationally recognized in the field and recently chaired a National Academies of Sciences, Engineering, and Medicine committee that authored a report on the topic.

Thomas has studied fuels made from blue-green algae and explored if carbon dioxide can be captured from the air and converted into fuels.

"I think we really can stop using fossil fuels, find ways of living our lives, and run the economy without emitting greenhouse gases," said Thomas, Anderson-Interface Chair of Natural Systems and professor in the H. Milton Stewart School of Industrial and Systems Engineering.

SAFs BY THE NUMBERS

2050
Self-imposed deadline for the international aviation industry to eliminate its carbon emissions

400K
Commercial flights that have used SAFs to date

50K
Barrels of SAFs produced per day projected in 2025

2M+
Barrels per day of jet fuel, expected demand by 2050

50%
Current minimum for petroleum-based fuel required in SAF blend to be certified for flight

"It's a big challenge, but it's not one of these impossible things."

Thomas worked on ethanol and other fuels for many years. She became interested in aviation fuels when she realized that cars and trucks can transition to electric or fuel cell systems and don't really need biofuels.

"The options for aviation are more constrained. Not only are biofuels the most viable option for decarbonizing aviation, the amount of biofuel that U.S. aviation would need is basically all the biofuel our nation can sustainably produce," Thomas said.

Just as she's convinced eliminating greenhouse gases is possible, she sees a future where the aviation industry stops using petroleum-based fuel. But that shift will require work beyond the technological limitations Steinberg is working through. Thomas pointed to political and economic hurdles, too.

For starters, although the government has enacted regulations and financial incentives to help decrease sales of vehicles that burn fossil fuel, neither exist for aviation.

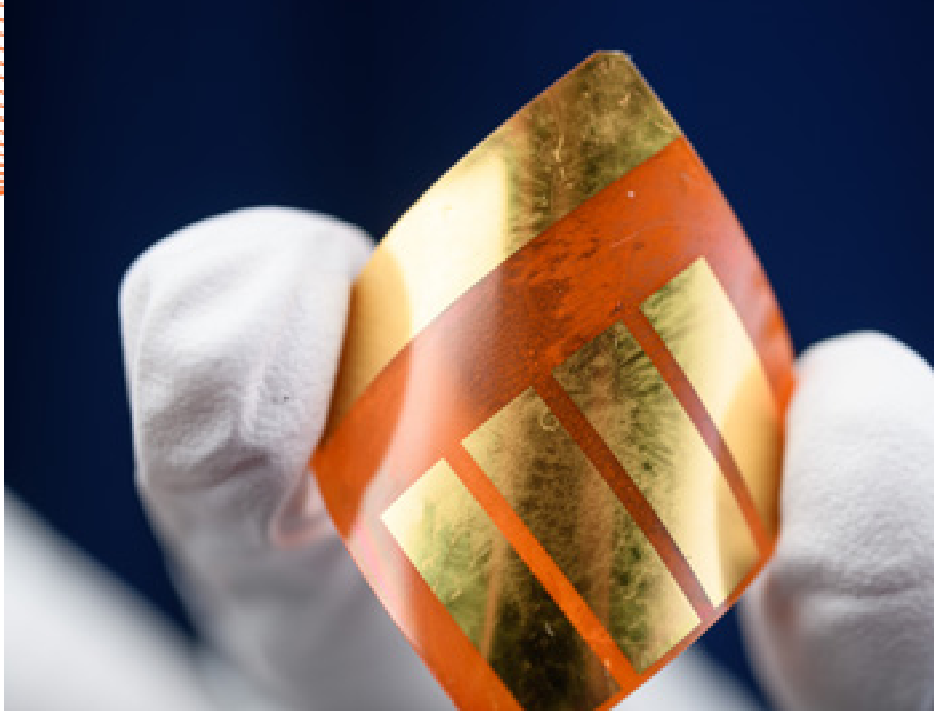
"Gas prices also are cheaper now than they were about a decade ago, so that has slowed the appetite for companies to invest in something that isn't as affordable," Thomas said.

In the meantime, Thomas stressed that engineers and scientists need to put more focus on the methods they use to evaluate emissions. Specifically, she said more needs to be learned about how new and future fuels decrease — or increase — emissions. According to Thomas, Georgia Tech can lead in that direction because it's a "can-do" place.

"When I suggest something here on campus, people are likely to say 'Yeah, let's go do that,'" she said. "That's true even if my idea isn't completely formed. We just go and try it out and put it together. Those are the things, along with our facilities and the vision of our leadership, that make Georgia Tech and the future of low-carbon fuels a really good combination."

"Our goal is to develop technologies that increase efficiency and simultaneously decrease emissions of sustainable aviation fuels."

Wenting Sun



HARNESSING THE SUN

JUAN-PABLO CORREA-BAENA'S JOURNEY TO SUSTAINABLE SOLAR ENERGY BROUGHT HIM FROM COLOMBIA TO CAMPUS

As a child in Colombia, Juan-Pablo Correa-Baena would look at the sky and think about how things could be different.

"Fossil fuels dominate Colombia's energy production landscape even though renewables are readily available," said Correa-Baena, associate professor and Goizueta Junior Faculty Chair in the School of Materials Science and Engineering. "My home country is a large producer of oil but also boasts a huge potential for solar energy production. I grew up wondering why Colombia didn't make that switch."

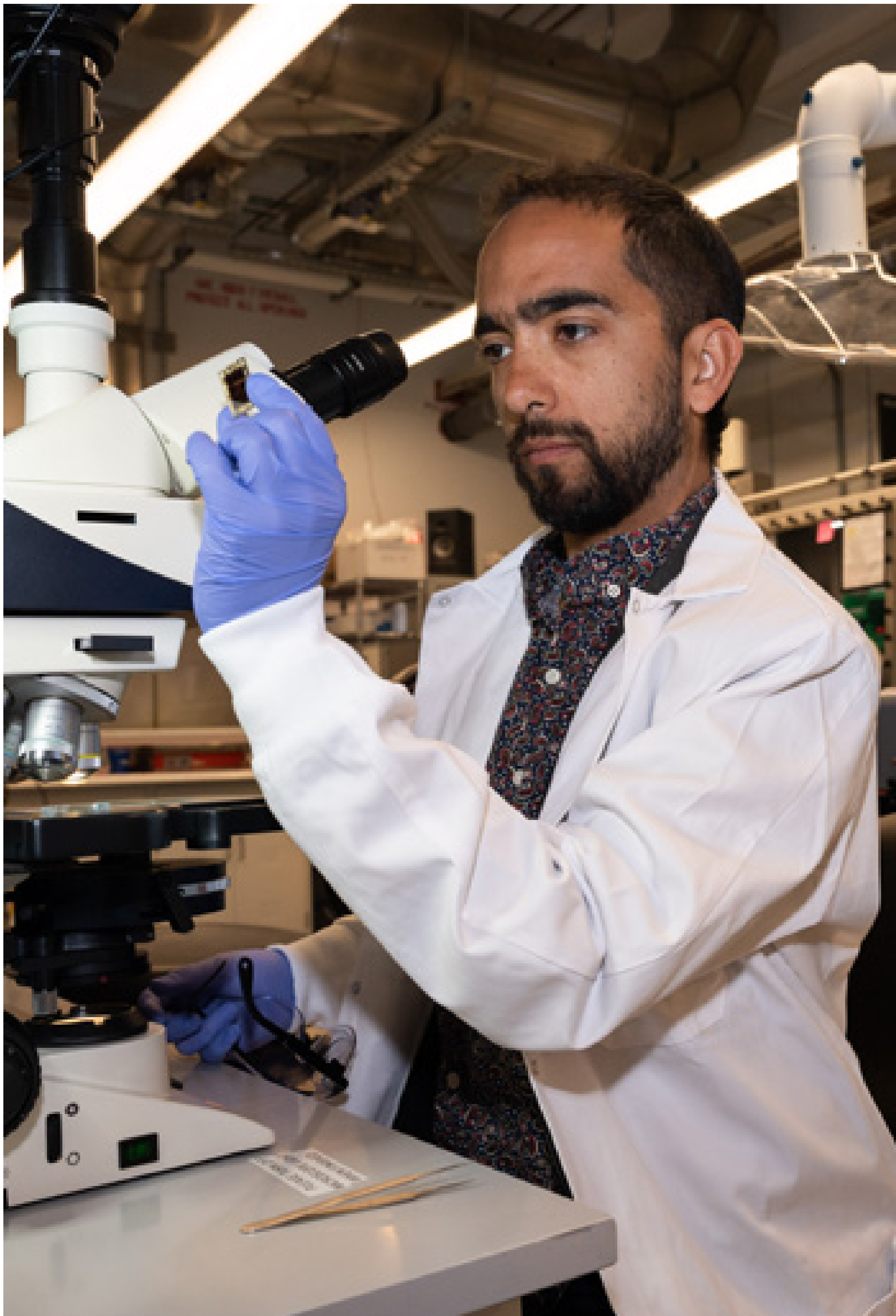
It wasn't until college that Correa-Baena was able to put his curiosity into action. After earning his undergraduate degree in mechanical engineering with a minor in environmental engineering, he focused on solar technology while pursuing his Ph.D.

He now leads a solar energy materials research initiative for Georgia Tech's Institute of Matter and Systems and Strategic Energy Institute.

"I want to ensure that all countries around the world have access to solar energy by helping lower deployment costs," Correa-Baena said.

His research focuses on the development of new materials for low-cost semiconductors used for optical and electronic applications. Correa-Baena's team also works on advanced techniques for characterizing these very small materials and their interactions. He was awarded a highly competitive Sloan Research Fellowship in 2024 to support these efforts.

The award came shortly after his recent study that unraveled the mechanism that causes degradation of a promising new material for solar cells — and how to stop it using a thin layer of molecules that repel water. His lab's findings are the first step in solving one of the key limitations of metal halide perovskites, a new material used to absorb light. They are already as efficient as the best silicon-based solar cells at capturing light and converting it into electricity.



Opposite page: Top, a flexible, lightweight solar cell made from perovskites, a material that could produce energy from sunlight more cheaply and efficiently. Bottom, Juan-Pablo Correa-Baena is a leading researcher developing perovskite technology.

This page: Anna Erickson (right) works with Ph.D. students Natalie Cannon (center) and Alex England in her Laboratory for Advanced Nuclear Nonproliferation and Safety.

CORREA-BAENA: JOYA CHAPMAN; ERICKSON: CANDLER HOBBS

The field's next challenge, Correa-Baena said, is to better incorporate solar energy into the nation's electrical grid.

"Now that solar is as affordable as oil, the U.S. must be more proactive in finding ways to transport and store it," Correa-Baena said. "The government often has been very reactive at this. 'It's cheap! Let's deploy it. Oh wait, how do we connect it?' The Inflation Reduction Act is a great proactive step that is shaping the future of solar energy deployment."

He's also encouraged by Georgia's investment in solar power and investments made by solar companies Qcells and Silicon Ranch, among others. And yet, just as he looked up as a child in Colombia, he sees the opportunities for more when he looks down as an adult.

"Whenever I fly in and out of Atlanta, I see a lot of roofs with nothing on them. Georgia gets so much sunlight, and those businesses, warehouses, and homes are prime spots for solar panels," he said. "Things are going well for deployment, especially with solar farms. But we must push for more consumer activism and talk to our politicians about paying closer attention to where this technology can be further deployed."

NUCLEAR POWER AND NET ZERO

FROM CHERNOBYL CLIPPINGS TO THE WOODRUFF SCHOOL, ANNA ERICKSON ADVOCATES FOR NUCLEAR ENERGY'S SAFETY AND STRENGTH

Her mom asked her to stop — repeatedly — but Anna Erickson kept on going. She was just 5 years old, yet Erickson would gather newspaper clippings about the Chernobyl nuclear disaster and read them to her younger sister again and again.

Her mother worried it would scare the baby. But that fascination set the groundwork for Erickson's lifetime of interest in nuclear energy.

Decades later, Erickson is one of the nation's most prominent researchers in nuclear power security, safeguards, and sustainability. Nearly every casual conversation about her job inevitably turns to the notorious nuclear disasters at Chernobyl, Three Mile Island, or Fukushima. But just as she was determined long ago to keep reading to her sister, she's similarly focused now on telling people that nuclear energy is safe — and necessary for the future.

"Nuclear has the best safety record among traditional energy sources," said Erickson, Woodruff Professor in the George W. Woodruff School of Mechanical Engineering. "Spent fuel, or what some call nuclear waste, lasts a long time. But we know how to handle and store it. Importantly, spent fuel can be recycled into additional energy sources for reactors using isotope separation techniques. Nuclear disasters are incredibly rare. And human health is much more negatively impacted by emissions from coal and fossil fuels."

The dangers are minimal, Erickson said, and the benefits of nuclear power are unmistakable. She noted that nuclear plants produce maximum power about 93% of the time. Their output isn't affected by weather, supply and demand, or financial markets.

For comparison, geothermal offers maximum power three-fourths of the time, natural gas 57%, and hydroelectric systems half the time. Coal produces max electric just 40% of the time.

Erickson said nuclear energy will be even more imperative in the years to come: more data centers and artificial intelligence will need substantial energy supplies all day, every day. Data centers currently represent about 4% of electricity demand, but Erickson said the number is expected to more than double by 2030. It's why Microsoft recently announced an agreement to reopen a nuclear unit at Pennsylvania's Three Mile Island and purchase all of the plant's electricity.

"Americans aren't good at consuming less, so future electricity needs for everything will only increase," Erickson said. "Nuclear shouldn't be, and can't be, the only source of power. But it definitely needs to supplement other carbon-free, sustainable sources."

To get there, Erickson suggested three strategies.

One: build more nuclear plants. When the third and fourth units began operating within the past year at Southern Company's Plant Vogtle in Waynesboro, Georgia, they were the first newly constructed nuclear units in the U.S. in more than 30 years. They're among 94 currently in operation around the country. However, to achieve America's goal of net-zero carbon emissions

> "Future electricity needs for everything will only increase. Nuclear shouldn't be, and can't be, the only source of power. But it definitely needs to supplement other carbon-free, sustainable sources."
>
> Anna Erickson

from power plants by 2050, the nation will need to triple the output of nuclear power and add 200 more nuclear reactors.

"Vogtle cost about $36 billion, so it's not possible to build 200 more at that cost," Erickson said. "Fortunately, we don't have to, because we learned so much as Vogtle was ramping up about supply chains and how plants could be built at scale."

She said a cheaper, faster approach for bringing additional nuclear power to the grid would be reopening decommissioned reactors and extending their operating licenses well into the future. This is her second strategy. Michigan's Palisades Nuclear Plant near Grand Rapids recently secured a $1.5 billion loan from the Department of Energy with plans to reopen in 2025. It would be the first shut down U.S. nuclear reactor to be revived.

Erickson's third strategy is to continue pursuing advanced nuclear power, including fusion technologies — something she admitted has been promised "in about 30 years" for decades. She said fusion is closer now than ever before and perhaps about 15 years from viability because of federal and private equity support. Multiple advanced fission reactors also are being designed by a number of national laboratories and private companies, promising additional diversity in nuclear energy generation.

Erickson is encouraged about nuclear power's future partially because public opinion has shifted. A 2023 Gallup poll found that support among Americans for nuclear power is at its highest point in more than a decade. Part of her job will be continuing to address misconceptions about the technology and advocating for its increased role in sustainability.

"We've been creating nuclear power for more than 70 years. If all its waste were stored at the same place, it would only cover one football field, 10 feet deep," Erickson said.

"We need to diversify to meet the nation's carbon zero goals. And nuclear is a clear path to making it happen."

Above: Units 3 and 4 of Plant Vogtle were the first newly constructed nuclear units in more than 30 years.

Opposite page: Top, Tequila Harris (center) with members of her Highly Advanced Roll-to-Roll iManufacturing Systems (HARRiS) lab group in the new roll-to-roll manufacturing facility. Bottom, The Modular Pilot Scale Roll-to-Roll Manufacturing Facility will serve as a test bed for scaling up manufacturing research. It is open to Georgia Tech researchers and academic, government, and industry partners.

SUSTAINABILITY ON A ROLL

TEQUILA HARRIS' ROLL-TO-ROLL MANUFACTURING TECHNIQUES MEAN FEWER STEPS AND LESS WASTE WHEN MAKING RENEWABLE MATERIALS

Sustainability is a cornerstone of Tequila Harris' lab, where she works on coating science and technology for clean water applications, renewable materials, and advanced roll-to-roll manufacturing processes.

A key focus is decreasing the number of steps needed to fabricate thin and thick film technologies used in these areas.

"Fewer manufacturing steps translates to less energy and water requirements, making the manufacturing methods more sustainable," said Harris, professor in the Woodruff School. "When you consider material scalability, fewer steps when fabricating billions of parts can have a significant impact."

Harris' lab explores how the manufacture and design of films, components, and systems affect both their functionality and their life expectancy. From that, she can determine process, structure, and property relationships to enhance performance.

In short, she looks to fabricate materials developed by chemical engineers, material scientists, and chemists, quickly, cheaply, and effectively.

"Our lab determines what systems, strategies, and tooling can be used to process things faster while maintaining the same, or better, performance," Harris said.

Harris' go-to tooling and manufacturing system combination for the last 18 years has been a slot die coating on a roll-to-roll facility. It's one of the fastest growing technologies for scaling thin film materials. She produces thin films, coated on a wide variety of substrates, that can be housed in large rolls for later use. When creating the materials at scale, Harris takes great care to detect and correct defects to minimize waste and increase the amount of usable material.

That relentless focus on eliminating waste is why the mantra in her Highly Advanced Roll-to-Roll iManufacturing Systems (HARRiS) group is "No gaps, no scrap."

PLANT VOGTLE: GEORGIA POWER COMPANY

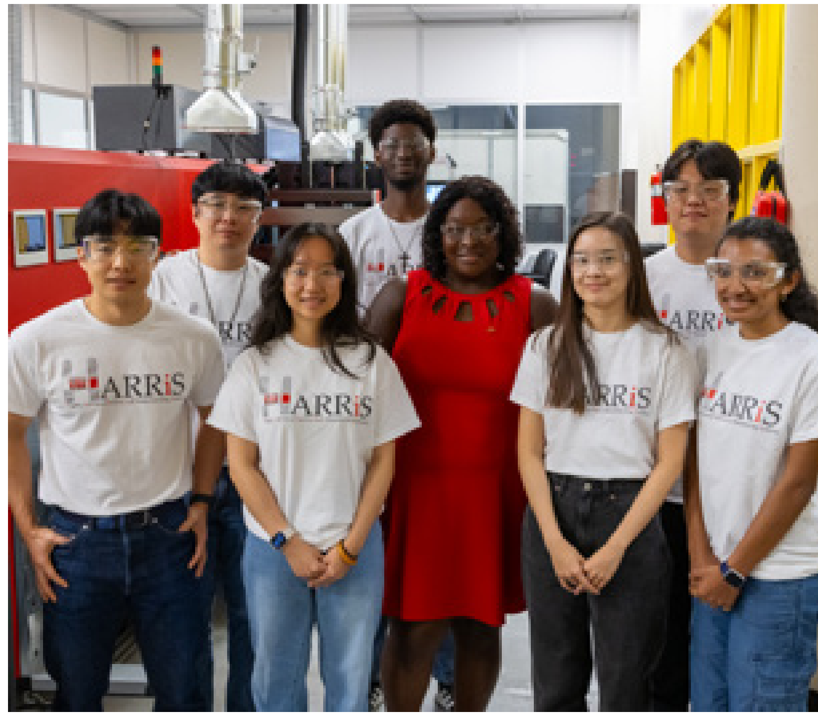
That work received a boost this fall. Harris opened a new modular, pilot scale roll-to-roll facility to advance thin film research and development beyond the lab. The facility is open for a large variety of materials that Harris' group can use across a plethora of different technologies.

"Using our new modular, pilot scale roll-to-roll manufacturing facility, we can analyze film fabrication at speeds a thousand times faster than what has been realized at the laboratory scale," Harris said. "Instead of creating material at one-tenth or three-tenths of a meter per minute, we process materials at coating speeds up to 200 meters per minute, using flexo, gravure, or inkjet printing in addition to slot die coating at the pilot scale."

The HARRiS lab works with academic, government, and industrial users, all with the goal of building an ecosystem around scalable manufacturing for a broad collection of materials. On campus, Harris works with Sankar Nair in the School of Chemical and Biomolecular Engineering (ChBE) on new membrane materials for papermaking. With ChBE's Carson Meredith and Meisha Shofner in MSE, Harris' lab is collaborating on renewable food packaging. She is planning for a future partnership with McDowell on his battery technologies.

Her focus on improving products and materials comes, in part, Harris said, from a childhood where she was exposed to a combination of a small farm-to-table lifestyle and industrial factories in neighboring towns where many people in her community worked.

"I preferred improving and making products to farming," she said. "In graduate school, I studied manufacturing and design of machine tools. When I began my career at Georgia Tech, my focus shifted from solely coating technology to the integration of coating science. This has led to the design and implementation of innovative manufacturing approaches with an understanding of the entire coating process and the quality and performance of the resulting materials."



LAB: ASHLEY RITCHIE; HARRIS GROUP: CHRIS MCKENNEY

BY JOSHUA STEWART

PLANTING THE SEEDS OF THE FARM of the FUTURE

Georgia Tech engineers are working to reduce the environmental impact of farming while creating technologies to help farmers feed a growing world and adapt to a changing climate.

On the farms of the future, growers will be able to apply precisely the amount of fertilizer plants need at exactly the right time. And they'll know just when to harvest the produce at peak nutritional value. The result? Less fertilizer runoff to pollute waterways. Less water for irrigation. Less planet-warming emissions in a sector that accounts for a third of the world's greenhouse gas generation.

That's the vision Yongsheng Chen is working toward in a lab where robotic arms and state-of-the-art imaging systems are allowing him to capture data in unprecedented detail and create digital models of crops.

Using hundreds of images of each plant, Chen's team in the School of Civil and Environmental Engineering builds representations in computers to map the relationship between the plant's physical growth and its nutrient content. Understanding the connections will help him zero in on the perfect time to harvest the crops.

"For example, lettuce typically might grow for 20 to 28 days before harvest. Is the 28th day a good day to harvest? Or is it the 20th day? The model might tell you 20 days should be enough to get optimal nutrition," said Chen, the Bonnie W. and Charles W. Moorman IV Professor. "That saves eight days' time and resources, including energy and fertilizers. You can use that model to minimize the greenhouse gas emissions and other resources needed for agriculture."

Harvesting lettuce or other crops at the peak moment ensures high quality produce. It also helps farms maximize their productivity. Growers can turn over fields at the optimal rate and avoid overburdening soil with too much fertilizer.

Overapplying fertilizers also wreaks havoc on downstream water bodies, where runoff can lead to overgrowth of plants in streams and lakes that cuts off oxygen for animal life in a process called eutrophication.

This kind of pollution has contributed to a dead zone in the Gulf of Mexico every summer that can grow as large as New Jersey. The area is so devoid of dissolved oxygen in the water that fish and shrimp hightail it away. Slower or nonmobile marine life like crabs and clams are left to die.

In a related project, Chen is adding another layer of prevention. His team is adapting an innovation called neural radiance imaging to examine crops' roots and study how they take in nutrients.

"We're able to link the fertilizer uptake kinetics we see in the produce so that we can determine how much nutrient — fertilizer — is needed at different times, so that we can deliver fertilizers more accurately," Chen said. "If you overdose the fertilizer, you end up with greenhouse gas generation, such as nitrous oxide, and rain-off from soil-based food production where all the fertilizer is washed into local rivers and lakes that become eutrophicated. That is not good. By investigating these root images, we'll be able to deliver the nutrients more accurately."

Ultimately, Chen said he wants to integrate those two approaches into a full digital agriculture system that would mean high productivity while allowing for maximum nutrition from crops.

For Chen, these issues are critical — and becoming more so. He's one of a number of Georgia Tech engineers tackling agricultural sustainability in hopes of reducing waste and pollution while also feeding a growing world population.

These researchers are helping lead national efforts to turn waste into an asset, reduce runoff and recycle excess fertilizer, and greatly reduce the carbon impact of creating the nitrogen plants needs to thrive. They're also working on technology to boost natural processes and help growers around the world adapt to a changing climate.

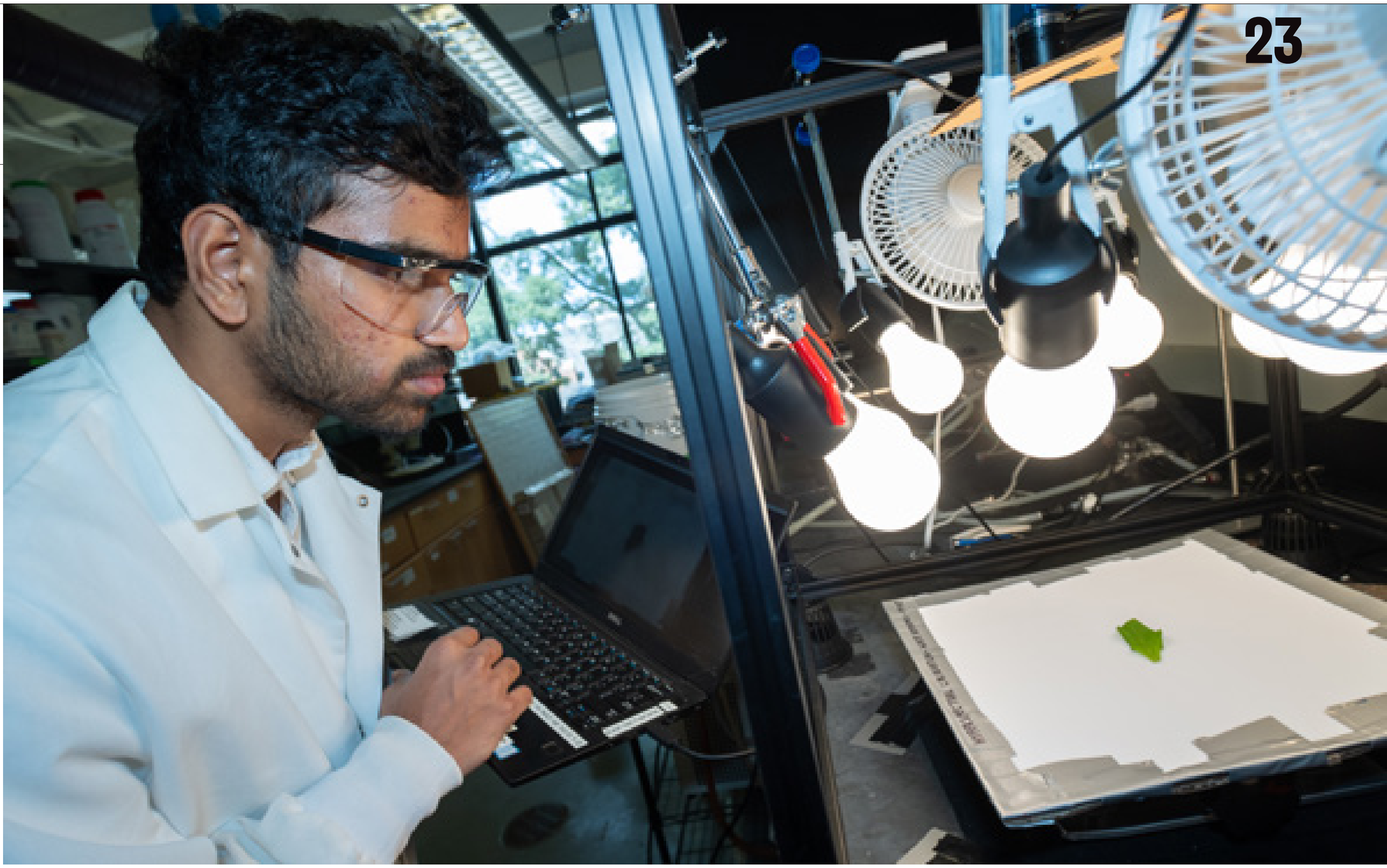
No More Wasting Wastewater

Chen sees wastewater as a key to addressing the challenges of feeding a growing and increasingly city-dwelling planetary population.

More than half of the world already lives in urban areas, and the United Nations projects it will grow beyond two-thirds by 2050. Meanwhile, the global population continues to increase, and food production must expand — by more than 50% by some estimates — to feed those people. To further complicate the picture, the U.N. Intergovernmental Panel on Climate Change suggests

Previous page: Yongsheng Chen examines lettuce growing in his lab's vertical farm with first-year environmental engineering student Swathi Mugundu Pradeep (seated) and Ph.D. student Yuming Sun.

Opposite page: Computer science master's student Harsh Muriki uses hyperspectral imaging to collect data about the nutrient content of a lettuce leaf.



CANDLER HOBBS

the expansion of cities will inevitably mean less land for crops, further suppressing food production.

Growing food produces lots of greenhouse gases. And those urban areas are already responsible for 70%-75% of emissions and energy use.

Chen and his team are developing an integrated and decentralized system of wastewater treatment and vertical farming that could address all of those issues, producing more food and turning a waste stream into a valuable resource.

"It's very challenging. We have to shift the current paradigm from a unidirectional waste treatment approach to a more circular economy," Chen said. "How do you do that? We propose recovering nutrients and water from wastewater so that we can grow produce within a city using vertical farming."

In Chen's vision, cities would capture and treat wastewater in multiple smaller locations rather than existing large, centralized treatment plants. Using a process his team is developing, the systems would recapture significant amounts of phosphorus, nitrogen, and ammonia, all key nutrients for growing crops.

The resulting "fertigation" water would both feed and water plants growing in compact, vertical farms co-located with the wastewater treatment systems.

AI4OPT

Chen leads the AI for Sustainability thrust of the Artificial Intelligence Research Institute for Advances in Optimization (AI4OPT), a multi-university effort to deliver a paradigm shift in automated decision-making. Funded by the National Science Foundation and headquartered at Georgia Tech, AI4OPT aims to deliver breakthroughs addressing societal challenges in energy, supply chains, sustainability, and chip design and manufacturing.

www.ai4opt.org

With such a system, people have local food, cities have fewer issues dealing with the waste of growing populations, and, as a bonus, Chen's approach virtually eliminates the carbon emissions from transporting produce across the country to feed mega population centers.

To see if the idea has legs, the researchers have done some ballpark estimates using the City of Atlanta's three major wastewater treatment plants and a variety of representative crops — broccoli; leaf, romaine, and iceberg lettuces; spinach; bell peppers; tomatoes; and strawberries.

"We can grow enough vegetables to feed Atlanta's 5 million plus population," Chen said. "We don't have to transport the vegetables from the West Coast. That is the beauty of this decentralized food production system."

The proposed system also would recover additional water that could be used for industrial purposes and power plant cooling or further treated to become drinkable water again.

Chen and his collaborators have worked for several years to develop the technology to make the system work and grow safe-to-eat vegetables. Their efforts have included an on-campus test site harvesting wastewater from residence halls, extracting nutrients and water, and growing vegetables.

> "We have to shift the current paradigm from a unidirectional waste treatment approach to a more circular economy … We propose recovering nutrients and water from wastewater so that we can grow produce within a city using vertical farming."
>
> Yongsheng Chen

Yongsheng Chen's work on agricultural and urban sustainability includes studying hydroponically grown food and assessing its nutrient content.

One of their key advances has been a unique membrane that effectively filters out contaminants while leaving the useful phosphorus, nitrogen, and water. Early results are promising: The membrane removed nearly 90% of contaminants like PFAS, often dubbed "forever chemicals," as well as antibiotics and other pharmaceuticals. And while they haven't tested for them, Chen said microplastics also should be filtered out of the resulting fertigation water.

The researchers continue to work on other membrane designs, too, using machine learning tools and decades of data from scientific literature to create a model that can suggest new materials. So far, they have a bank of eight promising membrane materials that should outperform current membranes. The team also is working to integrate their membrane filtration process into existing wastewater treatment systems.

Chen said his wastewater-to-vertical farm approach isn't all that different from nature, where groundwater and surface water used to nourish crops on traditional farms contains waste from birds and animals along with antibiotics and other human-produced contaminants.

Still, much work remains to advance Chen's technology to the point where it could serve large, urban areas. But he said the urgency is real, and the potential to solve many problems at once is compelling.

"There's a huge mismatch within urban areas between demand for food and supply. If we decentralize the wastewater treatment and the food production within the city, we will be able to minimize this discrepancy," Chen said.

"Plus, we can reduce the carbon emissions associated with food production and transportation as well as traditional wastewater treatment processes."

Closing the Fertilizer Loop

Marta Hatzell has her own ideas about turning wastewater into something valuable.

One project in her lab is exploring how to recover raw materials from the waste and produce urea, the most widely used nitrogen-based fertilizer. Typically, urea is manufactured commercially by creating ammonia and then combining it with carbon dioxide.

Instead, Hatzell's system would create urea fertilizer using CO_2 scrubbed from the atmosphere at a direct air capture facility and pairing it with nitrates recovered from a wastewater treatment plant.

"The idea is that capturing carbon dioxide gives us this solution rich in CO_2. Can we then merge that with wastewater that's rich in nitrate and do a catalytic process that converts it directly to urea? If we could, that would be a carbon-negative process. And then we also would not have to make fresh ammonia to make urea," said Hatzell, Woodruff Associate Professor in the George W. Woodruff School of Mechanical Engineering and the School of Chemical and Biomolecular Engineering.

Direct air capture systems are becoming an increasingly popular idea for removing carbon from the air and storing it underground or finding ways to reuse it. Georgia Tech has been a hub for developing the approach, with the world's foremost experts in the technology. Hatzell said it wouldn't be unrealistic to imagine a direct air capture system co-located with a municipal wastewater treatment plant, making it easy to draw from the streams of CO_2 and nitrate-rich waste.

Hatzell spends much of her time thinking about fertilizer — better ways to create it and new approaches to recycling or reclaiming the excess after use. Her goal is to reduce the carbon impact of a critical tool for food producers trying to feed more people.

She has developed processes that use light to produce ammonia at ambient temperature and pressure using far less energy than current high-temperature, high-pressure practices. Her team has created new chemical catalysts to convert waste fertilizer back into harmless nitrogen that also could serve as raw material for new fertilizer.

These and other projects in Hatzell's lab are aimed at reducing agriculture-related emissions upstream, metaphorically, of the actual farming and waterway pollution literally downstream.

Some of her newest work would tackle both ends of that spectrum for livestock farms, or concentrated animal feeding operations in industry parlance. Hatzell is working to recover valuable compounds from animal waste with a relatively inexpensive process that yields clean, nutrient-rich water that can be used — like Chen's nutrient-rich water — for crop fertigation.

"We've demonstrated the ability to get really high recovery of the nutrients that we want, at high weight percents, and at a reasonable cost," Hatzell said. "That is always the challenge with nutrient recovery systems. For agriculture, you have to have low cost and high recovery, and you have to do it with energy efficiency."

Hatzell's targets are storage lagoons where waste collects from animal farms. Normally, biological processes slowly decompose the waste.

Her team instead would use electricity and special filtering membranes to extract useful ammonia from the waste. Their process would produce 90% purified water and 10% ammonia, with contaminants like PFAS, pathogens, and antibiotics stripped out.

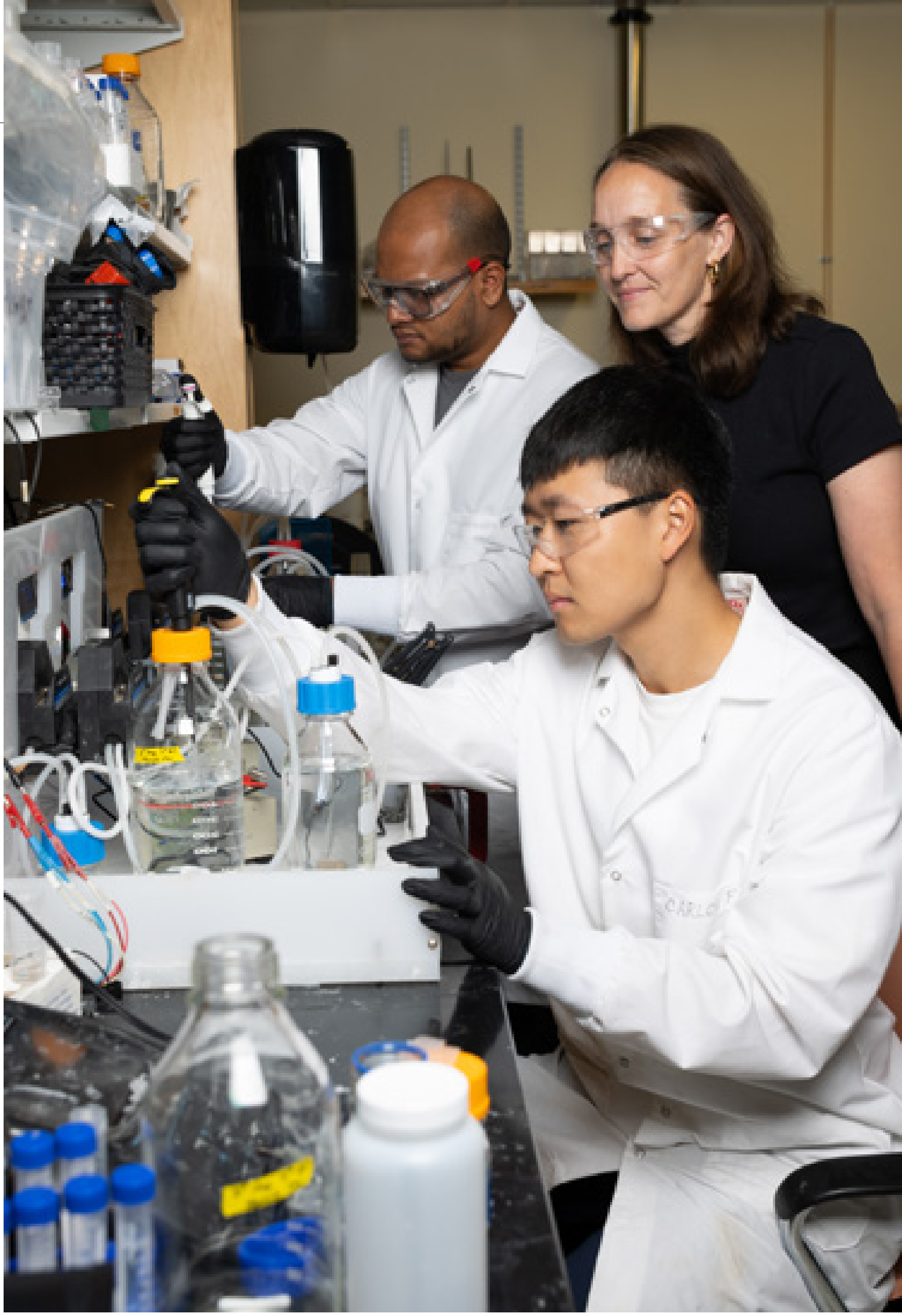
"At the end of the day, you would get this pure water-plus-ammonia mixture," Hatzell said. "We could crystallize that out to make solid fertilizers like ammonium phosphate or ammonium nitrate. But we think it's best to just connect that ammonia water to an irrigation system and deliver it as a liquid fertilizer."

Why is ammonia so important? It's the fundamental building block for fertilizers, replenishing nitrogen in the soil that plants quickly deplete as they grow. The air we breathe is mostly nitrogen, but not in a form that's biologically or chemically useful. Combining it with hydrogen to create ammonia allows it to react with soil and feed plants.

Producing ammonia isn't all that easy. It requires significant petroleum-based energy and can only be done at 100 or so large-scale facilities worldwide because of the high temperatures and pressures required. That also means fertilizer is usually produced as solid granules that are easier to ship around the world.

Transporting liquid like Hatzell's water-ammonia fertilizer is much more challenging — distribution would have to be across tens of miles rather than hundreds to be worthwhile. Yet the benefits could be substantial, she said.

In addition to dealing with problematic livestock waste lagoons, liquid fertilizer application can be much



CANDLER HOBBS

Marta Hatzell's lab is developing processes to extract reusable ammonia from waste at livestock farms. Ph.D. students Mohammed Tahmid (standing) and Hyuck Choi are among the researchers working with her to use electricity and special filtering membranes to recover the useful nutrient.

more precise than a few blanket applications of solid granules every year. With automation, artificial intelligence, satellite imaging, and robotics, Hatzell said engineers can design systems that precisely apply the right amount of nutrients alongside the right amount of irrigation at just the right time. And that's far easier to control than granular products.

The results would be less waste, more food, and maybe even value for farmers from what can be a cost center now. Sometimes they have to actually pay to dispose of the animal waste that has collected.

But this all would mean big changes in how things are done.

"It's changing what a fertilizer looks like: Instead of starting with pure, virgin feedstocks, let's start with waste that is accumulating at agricultural sites," Hatzell said. "That's the first paradigm shift. The second is to move from the solid, granular, salt-based fertilizers to a liquid-based fertilizer. And then that creates more circularity."

"Circularity" is a key driver of Hatzell's work. It means converting the nitrogen production cycle from a straight line into a circle, where waste isn't wasted anymore.

"I think there's such a good economic and societal motivator for coming up with technologies to deal with waste," Hatzell said. "That's why we started to work in this space. There's an economic need, an engineering need, and a societal need."

CASFER

Hatzell is one of the Georgia Tech researchers leading a National Science Foundation-funded center focused on resilient and sustainable food production. The Center for Advancing Sustainable and Distributed Fertilizer Production (CASFER) includes four other universities working to decarbonize nitrogen-based fertilizers and develop the next generation of fertilizer technology. Hatzell leads the center's efforts to capture, concentrate, and recycle nitrogen-based nutrients.

www.casfer.us

Boosting Nature's Process

A project getting underway spanning Atlanta and Chile involves chemical and biomedical engineers working to speed up and amplify natural processes rather than recovering or reusing materials. The goal is to help farms be more productive, even in the face of a changing climate.

Lily Cheung and Shu Takayama spent a week this summer with partners and farmers in the South American country to understand their needs and approach to farming. With support from the National Science Foundation (NSF), the pair of Georgia Tech engineers aim to develop biomaterials or natural polymers that can help retain water in the soil, speed up creation of compost, fight pathogens, and perhaps increase the availability of phosphate for plants.

It's not what they originally had envisioned when they set out to design a project for the NSF's Rules of Life research program, but that was the whole point of their visit to Chile — to discover what farmers truly needed before they created solutions.

Chile is an excellent proving ground, Cheung said, because the country has a range of agricultural operations, from small subsistence farms all the way up to industrial crop production. The materials or processes the researchers create with their Chilean collaborators will be useful for American agriculture and farms in other parts of the world, too.

"Water is a problem, nitrogen is a problem, phosphate is a problem," said Cheung, assistant professor and Roy C. and Polly B. Sheffield Faculty Fellow in the School of Chemical and Biomolecular Engineering.

"We're working to help small farmers without having to rely on external inputs and non-agroecological practices. For example, how do we make composting faster? That was one question that we started thinking about during our visit. It was not in the original conception of the project, but if it's what a small farmer needs, then that's what we need to think about."

Cheung said they discovered small subsistence farmers can get all the nitrogen they need from compost. Medium-sized farms, on the other hand, might benefit from the team creating new biomaterials to encourage the growth of microbes that infuse more nitrogen into the soil through a process called nitrogen fixation.

Takayama said they were struck in Chile by how much climate change has altered the landscape for many farmers. For example, land that used to be fine without irrigation now requires extra water, yet the infrastructure isn't in place to support it.

The Covid-19 pandemic also limited the availability of fertilizer for many farmers in Chile, so there's a strong desire to eliminate the need for that kind of expensive, imported material.

"We had this idea about nitrogen fixing, but we went there and found climate change, water, and pathogens are huge problems," said Takayama, professor and Price Gilbert Jr. Chair in the Wallace H. Coulter Department of Biomedical Engineering. "The individual farms are so small — they have a little bit more than an acre, and they raise their whole family from that using hardly any equipment and minimal external inputs like fertilizers or pesticides because of the high costs. It completely changed the perspective of what we're trying to do."

Takayama said the team is exploring simple polymers like swelling hydrogels that could retain and slowly release water to help with drought issues. On a more fundamental level, he also wants to understand how different polymers, materials, and bacteria impact soil

PHOTOS COURTESY: LILY CHEUNG & SHU TAKAYAMA

microstructure. Facilitating the right soil structure could be key to boosting microbial nitrogen fixing processes as well as harboring microbes that make phosphate soluble and available for growing plants.

The Georgia Tech team's collaborators include global environmental science and governance scholar William San Martín at Worcester Polytechnic Institute, soil engineer Osvaldo Salazar at the University of Chile, and Sigrid Vargas from Chile's Institute of Agriculture Research. They're also working with a network of government agriculture extension professionals who will share their findings with farmers across the country.

Cheung said they learned from these professionals that it will be key to set up demonstrations to show farmers the effectiveness of whatever solutions they design. That, along with more detailed conversations with farmers, will be the subject of future trips during the five-year project.

Cheung said they're working with a real sense of urgency, because they've seen how critical it will be for farmers in Chile — and other parts of the world — for them to develop practical solutions.

"It's tough research. It will take some years," she said. "But we have to deliver."

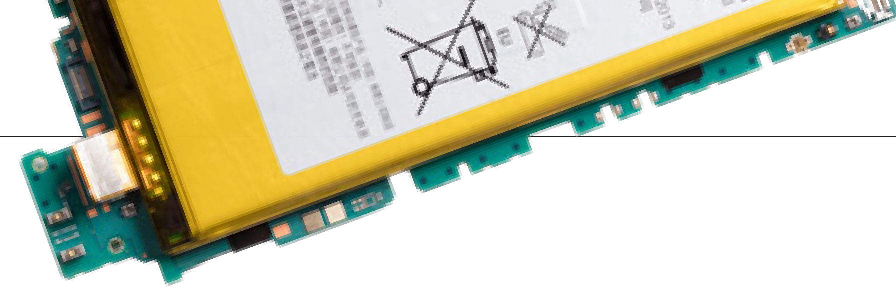
Clockwise from top left: Lily Cheung and Shu Takayama with an aquaculture researcher in his lab at the University of Chile.

Takayama and Cheung at one of the farms they visited during their trip to Chile.

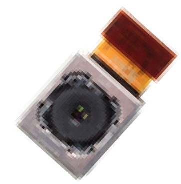
A student from the University of Chile taking soil samples from a small farm.

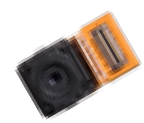
The research group visiting a greenhouse owned by one of the small farms they visited.

BY JASON MADERER



To Hell with Garbage





In the quest to **reduce, reuse, and recycle,** Georgia Tech engineers are at work on ways to divert more trash from landfills, tame plastic pollution, and cut waste from electronics.

For decades, we've been conditioned to look for that little triangle of arrows and taught the mantra "reduce, reuse, recycle."

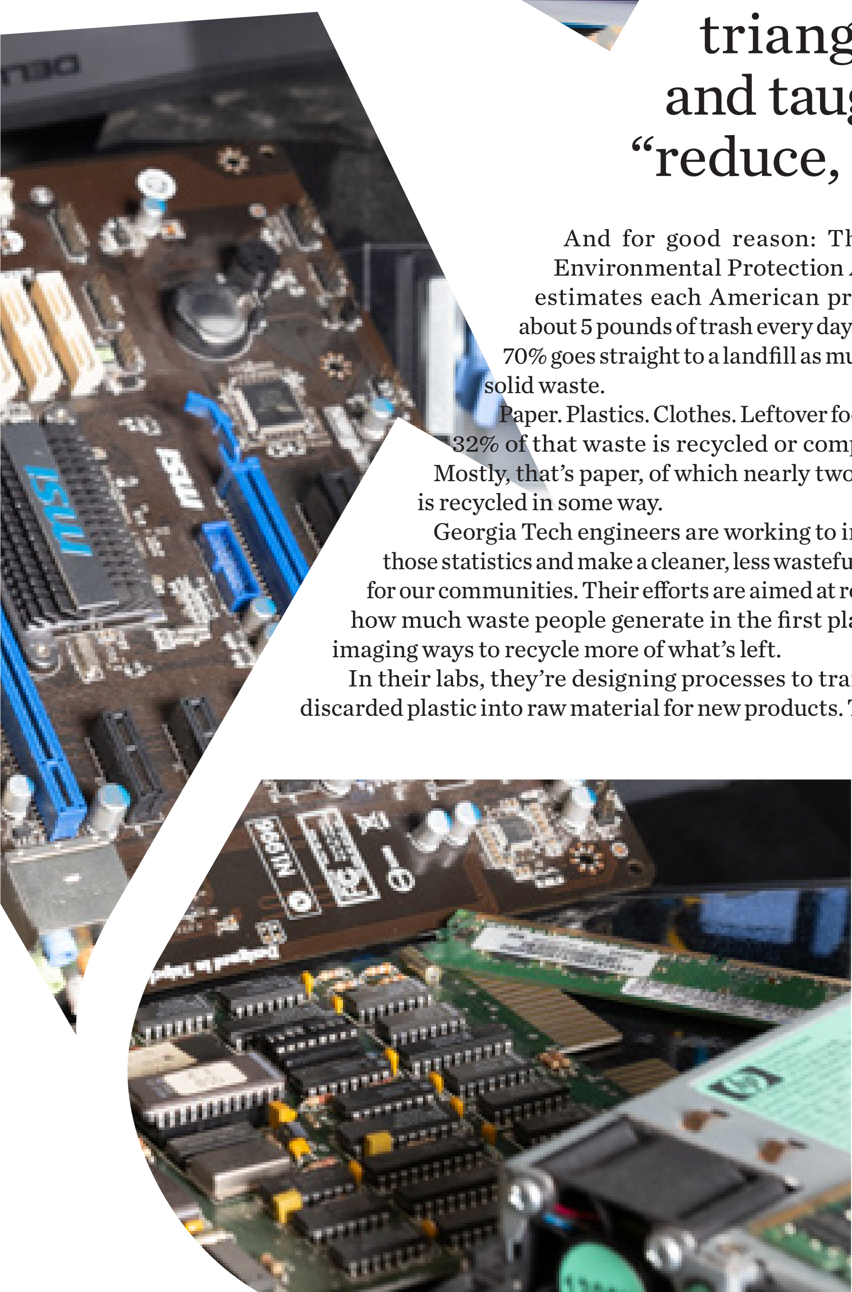
And for good reason: The U.S. Environmental Protection Agency estimates each American produces about 5 pounds of trash every day. Nearly 70% goes straight to a landfill as municipal solid waste.

Paper. Plastics. Clothes. Leftover food. Just 32% of that waste is recycled or composted. Mostly, that's paper, of which nearly two-thirds is recycled in some way.

Georgia Tech engineers are working to improve those statistics and make a cleaner, less wasteful future for our communities. Their efforts are aimed at reducing how much waste people generate in the first place and imaging ways to recycle more of what's left.

In their labs, they're designing processes to transform discarded plastic into raw material for new products. They're creating new kinds of plastic from biological material to vastly reduce plastic pollution. They're developing systems to eliminate emissions and cut water use in the carbon-intensive paper-making industry. They're also addressing one of the newest trash problems in our digital age: electronic waste.

In the three R's of sustainable behavior, "recycle" comes after admonitions to reduce what we consume in the first place and then reuse what we can. That may be because recycling is the hardest to do, and it's often not economical, even when processes exist to do it. Work at Georgia Tech and by its alumni won't rearrange the R's, but it may well reshape how we deal with our trash.



Working From Behind in Race Against E-Waste

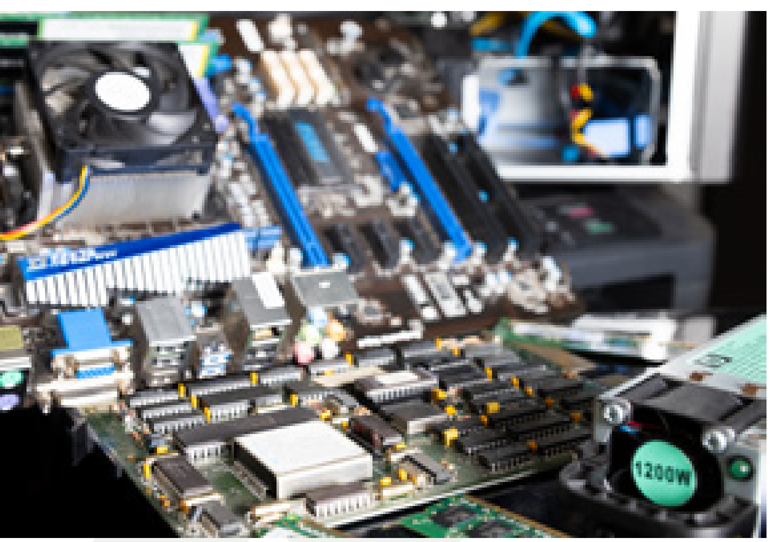
The World Health Organization estimated in 2022 that nearly 62 million tons of waste from electronics is created every year. Only 22% is collected and recycled.

It's not a surprise to Antonia Antoniou and Vanessa Smet, faculty members and collaborators in the George W. Woodruff School of Mechanical Engineering.

Their research focuses on improving electronic packaging for better performance, while also tying that innovation to sustainable fabrication and recyclability. They're looking at new, more sustainable ways to assemble and connect components of electronic systems such as active chips, resistors, and capacitors, both to each other and to their surroundings.

They know that they're working from behind.

"Packaging was typically an afterthought until about 10-15 years ago," said Smet, an assistant professor and expert in electronics packing. "The main focus was the chip's performance. Although a chip by itself is obsolete without being powered and able to communicate with other critical system components, everything related to its integration has been treated as a necessary evil."



only
22%
of electronic waste
is recycled every year

That's a problem, Smet said, because many of the materials involved in creating these integration platforms, such as thermoset polymers with reinforcing fibers, copper, and other metals, don't degrade or are dangerous when they breakdown in landfills.

It's one reason why Antoniou called packaging the "next driver of innovation for high performance electronics." It's an interdisciplinary field, with mechanical engineers teaming with experts in materials science, electrical engineering, and manufacturing.

Antoniou works on the mechanics side of electronics packaging, figuring out how to design materials and their mechanical properties, and how to keep them from failing. Smet is more of a generalist: She has an applied physics background and looks at packaging as a science to develop comprehensive solutions that jointly advance electronics performance, reliability, and sustainability. She aims to transform that knowledge into new materials and industry-scalable manufacturing practices.

Smet said packaging is coming to the forefront now because of the continuing rise in demand for better performing electronics and the scarcity and expense of the materials used to make them.

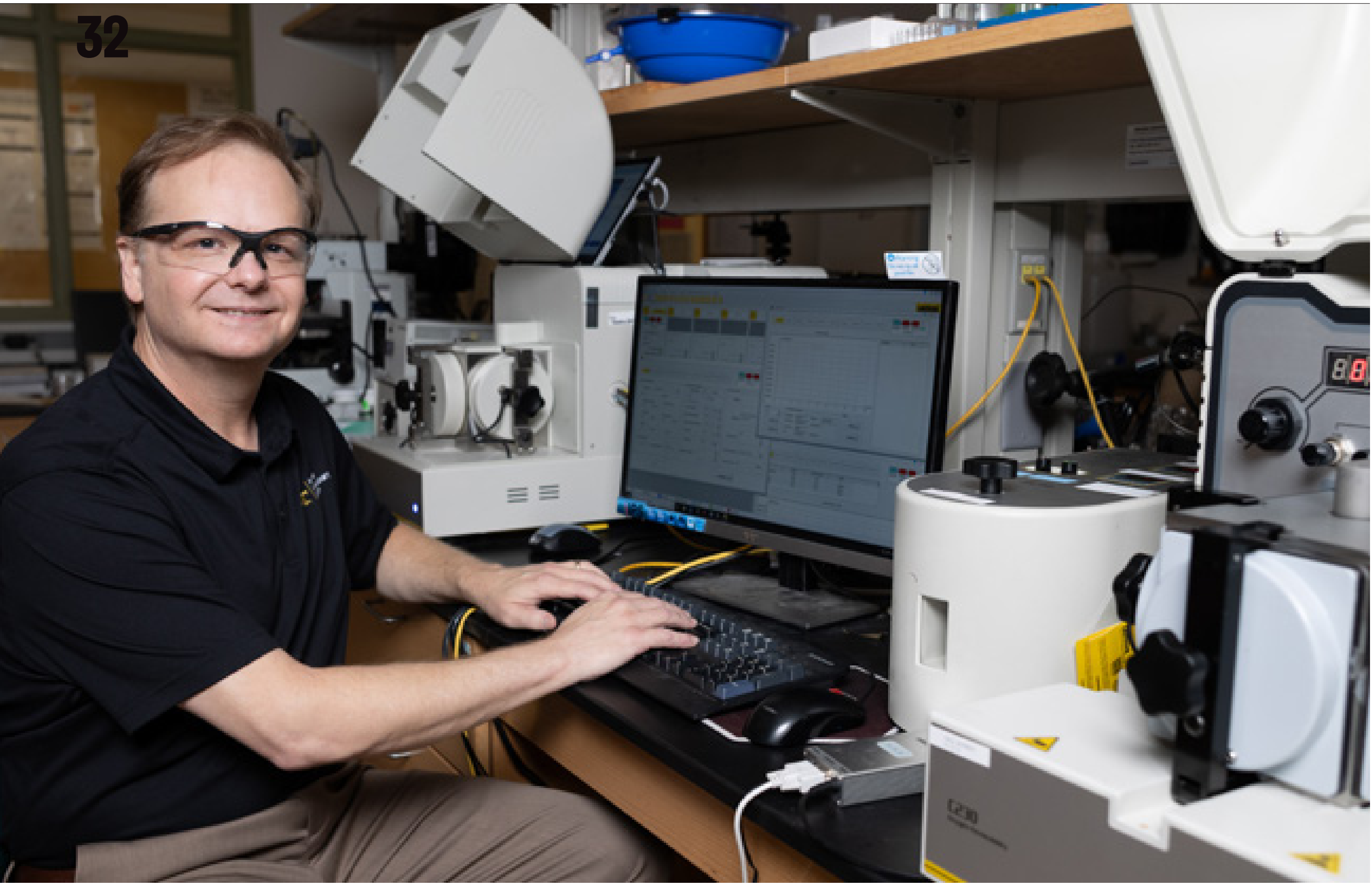
"Think about short-term electronics, like phones, that we may keep for just two to three years before throwing away," Smet said. "There are materials in them that are beneficial to recover, like gold and copper. At the same time, our field is also looking to create sustainable practices to ensure that the manufacturing of electronics is cleaner."

One idea born out of Georgia Tech labs nearly 20 years ago was using glass substrates, instead of silicon, on computer chips. The technology now is used by companies in Georgia, at Intel, and around the world. Another example Smet pointed to is the switch from copper packaging to recyclable aluminum and graphene, which allows for a cleaner manufacturing process. The key, she said, is making sure new components allow for the same, or increased, signal and power efficiency and reliability than the materials used for decades.

"Electronics are in everything," Antoniou said. "The process to make them must be cleaner. If we don't break the waste cycle soon, we'll be in even bigger trouble than we are now. It's becoming more urgent as time goes by, and industry must do more sustainable packaging for electronics recycling and end-of-life."

Antonia Antoniou (left) and Vanessa Smet are working to advance electronics performance and sustainability.

CANDLER HOBBS



Lowering Barriers for Sustainable Packaging

Carson Meredith is a 1993 Georgia Tech chemical engineering graduate.

CANDLER HOBBS

Carson Meredith's group in the School of Chemical and Biomolecular Engineering (ChBE) is focused on a different kind of sustainable packaging: advanced barrier packaging.

It's a fancy name, but it's simply the plastic packaging most of us encounter every day with food and medicines. They're a staple in supermarkets: pouches for deli meat and cheeses, the see-through wrappings that cover steak and ground beef, and vacuum-sealed food bags, to name a few.

By providing a barrier to oxygen and water vapor, the plastic wraps extend shelf life by days, weeks, even years. Ironically, the wraps themselves have a very short lifespan.

Unlike simple plastic grocery bags that can be recycled, the barrier wraps are more complex, making them one-and-done single-use materials. They're made up of several different types of plastics layered into a single film. And that, Meredith said, makes it too difficult and expensive for recycling. It's why he and his collaborators are searching for new technologies and processes to change the materials' chemistry and make them more environmentally friendly.

"The amount of plastics in our oceans is certainly upsetting and gets people mobilized. And that social awareness is good," said Meredith, professor and James Preston Harris Faculty Fellow. "But the bigger sustainability problem is the large carbon footprint of constantly remanufacturing these single-use plastics with fossil fuel-based feedstocks instead of finding ways to reuse their carbon."

Meredith and his collaborators have pioneered renewable, biodegradable, and recyclable barrier materials that can serve as alternatives to the familiar synthetic plastic barriers. About a dozen years ago, long before he was tapped as executive director of Georgia Tech's Renewable Bioproducts Institute (RBI), Meredith received RBI funding to explore whether plant-derived materials could be used for advanced barrier packaging.

He found that blending cellulose nanomaterials with chitin nanofibers — carbohydrates found in the cell walls of mushrooms or crustacean food waste — is effective at generating the oxygen and carbon dioxide barriers important in packaging. These renewable resources have become a main focus of his lab and led to numerous collaborations funded by the Department of Energy (DOE) and industry partners. These materials can even be coated onto paper to transform it into a gas barrier, a major focus of his group's work. Using paper as the base material is attractive because it is derived from a renewable resource and it is recycled at rates exceeding 70%.

Meredith also is looking at making paper packaging more sustainable. It's a burgeoning field because of the convenience and popularity of online shopping and shipping.

"In North America 'working forests' that produce wood for paper are required by law to replant harvested trees. They usually do so at a rate higher than they are cut, so it is a sustainable resource," Meredith said. "However, the carbon footprint of making paper is still fairly high, especially in mills that make it from recycled products."

When a mill makes "virgin" paper from trees, Meredith said, they use lignin derived from the wood as a biofuel to create heat for drying purposes. It's a circular system: the bio-based carbon emitted during combustion is absorbed by growing more trees. But mills that make paper from recyclables often don't have the convenient lignin biofuel available. They must find their own fuel — very often natural gas — to dry paper and paperboard products.

"Producing paper requires hundreds of kilograms of water for 1 kilogram of dry product. Evaporating that water is tremendously energy intensive. Our lab is trying to de-fossilize the generation of heat in the production of paper and paper packaging to minimize the carbon footprint," Meredith said.

One way they're doing that is by developing a papermaking machine that produces zero carbon dioxide emissions. The device is part of a new $3.1 million DOE award with the Woodruff School's Cyrus Aidun and RBI's Patricia Stathatou, who will join the ChBE faculty in January 2025. The development makes use of Aidun's multiphase forming process being installed as a pilot facility at RBI, which replaces about 50% of the water with air bubbles for paper forming. The remaining water is to be dried with electrified inductive and infrared heating that could be supplied by renewable or clean electricity.

"If you don't need as much water to form the paper, you don't have to remove as much water later. So the process ends up saving a lot of energy and reduces greenhouse gas emissions," Meredith said.

In another interdisciplinary project with Victor Breedveld (ChBE), Blair Brettmann (ChBE/School of Materials Science and Engineering), Chris Luettgen (RBI/ChBE), Scott Sinquefield (RBI), and Valerie Thomas (H. Milton Stewart School of Industrial Systems and Engineering), the team is improving mechanical dewatering steps that remove water without heat.

"The public recycles the majority of used paper, and industry has an established process for using recycled material. The last hurdle is reducing its carbon footprint," Meredith said. "I'm proud that Georgia Tech is leading the nation in innovative ways to do that."

70%

of used paper products are recycled in the United States

Meredith has created materials made with crustacean byproducts as a more sustainable alternative to traditional plastic packaging.

ALLISON CARTER

Closing the Circle to Recycle Plastics, Organic Waste

Bob Powell's career in sustainability began as a 5-year-old child in his grandmother's garden when she warned him about spreading too many pesticides on her tomato plants.

"She told me that rain would take the pesticides into the creek, which flowed into the river, which fed into the Gulf of Mexico. She said the chemicals would harm fish and animals," Powell remembered. "That's when I first realized people and waste can have a negative impact on our world."

Powell would later attend Georgia Tech and earn his electrical engineering degree in 1988, followed by a master's degree in management in 1990 from what's now the Scheller College of Business. An education filled with microelectronics and business skills took him around the world and equipped him to take leadership positions at gas and electric companies. He often played a main role in acquiring other companies.

His job eventually brought him to Jakarta, Indonesia in 1995, where another 5-year-old boy refocused him on sustainability.

"I looked out my window as we drove through a neighborhood and saw a child running in the night, leaping over open sewers," Powell said. "It made me think about my 5-year-old son at home."

That image, framed by a taxicab window, triggered a flood of thoughts about waste and its effect on children. Powell had spent his career involved in wind and solar energy, gas, and the electric grid. But deep down, he knew that others in those fields could have a grander impact than he ever would. With memories of his grandmother and the boy in Indonesia, he shifted his full focus toward waste and how to eliminate it worldwide.

In 2016, he founded a company called Brightmark that uses circular innovations to recycle plastics and organic waste.

"Our company wasn't founded on technology. It was founded on a mission: reimagining waste," said Powell, Brightmark's CEO and president. "Our goal is to look at the waste we create and to eliminate it to create fewer environmental impacts."

Brightmark has built more than 30 circularity centers nationwide to address cow manure and other organic sources of greenhouse gases and partnered with dairy farmers, waste management companies, and food processors. The centers store the manure in anaerobic digesters, capturing its methane and converting it into renewable natural gas. The remaining solids created by the anerobic digestion technology are turned into fertilizer and compost. Excess water is returned to the farm or transported to nearby water treatment facilities.

To address plastic waste, Powell's company processes discarded plastic, then dries, shreds, and compresses it into small pellets. The pellets are heated using a patented pyrolysis process where the plastic chemically breaks down when exposed to high temperatures in an oxygen-starved environment. Released vapor is captured and cooled into a liquid, then processed into pyrolysis oil that is sent to customers as building blocks for new plastic products. To date, Brightmark has recycled nearly 6 million pounds of plastic waste.

Though his career has been spent building, acquiring, and starting businesses, Powell said being trained as an engineer at Georgia Tech continues to benefit him 36 years after receiving his degree.

"The foundation Georgia Tech provided serves me well, especially when chemistry, thermodynamics, and Boyle's Law come up at our centers," he said.

"More than anything, I'm thankful for Tech teaching me about intuition and thinking differently about ways to solve problems.

"We're trying to solve a global issue — one that is bigger than Brightmark. I'm proud to be part of a movement that is improving our amazing Earth."

6 million
pounds of plastic waste recycled by Brightmark to date

PHOTOS COURTESY: BOB POWELL / BRIGHTMARK

Right: Bob Powell at the Athena project site where anaerobic digesters convert methane from cow waste into renewable natural gas and fertilizer.

Below: Powell walks in front of bales of plastic to be recycled at Brightmark's circularity center in Ashley, Indiana.

Taming the Flood

Civil engineer Iris Tien is helping coastal communities improve their resilience with the right flood-control infrastructure in the right places.

Closed roads causing headaches for commuters. Power outages from downed lines. Homes and businesses damaged from rising water.

For many people who live near the southern coast, a summer thunderstorm can be more than an inconvenience. When they drop inches of rain in a flash, the storms can quickly overwhelm systems designed to carry away all that water. If they persist, rivers can swell, pushing water upstream and inland.

And, by all accounts, it's only going to get worse.

A study in *Nature* published in the spring found many coastal areas might be underestimating their flood risk thanks to sea levels that are rising and land that's sinking. High tides alone could create substantial flooding problems by 2050 in the 32 coastal areas the study's authors evaluated. Places like Savannah, Georgia, and surrounding Chatham County are some of the most at risk communities.

As communities grapple with mitigating current and future flood risks, Iris Tien and researchers in her civil engineering lab are working to help. Her team is developing a framework to help residents and city planners identify the right kind of flood-control infrastructure and the right places to put it.

"One of the big gaps I saw while working with coastal communities is that a lot of these infrastructure decisions are made ad hoc," said Tien, Williams Family Associate Professor in the School of Civil and Environmental Engineering. "It's often not very systematic. It's not really data-based. This also leaves the process open to potential bias, where you don't necessarily develop these solutions for the places that need them the most."

Gray or Green?

Since Tien is a civil engineer, it was natural for her to consider flood mitigation in the context of infrastructure systems. After all, her research focuses in part on infrastructure networks and the relationships and interdependencies between them.

For flood control, the choices largely come down to deciding between building "gray" solutions or "green"

ISTOCKPHOTO / HORKINS

ones, each with their own benefits and costs. Gray infrastructure includes more traditional drainage systems and stormwater sewers. Green solutions could be ponds or basins, even parkland, that harness nature's processes for collecting, managing, and slowly releasing floodwaters. Such systems also sometimes have additional benefits for the community that should be weighed when making decisions, Tien said.

"One of the things we wanted to do was to somehow account for the added multiple benefits of green infrastructure," she said. "Those benefits can include increased access to green space, improved air quality, and potential educational opportunities. Green infrastructure might even increase access to healthy food if you incorporate a neighborhood garden."

While those kinds of positives make green infrastructure popular with communities, they don't mean it's always the perfect choice.

"In public surveys or town halls, everyone votes for green infrastructure. But sometimes, gray infrastructure can be a very cost-effective way to address a potential issue," Tien said. "And so, we're looking at that balance and the tradeoffs for communities that are subject to flooding."

The tool Tien and her team are building models all of those factors using a spatial mapping approach. They're using data such as the distances from existing infrastructure systems, maps of flood zones, locations of other community assets, and more. The spatial approach means it's easy for the team to create visualizations for community stakeholders that help them see the recommendations.

Preferences Matter

Tien said they've also worked to incorporate the explicit preferences of the communities. Similar areas could end up with different recommended solutions or locations as a result.

"Everything is hyperlocal; a different city or community might care about different things," Tien said. "If you value air quality and food production more, then you might be weighted more toward one type of solution. If you value lower costs or building onto an existing system, a lot of gray infrastructure can be built into an existing larger network, so then you might be weighted a little bit more that way."

The key, she said, is meeting local needs while addressing the flooding issues. In a pilot project with Savannah-Chatham County, Tien's team had conversations with a variety of stakeholders with different roles in making infrastructure decisions to inform their work. Planning and zoning staffers, stormwater engineers, and policymakers all brought different needs and perspectives to the table.

"In public surveys or town halls, everyone votes for green infrastructure. But sometimes, gray infrastructure can be a very cost-effective way to address a potential issue. And so, we're looking at that balance and the tradeoffs for communities that are subject to flooding."

Iris Tien

The goal isn't to offer hard and fast prescriptions to build a specific kind of system in a specific location. Rather, the modeling will provide decisionmakers with a suite of ideal options to help them allocate their limited resources.

The next step is to beef up the hydrological modeling part of Tien's framework in hopes of calculating a return-to-normal timeframe estimate after a storm event with different infrastructure approaches. Knowing the real-world performance of a particular solution, green or gray, would help flood-prone areas make informed choices.

"We're building those probabilistic models to see, if you have a likelihood of this level of event, then with these different solutions, can we quantify what the benefit is of one versus another? I think it's important to dig a bit deeper on the engineering side and actually produce numbers: it'll take three days to return to normal or six hours or whatever the number might be," Tien said.

Mitigating coastal flooding for more resilient and sustainable communities continues a thread of Tien's work along the Georgia coast. For years, she has collaborated with other Georgia Tech researchers on a project installing sea-level sensors throughout Chatham County to monitor water levels and report data in real-time. This includes recent work creating a tool to help coastal areas find ideal spots for water level sensors considering flood risk, population vulnerability, and more. Her gray and green infrastructure decision-making framework complements those efforts by adding long-term planning resources for coastal residents and local officials.

Tien said research efforts like these highlight how important it is to engage directly with communities to develop practical solutions.

"We want our research to be serving real needs to make real, positive community impacts."

▶ JOSHUA STEWART

GET INVOLVED

If your community is working to address flooding issues and would be interested in collaborating with Iris Tien's research group to apply their work, drop a note to editor@coe.gatech.edu.

Why Equitable Sustainability Matters

Growing up in a Midwestern inner city led Joe Bozeman to a career understanding how sustainability takes shape for people of many different backgrounds.

Joe Bozeman III spent much of his youth in inner-city Dayton, Ohio. It was a difficult childhood, where the threat of physical and emotional harm was never far away. Bozeman often lacked access to healthy food and lived in a home where adequate electricity, heating, and cooling were sometimes unavailable or unaffordable.

He bounced between Dayton and its suburbs during middle and high school before landing at nearby Wright State University as an undergraduate student.

It was those tough formative years, Bozeman said, that put him on his career path as an assistant professor in the School of Civil and Environmental Engineering (CEE). His peers often teach and conduct research on innovative building construction, new ways to effectively provide society safe and clean drinking water, sustainable transportation and farming approaches, and a wide range of other topics. Bozeman, however, noticed a gap in integrating social equity into sustainability research.


Joe Bozeman

"I'm attracted to the field of equitable sustainability largely due to those lived experiences and recognition of a sociotechnical gap in academia," Bozeman said. "I was fortunate that close family members — mostly professional musicians and computer programmers — encouraged me to explore intellectual and scholarly pursuits in music and engineering."

While he still dabbles in music, Bozeman primarily focuses on equitable sustainability. His peer set isn't very large — a shortage he laments.

"This is a problem given that engineers influence everything: the homes we live in, the buildings we work in, how we move from point A to B, the quality of our food, and what we drink," Bozeman said. "This compells me to help fill this gap by using my technology-centric and practitioner expertise to influence how researchers and policy makers, especially from engineering and public policy disciplines, use technical information to make decisions."

Bozeman's work in equitable sustainability covers a broad range of topics, from electric vehicle (EV) adoption to the impact of food choices on the environment.

One current project focuses on EVs' impact on communities, including better understanding the effects of more than 50 lithium mining sites in the U.S. Lithium is a key component in EV batteries.

Because EVs are heavier than gas-powered vehicles, Bozeman and researchers from the University of California campuses in Irvine and Los Angeles also are looking at particulate materials shed when drivers of heavy EVs hit the brakes.

"Most people just assume that the air will get better simply by switching to EVs," Bozeman said. "But when you couple the emissions generated from brake particulate matter with those from mining, we must learn more about how that pollution compares with emissions generated by gas-powered vehicles."

The project is funded for three years through the Sloan Foundation. In Atlanta, the primary roadway study area is Buford Highway — a 10-mile corridor home to many ethnic groups, businesses, and immigrants. The study also will focus on Los Angeles' I-710 corridor, where surrounding neighborhoods are disproportionately Black and Hispanic.

Bozeman recently completed a National Science Foundation-funded project that looks at the likelihood that the public will accept EVs and want to own one.

CANDLER HOBBS

He and collaborators from the University of Pennsylvania and Carnegie Mellon University surveyed 3,000 people across gender, race, and socioeconomic status. They also asked respondents about their level of trust in government and their political leanings.

Their preliminary findings show that ride-share and public transportation commuters are very open to owning EVs, but their actual ownership of one is less than survey respondents who said they prefer driving their own vehicles. They also discovered that political ideology was an important predictor of intent to purchase EVs: people who identified as more liberal had a higher urge to buy. Self-identified conservative respondents expressed less intent.

"This had to do with a person's willingness to trust that the government will have sufficient charging infrastructure in place for EVs," Bozeman said. "Understanding how U.S. political ideology and trust in government connects with race and gender is key to developing effective policies that encourage sustainable EV adoption."

In other projects, Bozeman looks at food equity and sustainability and how it's impacted by spending patterns across community types. Because many U.S. neighborhoods are segregated by income class, race, and ethnicity, he said that understanding how distinct majority Black, white, and Hispanic communities affect the physical environment through food spending is important for environmentally concerned policymakers and businesses.

A few years ago, he looked at the dietary habits of white, Black, and Latin Americans. White consumers, on average, had the most greenhouse gas emissions. Bozeman and the research team attributed this mostly to eating a lot of red meat and water-intensive fruit, such as blueberries. Black Americans had the largest impact on land use, largely the result of consumption of land-intensive protein such as poultry and fruits such as oranges.

He then followed that study with another looking at socioeconomics and the environmental effects of the three demographic groups for each dollar they spend on food. He found that the Latino demographic affects land, greenhouse gas emissions, and water the most on average when it comes to what they eat.

"White Americans, on average, make more money than those who are Black or LatinX, who tend to make about the same amount," Bozeman said. "But when it comes to land, greenhouse gas, and water-intensive foods, LatinX consumers impact the environment the most per dollar spent."

Bozeman said that's because they spend more on calorie-dense, highly processed, and environmentally unfriendly food groups.

"They'll buy in bulk, often out of necessity because of fear of food scarcity and a lack of buying power. White Americans typically have more buying power and freedom. And thus, they're better able to pick and choose how sustainable their food choices are."

Bozeman's said his work provides culturally meaningful data and insights to guide engineers and policymakers — data that are too often lacking or nonexistent. He expects to produce more in this area and to inspire others to do the same.

"My ultimate goal is to provide easy-to-use tools and frameworks to systematize equitable sustainability outcomes in the broad areas of food, energy, and circularity, where we move away from unsustainable and resource-wasteful practices to more sustainable and reuse practices," he said.

▶ **JASON MADERER**

CHARLIE LAYTON

Driving Change

Alumna Amanda Nummy is helping move the automotive industry toward more sustainability, from the materials used in vehicles to recycling cars and trucks after they come off the road.

Something clicked for Amanda Nummy early in her first semester at Georgia Tech.

She was sitting in an engineering exploration course because she was undecided on a specific engineering discipline. On that fateful day, a representative from the School of Materials Science and Engineering was explaining their field, providing a show-and-tell of sample materials researchers and students had developed.

Seeing those tangible pieces, designed for uses in medicine, aerospace, and more, was revelatory for Nummy.

"It sparked the idea that materials are everywhere," she recalled. "I thought, 'If I get a degree in materials, I can do anything I want to do. I can get close to whatever industry I want.'"

More than a decade and a half later, that industry is vehicle design and manufacturing, where Nummy has become a leader in finding ways to make more sustainable cars and trucks.

That can mean working to incorporate more durable plastic polymers into vehicles to make them lighter and less expensive. It can mean helping her company, Hyundai Motor Group, design vehicles for recyclability at the end of their lives. Or it can mean finding ways to turn plastic waste in our oceans into new plastic for car parts.

> **"In my opinion, there's no such thing as an unrecyclable material. There are just materials that are traditionally not dealt with in standard recycling processing."**
>
> Amanda Nummy

"I've always felt that plastic, specifically, kind of got a bad reputation, and that there is an opportunity for appropriate and responsible use of plastics," said Nummy, who earned her polymer, textile, and fiber engineering bachelor's degree in 2011. "That's been a focus for me: How do we use these materials in a way that is beneficial rather than detrimental and pursue a mindset shift around how we select and design with materials."

From Bottle to Bumper?

In many ways, Nummy was ahead of the curve, making the business case for sustainability in the years before many carmakers adopted commitments around environmental sustainability.

As a senior polymer engineer for Hyundai and Kia, she is charged with finding and developing materials to meet the performance needs of designers and engineers while balancing the cost demands of the purchasing department. She has worked extensively on plastics for vehicle exteriors and powertrains, but responsibility for all the plastic components for vehicles in North and South America essentially falls under her purview.

"I really try to emphasize that sustainability and efficiency can go hand in hand," Nummy said. "You can have material reduction, which often means cost reduction, waste reduction, weight reduction, and processing improvements. Translating those sustainability aspects into metrics that are relevant to the business is where I've had luck moving projects forward."

One project is converting plastic waste collected along the coastline into recycled plastic pellets formulated specifically for use in vehicle parts. She partnered with a company in Costa Rica that collects and processes the waste.

Their collaboration resulted in a high-density polyethylene automotive plastic with a double-digit percentage of recycled content that met performance requirements and wasn't prohibitively expensive. Originally, that material was targeted for a cooling pipe in electric vehicles, but Nummy said it also could be used for exterior pieces or even door trim components.

Her Costa Rican partners also collect significant amounts of the plastic often found in water bottles and can turn that into a textile. She's pitching an interior component that would use the hard plastic she formulated with the recycled textile on top. The team also is looking at blending two different kinds of plastic materials for new applications.

In another project, Nummy explored recycling used personal protective equipment from healthcare and research settings. The idea was to turn face masks collecting in landfills or becoming litter into a useful new material. Again, the driver was waste ending up where it shouldn't be and Nummy's desire to create secondary value to short-circuit that cycle.

"In my opinion, there's no such thing as an unrecyclable material," she said. "There are just materials that are traditionally not dealt with in standard recycling processing."

Sustainable from the Beginning

Vehicle sustainability also can take the form of designing new materials to reduce weight, require less material in the first place, and shrink the manufacturing and processing footprint. That means extended range for the vehicles and less impact on the environment from the very beginning.

Nummy's efforts have included developing a polymer composite for the open bed of a new sport adventure vehicle. It's thinner and just as durable as typical truck-bed materials. A similar project is creating a polymer composite enclosure for electric vehicle batteries. Usually made of metal, these components have to withstand rigorous testing for flammability and durability.

"Both the truck bed and the battery enclosure came from this idea to do a holistic design up front," Nummy said. "If we had a blank sheet of paper, and we wanted to balance the weight, the cost, the quality, and the sustainability, how would we do that? We looked at material, processing, and design options, and came up with an optimized version of those designs."

As part of the battery project, Nummy also developed a new testing standard published by Underwriters Laboratory. Instead of investing hundreds of thousands of dollars to design and produce prototype enclosures with new materials — costs that include creating the necessary tooling and production processes — she led creation of a scaled-down version of a key flammability test that allows engineers to design and test new enclosure materials quickly and less wastefully.

"When we move to a plastic from conventional metal, there can be lower processing energy initially, and lower processing energy again through the recycling step. There's a full lifecycle sustainability story there that we don't often talk about," Nummy said.

She's working on that recycling step at the other end of the vehicle lifecycle too, exploring how to reclaim plastic from automotive shredders. The hope is to recover plastic at a molecular level and turn it into in new plastics for new cars.

A key part of Nummy's approach to boosting use of new materials is flipping the traditional way automotive design happens. Instead of standing by for engineers and designers to come to the materials team with a need or working in a silo, she likes to present the design team with new materials to see how they can use them.

"I have tended to look at the material as the enabler of a design or technology. I do a lot of qualification and validation upfront to understand how these materials perform, and then take that data to the broader cross-functional teams and say, 'Here's what this material can do. Let's figure out a way this fits into the functional challenges we're trying to solve on a vehicle.'"

▶ **JOSHUA STEWART**

One of Amanda Nummy's projects is a polymer composite for a truck bed that is thinner and just as durable as traditional materials.

COURTESY: AMANDA NUMMY

Building a Legacy

What started as a student design for a sustainable building competition soon will be a net-zero-energy home in Atlanta's historic Vine City neighborhood.

Less than seven minutes from Georgia Tech's campus lies the historic, vibrant neighborhood of Vine City. There, engineering and design students are reinventing what it means to live sustainably — turning a blighted single-family home into a net-zero-energy living experiment.

The group first formed to compete in the U.S. Department of Energy 2024 Solar Decathlon Design Challenge, where students design buildings capable of producing at least as much energy as they consume. Using reclaimed materials alongside energy efficient systems, including a 1-ton air-source heat pump and a rooftop solar system, the team's design earned first place in the single-family home division.

But they didn't want to stop there. The group was eager to transform its ideas into something practical and applicable in the real world.

"Our aim was not just to win a competition but to ignite a sustainable transformation in Vine City," said Arya Desai, a fourth-year civil engineering student. "By integrating cutting-edge, eco-friendly designs into this historic neighborhood, we're setting a precedent for what the future of urban living can and should look like."

The Georgia Tech team connected with the Westside Future Fund (WFF), a nonprofit organization committed to revitalizing Atlanta's historic westside neighborhoods, to bring their sustainable house design to life. The organization has worked with Georgia Tech students and professors over the years.

"We've always tried to bring as much real-world experience to the Tech projects that we collaborate on. It's one thing to have an idea and the technical know-how to design something, but making it a practical, affordable reality isn't always so easy," said Lee Harrop, WFF's vice president of real estate development. "WFF is proud to partner with the Tech team to make this house a reality."

The collaboration isn't starting from scratch: The group's competition design was based on an actual site owned by WFF. Now, the organization will provide the property and some baseline funding to construct a house based on the students' ideas. The students are raising additional money to implement the green technologies they incorporated in the design to reach net-zero goals.

"For a home to be truly affordable, it needs to have reasonable utility costs. Many older homes in Atlanta have inadequate insulation and inefficient appliances, for example," Harrop said. "We view this as an opportunity to see how we can push the envelope in terms of building technology on this and future homes."

Why Vine City?

The team was drawn to Vine City because of its significant role in Atlanta's history and the opportunity to reimagine what could be possible for the community.

The Georgia Tech team took first place in their division in the U.S. Department of Energy Solar Decathlon Design Challenge. From left: Jackie Zong, Anushka Kibria, Arya Desai, Wyatt Williams, and Rachel Witherspoon.

COURTESY: GEORGIA TECH SOLAR DECATHLON TEAM

CANDLER HOBBS

Tech students Wyatt Williams (pointing), Arjun Thangaraj Ramshankar, and Rachel Witherspoon at the site of the net-zero energy home they will construct in Atlanta's Vine City neighborhood.

Martin Luther King Jr. and others lived in the neighborhood as they led the civil rights movement. However, Vine City residents have confronted significant challenges as decades of underinvestment resulted in vacant houses, underperforming schools, and few resources. In recent years, an influx of interest — and money — in the area have raised fears of gentrification as long-time residents risk being pushed out of their homes and the city.

"Vine City is a neighborhood that's historically disadvantaged. People there have been faced with energy burden, housing costs, and gentrification for years," said Jackie Zong, a fourth-year civil engineering student.

"It's really sad to see what's happening to the neighborhood today; many people have had to leave their homes because they can't afford their energy bills. So that's why we decided to partner with Westside Future Fund and to work on this project in Vine City."

According to WFF data, approximately half of the residents in Vine City and the nearby English Avenue neighborhood are burdened by housing costs, spending more than 30% of their income on housing. Harrop said keeping energy costs down is a key factor in making homeownership more affordable for legacy residents. That's why a near net-zero-energy home holds such promise for the area.

Still, the Georgia Tech team didn't want to create a showcase house; instead, they aim to build something that genuinely integrates with the neighborhood. They've held several community events to share their plans and gauge the community's perception.

They did encounter initial skepticism. Some community members thought the new house would lead to increased gentrification rather than help residents stay in the neighborhood.

"One resident thought that this would be another Airbnb sort of development," Zong said, referring to the short-term

> **"By integrating cutting-edge, eco-friendly designs into this historic neighborhood, we're setting a precedent for what the future of urban living can and should look like."**
>
> Arya Desai

Above: Jackie Zong, Rachel Witherspoon, and Jingqi (Kiki) Ruan talk about their plans for the abandoned and crumbling home in Vine City.

Below: Rendering of the team's net-zero energy home design.

RENDERING COURTESY: GEORGIA TECH SOLAR DECATHLON TEAM; TOP PHOTO: CANDLER HOBBS

rental website. "We explained to her that we're building this house for legacy residents from the neighborhood. That made residents happy and much more supportive. There are other projects building residences that ultimately are posted on Airbnb and other rental websites, and it's really tearing the community apart."

What Near Net-Zero Looks Like

Software modeling tools allowed the students to optimize their design based on energy performance simulations, ensuring the group's orientation, material selection, and system choices all contribute to the house's energy efficiency without significantly increasing upfront costs.

The team will incorporate an air-tight building envelope, continuous insulation, and high-performance windows — energy-conserving measures often lacking in older homes like those in Vine City. They'll use an efficient heating, ventilation, and air conditioning system, including an air-source heat pump and an energy recovery ventilator to manage heating and cooling with reduced energy usage.

The team also will install a solar panel system capable of generating more than 7 kilowatt-hours of electricity each year, enough renewable power to meet the house's energy needs. Excess energy will be channeled back to the electric grid, generating credits that will reduce the power bill.

With assistance from the Lifecycle Building Center — a nonprofit specializing in reclaiming materials for sustainable and affordable construction — the group will acquire reusable building materials, greatly reducing the carbon footprint of construction.

"We hope our project can become a guideline for all future developments in the area — to promote sustainability but also make sure homes remain affordable," Desai said. "Ultimately, we want to keep the residents in the neighborhood for a longer time with better living conditions."

▶ **DHANESH AMIN**

10 TO END

10 Questions with Mark Cupta

Alumnus Mark Cupta started his career in a variety of research, engineering, product development, and business strategy roles at Fortune 500 companies. Cupta is a double Jacket, having earned a bachelor's in chemical and biomolecular engineering in 2004 and a master's in 2006. Now he's a managing director at Prelude Ventures, a venture capital firm that invests in and supports bold ideas and entrepreneurs working to have a positive impact on our climate.

BARAK SHRAMA

1 ▸ Why did you choose Georgia Tech? Georgia Tech was the only school I applied to coming out of high school. Looking back, it does feel a bit naïve or risky, but I was determined. Ever since I can remember, I wanted to be a scientist or engineer. Growing up in Georgia with one of the best engineering schools in the world in my backyard just felt like too big of an opportunity to pass up.

In fact, I chose Georgia Tech twice: I had multiple options for my engineering graduate degree. However, Tech's chemical engineering school was the only program that specifically met all my needs. I truly felt wanted there.

2 ▸ What drew you to chemical and biomolecular engineering? My father has an advanced degree in chemistry, and growing up, he would occasionally bring pieces of his work home to share with me. This stoked my curiosity for chemistry at an early age. Over time, I learned I was far more interested in how chemicals or materials were made and how they functioned. Chemical engineering felt like a natural choice.

3 ▸ What is a climate investor and how did you end up as one? Climate investors come in all shapes and sizes. Anyone who considers climate change as a factor in the products they buy or the money they invest can be a climate investor.

I personally developed a passion for venture capital investing during my time in business school at Stanford. I found I had little to no interest in the traditional markets for venture capital, which are largely focused on software. I wanted to invest in companies and technologies that drove innovation in the physical world. I also wanted my investments to have a positive impact in addition to their financial returns. Investing in climate was the perfect combination of all those factors.

4 ▸ Why does investing in climate-related tech appeal to you? Addressing climate change is the biggest challenge facing humanity today. Nearly everything we make, do, or use has an impact on our climate. The scope and scale of the problem is enormous, but that also makes it an incredible investment opportunity. The companies I get to work with on a daily basis are transforming multibillion dollar industries

— energy, transportation, food and agriculture, industrials, and the built environment. Working on something I deeply care about combined with the fact that I get to satisfy my extreme curiosity toward innovation has transformed my work from a career to a true calling.

5 ▸ What kinds of technologies do you want to invest in? My specialty is investing at the intersection of frontier technology and climate. I look for companies that solve problems in ways that demonstrate a step-change improvement in their markets. I also gravitate toward technological innovations that leverage macro trends to do something that previously seemed impossible. Companies applying recent advancements in fields like material science, biology, robotics, and artificial intelligence to climate problems will almost always get my attention.

6 ▸ What qualities do you look for in a promising climate startup? I do not differentiate a promising climate startup from any other venture capital startup. As an early-stage investor, we are evaluating similar characteristics in companies: the quality of the team, the transformational nature of the technology or business model, and the size of the market opportunity, for example. The difference is that I also screen investments based on their potential to reduce greenhouse gas emissions. Then, I assess whether the business has the potential to become a category-defining company in its sector.

7 ▸ How did your Georgia Tech education prepare you for this work? Georgia Tech engineers are trained to break down difficult problems into digestible parts to come up with viable solutions. That skill set is drilled into you in nearly all aspects of your education. A venture capitalist's most important skill is their ability to climb a steep learning curve in a wide range of market sectors, technologies, and business models. I see hundreds of companies each year, but I only make investments in a few. My engineering background provides me with a toolkit that is essential for my decision-making process.

8 ▸ What are some of the most exciting climate-related technologies you see coming in the near future? One theme that we are particularly excited about at our firm is the "electrification of everything." We continue to make great progress on decarbonizing our electrical grid, and that enables us to use renewable electrons to decarbonize other industries. The obvious example is electric vehicles, but we are seeing exciting technologies that will use renewable energy to decarbonize heavy industries like steel, cement, fertilizer, and hydrogen production. With that in mind, we also need to continue to invest in the future of zero-carbon energy production and grid stability. This includes long-duration, grid-scale batteries and moonshot ideas in geothermal and fusion power.

> **"I've been involved in climate investing for over a decade, and I can honestly say that the quality and quantity of people dedicating their careers to climate is accelerating. There is real momentum in this sector, and I'm excited to see what we can do together over the next decade."**
>
> Mark Cupta

9 ▸ Have you learned something from your work that's changed your own choices or behavior to reduce your climate impact? The average U.S. citizen is responsible for just under 100 pounds of carbon dioxide equivalent emissions per day. That disheartened me when I first thought about how to reduce that number in my own life. I have done obvious things like using an electric vehicle for my daily commute and replacing an old natural gas heater with an electric heat pump. I've come to realize that the most important thing I can do to reduce my climate impact is vote with the climate in mind. Effective policies that will help drive change in the large emitting industries and infrastructure is the biggest lever we have as a society.

10 ▸ What makes you most hopeful about our ability to mitigate the effects of climate change? It's easy to feel the gloom and doom of climate. We are seeing record-setting weather events with devastating effects more frequently all over the planet. My hope lies with the people working in this field. I've been involved in climate investing for over a decade, and I can honestly say that the quality and quantity of people dedicating their careers to climate is accelerating. There is real momentum in this sector, and I'm excited to see what we can do together over the next decade.

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parting shot

Wenting Sun, aerospace engineering associate professor, investigates combustion processes of conventional jet fuel and sustainable aviation fuels in an effort to minimize emissions from both.

▶ LEARN MORE, PAGE 10