Cornell Engineering

Electrical and Computer Engineering

ECE CONNECTIONS

2021/2022

SUSTAINABLE ENERGY FOR A HIGH-POWERED WORLD

Page 14

DIRECTOR'S REFLECTIONS ALYSSA APSEL

In April, the United Nations released a report on climate change with a dire warning that harmful carbon emissions from 2010-2019 have never been higher in human history. Scientists argued that it's "now or never" to limit global warming to 1.5 degrees Celsius. Based on the latest findings of the Intergovernmental Panel on Climate Change (IPCC), the UN Secretary-General insisted that unless governments reassess their energy policies, the world will become uninhabitable. This statement makes it crystal clear that fighting climate change and enabling a sustainable future is perhaps the most salient grand challenge of our lifetime.

Striking a more positive note—and insisting that it is still possible to cut in half emissions by 2030—the IPCC made a call to action and urged governments to ramp up action to curb emissions. While technology alone cannot solve these problems without policy action, scientists and engineers do have an important role to play. This is why we have chosen to use this issue of Connections to highlight important work in energy and sustainability ongoing in Cornell ECE.

A number of grand challenges exist: These range from sustainable transportation and urban planning to improving the built environment to optimizing complex food production and consumption systems. In ECE, research spans this whole range of problems. For instance, while a primary limitation to the widespread adoption of electric vehicles is drivers' range anxiety, not being able to recharge on long car trips, Assoc. Prof. Khurram Afridi imagines a world where the means of wirelessly charging these cars is embedded directly into the road itself.

Afridi is also working with Prof. Lang Tong and Asst. Prof. Francesco Monticone to explore ways to adapt the power grid to accommodate this new mode of transportation and revolutionize clean and efficient power delivery. In a different direction, Prof. Dave Hammer has spent a career exploring plasma physics with the goal of understanding fusion and its potential for clean energy production. Meanwhile, several groups are pursuing research into high efficiency computing and power grid management to support a sustainable future.

Technological advancements in sustainable transport, clean energy, and efficient computing provide opportunities to improve the health of populations while reducing their pollution and carbon footprint. As educators, however, we recognize that technology solutions alone are unlikely to solve the persistent environmental, societal and health problems that people are facing around the world.

To achieve sustainable, long-term solutions we need concerted action from key stakeholders—government, planners, health professionals, researchers, businesses—as well as individual citizens. Importantly, this requires effective public policy and business engagement to ensure translation of scientific outputs into actionable long-term solutions. Cornell ECE can play a role both on the technology side, and equally importantly in educating the next generation of leaders to meet these challenges.

HOW WILL YOU MAKE AN IMPACT?

Nobody knows better the impact a gift can make than a former Cornell student. You walked these halls, you studied in these classrooms, you worked in these labs. You've seen the names on the signs and plaques that remind us of the contributions people like you have made to the education and research excellence in Electrical and Computer Engineering. How will you make an impact?

Professor of Practice

Endowed Teaching Positions like Professor of Practice enable us to attract and retain distinguished and highly experienced individuals in professional electrical and computer engineering fields and who can provide effective, practice-oriented instruction in areas that supplement the core pedagogical instruction provided by tenured and tenure-track faculty. This builds our program and enables us to better serve our students with hands-on, industry relevant experiences.

Hiring exceptional Professors of Practice is a necessary component of our strategic plan. ECE has positions available for practitioners skilled in software and/or microcontrollers. These positions require ECE to add several practical courses to its curriculum. Courses such as C++ and Linux could be taught by lecturers and/or leaders in industry with extensive hands-on experience in the field.

Graduate Ph.D. Funding (Graduate Fellowship)

Our Engineering Graduate students are the future leaders of the technology economy, and it is critical that we attract and recruit the best students to our program. Tightening federal research budgets means we are competing at a much higher level to secure research support and attract top students to our program, and we are finding that federal programs increasingly require some form of matching to get support. Schools with the ability to match graduate student fellowships are much more effective at obtaining research support.

Joe Rogan, Major Gifts Officer, College of Engineering

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INSIDE THIS ISSUE

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Cover image provided by William Potter, Ph.D, research support specialist in the Lab of Plasma Studies. Read more about this work on Page 14.

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$5M GRANT WILL TACKLE PANGENOMICS COMPUTING CHALLENGE

by Eric Laine

As scientists continue to catalogue genomic variations in everything from plants to people, today's computers are struggling to provide the power needed to find the secrets hidden within mass amounts of genomic data.

A team led by Christopher Batten, associate professor in the School of Electrical and Computer Engineering, is responding with the Panorama project, a five-year, $5 million NSF-funded effort to create the first integrated rack scale acceleration paradigm specifically for computational pangenomics.

"The field of computational genomics is undergoing a sea change," Batten said. The traditional method of examining DNA using a single linear reference genome is quickly giving way to a new paradigm using graph-based models that can address the sequence and variation in large collections of related genomes.

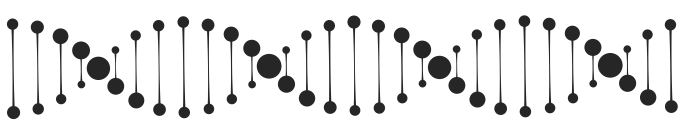
"With a single reference genome, you could understand other genomes as they relate to that single reference," Batten said, "but it's hard to understand how they relate to each other, and to everything else."

Genetic researchers would be thrilled to investigate pangenome graphs that include millions of genomes, but for now it's impossible. The computing power needed is just not available. The demands of graph-based pangenomics require rethinking the entire software/hardware stack. But this is not simply a "big data" problem.

"Yes, the data is big," Batten explained, "because there is a lot of data. It's also sparse because it's irregular; not every sequence is the same and elements are missing. It's dynamic because geneticists are adding newly sequenced genomes every day. And since each DNA sequence is unique to each person, we must keep it private."

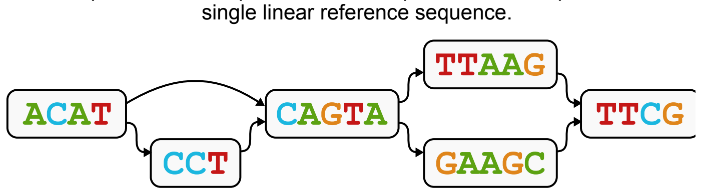
Building a computer system that can get answers from this big, sparse, dynamic, and private data set requires a collaborative approach from computer systems researchers working simultaneously on different layers of the stack.

"We need to rethink how we build computers," Batten said. "That's why this project is so ambitious. In the past, you just waited two years and your computers would naturally become faster. But the slowing of Moore's law means that inevitable improvements in performance are just not occurring anymore. So you need a cross stack approach to really make an impact."



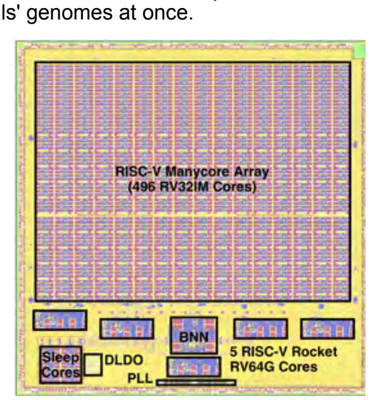
Reference: ACATCCTCAGTATTAAGTTCG
Genome 1: ACAT---CAGTATTAAGTTCG
Genome 2: ACATCCTCAGTAGAAGCTTCG

Traditionally, **computational genomics** represented DNA as linear sequences of basepairs. All DNA sequences are compared to a single linear reference sequence.



Computational pangenomics uses an intricate network of smaller sequences that efficiently represents the relationships between many individuals' genomes at once.

The Panorama project will use **software/hardware codesign** to accelerate computational pangenomics. For example, the chip shown on the right was fabricated by PIs Taylor, Batten, and Zhang in 2017 and includes 500+ RISC-V processors along with application-specific accelerators for machine learning. The project will use similar techniques but applied to the emerging area of computational pangenomics.



That impact will take the shape of a prototype computer the team will design and build. Most laptop computers have four to ten cores, or central processing units. The Panorama prototype will have a million cores. The project's vision for this powerful new computing tool is analogous to the impact of the Hubble Space Telescope: it will enable computational biologists to observe what was previously unobservable.

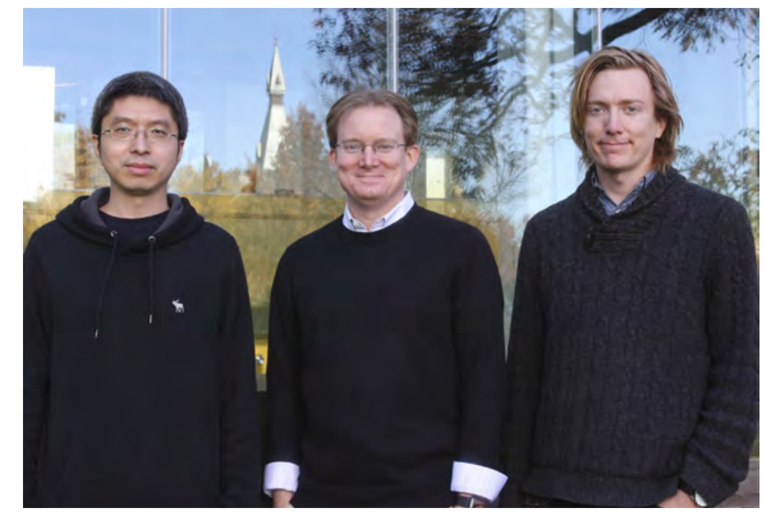
The team Batten assembled to build this revolutionary system includes seven principal investigators from three universities with expertise in computational biology, programming languages and compilers, computer architecture, and security and privacy. The highly interdisciplinary team has a proven track-record of working and publishing together.

It started with a fortuitous meeting at an open-source software and hardware conference Batten attended in Belgium in January 2020 with longtime friend and research collaborator Michael Taylor, an associate professor of electrical and computer engineering at the University of Washington. There they connected with Pjotr Prins, one of the world's leading researchers in computational genomics. Prins is an assistant professor at the University of Tennessee Health Science Center.

Together they realized the potential to make revolutionary advances in computing by focusing on the specialized domain of computational pangenomics, and its graphs of big, sparse, dynamic, and private data.

Prins brought in his UTHSC colleague, assistant professor Erik Garrison, a pioneer in the field of computational pangenomics. Batten also tapped resources from Cornell Engineering's multidisciplinary Computer Systems Lab. Associate professor Zhiru Zhang (ECE) is an expert in hardware accelerators and efficient machine learning algorithms; professor Ed Suh (ECE) is focused on designing hardware to ensure the security of the entire computer system; and assistant professor Adrian Sampson (CS) specializes in programming languages and compilers.

"To unlock the full potential of pangenomics, we can't simply rely on traditional bioinformatics tools built to handle linear genome sequences," said Zhang. His group will investigate new graph learning algorithms, domain-specific programming models, and hardware accelerators. "We must develop new algorithms and hardware that can efficiently process the large and irregular pangenome graphs to effectively analyze many individuals' genomes at once and understand the intricate relationships between them."



The Panorama team includes (L-R) Zhiru Zhang, Christopher Batten, and Adrian Sampson (Computer Science) among others.

UTHSC currently works with a computer powerful enough to do a simple analysis across 60 people. It takes about a day. "If you double the number of individuals, the time will not double," Prins told the Daily Memphian. "It will get even slower, maybe four times as slow." Analyzing 1,000 people would probably take a month. "We want to be able to do it in minutes," Prins said.

In pangenomics, the goal is not to understand a single individual; it's to analyze the genomes of an entire population and study the relationships between individuals. Adrian Sampson, assistant professor in computer science, tried to explain the scale of the problem.

"Imagine sampling a thousand salmon from a given river to understand the biodiversity in that river," Sampson said. "Researchers are also interested in the way each individual salmon differs from every other salmon. In a sample of 1,000 salmon, there are nearly 500,000 pairs of salmon to be compared to each other to understand the entire pangenome."

Unlike data collected from other animal species, human DNA data is considered ultimately intimate and personal, in addition to being subject to strict regulation, and that's why privacy and security are a major focus of the Panorama project. Ed Suh, professor of electrical and computer engineering, is an expert in computer hardware security.

"Rack-scale acceleration in the cloud promises to unlock a new level of computing capabilities," said Suh. "However, security and privacy concerns often limit the amount or the type of data that we can bring into the cloud for processing."

"A DNA sequence is arguably one of the most personal and private information a person has," said Suh. "To fully leverage the potential of the rack-scale acceleration, our system needs to be able to provide strong assurance that sensitive and private data can only be used for specific purposes and cannot be stolen or altered by untrusted entities."

Sampson articulated the excitement shared by the entire team, that the Panorama project introduces totally new challenges in hardware design and programming. "We have an opportunity to generate specialized, single-purpose hardware that is really only capable of solving these enormous genomics problems," he said. "This is not an easy task, but if we can achieve it, we'll help biologists solve problems that they can't even begin to approach with the computers they have today."

The project's name captures its holistic, cross-stack, software/hardware approach: a panorama is an unbroken view of the whole region surrounding an observer. The Panorama project outlines an ambitious set of research directions in the context of computational pangenomics, although the fundamental ideas will be broadly applicable across machine learning and graph processing.

CHIANG’S TEAM EXCELS IN ARPA-E GRID OPTIMIZATION CHALLENGE

by Eric Laine

Professor Hsiao-Dong Chiang is leading a research and development team through a series of energy grid optimization challenges set up by ARPA-E, the Advanced Research Projects Agency–Energy. So far, they are ranked #2.

ARPA-E is the U.S. government agency tasked with funding research into advanced energy technologies, and its Grid Optimization (GO) Competition is aimed at developing software management solutions to address challenging power grid problems. The ultimate goal is to create a more reliable, resilient and secure American electricity grid.

Optimizing the nation’s power grid could save consumers $50 billion each year, according to the Federal Energy Regulatory Commission (FERC). Participants in the GO Competition are challenged with finding a way to deliver an adequate supply of energy to customers at the lowest possible production cost by managing how the power is distributed throughout the grid.

“There’s been a lot of research in this area over the past 50 years,” said Chiang, “but few of these efforts produced practical applications or went into production.” Two energy management companies founded by Chiang, Global Optimal Technology (GOT) and Bigwood Systems, Inc. (BSI), both based in Ithaca, NY, have been focused on these kinds of problems for more than two decades.

“GOT is an optimization technology company while BSI is focused on power grid monitoring, assessment, control, and optimization,” Chiang said. Researchers from both companies make up the team competing in the ARPA-E challenges. The algorithms they are developing could have a major impact on the future of energy delivery. The companies already hold 25 patents in the field and serve customers from the Tennessee Valley Authority (TVA) to the Tokyo Electric Power Co. (TEPCO), the largest private electric utility in the world.

Professor Hsiao-Dong Chiang. Photo provided.

“We approach the ARPA-E GO Competition with a deep understanding of the problem domain and industry practice,” Chiang said. “The problem demands an innovative solution methodology and sophisticated programming technology.”

The GO Competition began with Challenge 1, which tasked the teams with finding solutions to a security constrained optimal power flow (SCOPF) problem. Challenge 2 expands upon that SCOPF problem by adding new variables including transmission line switching, adjustable transformer tap ratios, phase shifting transformers, switchable shunts, fast-start unit commitment, and price-responsive demand with ramping constraints.

When the official results of GO Competition Challenge II were announced, Chiang’s team “GOT-BSI-OPF” was ranked #2 overall and is expected to receive an award of $420K. The next event in the competition, Challenge 2: Monarch of the Mountain, is set to begin in January. This event eliminates the hardware and time limits set in the original challenge to encourage competitors to simply find the best solutions possible.

“It’s challenging, but it’s a very rewarding,” Chiang said, reflecting on his team’s work in this competition, as well as in the global marketplace. “When you see people using your software on a 24/7 basis as a critically important tool, it’s very, very rewarding.”

Photo by Dhahi Alsaeedi (unsplash.com).

MOVIES, MUSIC AND PICTURES CAN TRAIN A SYNTHETIC BRAIN

by Eric Laine

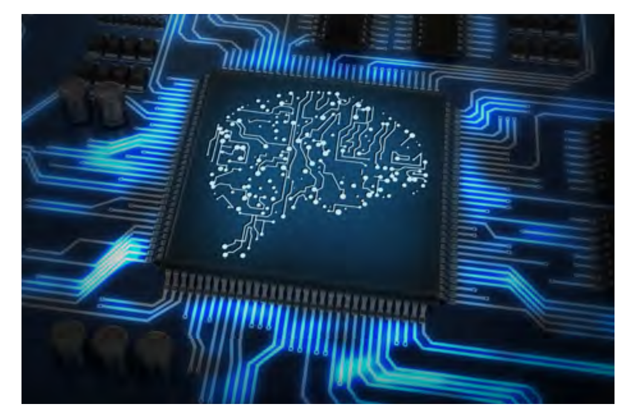
A new AI-based technology developed by Cornell researchers will help gain new insights into how our brains respond to external stimuli.

Meenakshi Khosla, doctoral student in the field of electrical and computer engineering, along with her adviser, Mert Sabuncu, associate professor of electrical and computer engineering in the College of Engineering and colleagues at Weill Cornell Medicine, are authors of a new paper published in Science Advances, “Cortical response to naturalistic stimuli is largely predictable with deep neural networks.”

“Major discoveries in the field of sensory neuroscience have been driven by controlled experiments that present animals with carefully designed artificial visual and auditory stimuli,” Khosla said. “In this study, we present an alternate way to expedite neuroscientific discovery.”

This alternate method involves collecting neural responses to rich, complex stimuli that mimic natural conditions, namely movies, and training computational models with different inductive biases to predict the evoked response. The study uses neurological data from the Human Connectome Project database, collected while subjects were passively watching movies including clips taken from commercial films including “Home Alone,” “Star Wars” and “Inception.”

“We developed an AI-based technology that can reliably predict the activation patterns across the brain of a person watching a movie, listening to an audio track or looking at a picture,” said Sabuncu, also an assistant professor of electrical engineering research in radiology at Weill Cornell Medicine. “We can view this technology as a synthetic brain that can allow researchers to gain new insights into how our brains respond to external stimuli.”



Stock photo.

Such a synthetic brain can lead to novel neuroscientific findings and brain-computer-interface tools for assisting or augmenting cognitive or sensory and motor functions.

Amy Kuceyeski, an adjunct associate professor of computational biology in the College of Agriculture and Life Sciences and an associate professor of mathematics in radiology at Weill Cornell Medicine, is a co-author and collaborator in the work.

“Studying how the brain processes external stimuli is an important area of neuroscience research because it allows a window into how the brain works,” Kuceyeski said. “Knowing how the brain processes images and sound may provide ideas on how to mirror these mechanisms in artificial systems, such as computer vision.”

The researchers’ proposed approach can replicate findings from a large number of prior studies in neuroscience, spanning research on multisensory integration, cortical temporal hierarchy and functional selectivity within the brain.

Taken together, the paper states, the findings underscore the potential of neural encoding models as a powerful tool for studying brain function in ecologically valid conditions.

METAMATERIALS RESEARCH CHALLENGES FUNDAMENTAL LIMITS IN PHOTONICS

by Eric Laine

Cornell researchers are proposing a new way to modulate both the absorptive and the refractive qualities of metamaterials in real time, and their findings open intriguing new opportunities to control, in time and space, the propagation and scattering of waves for applications in various areas of wave physics and engineering.

The research published in the journal Optica, "Spectral Causality and the Scattering of Waves," is authored by doctoral students Zeki Hayran and Aobo Chen, M.S. '19, along with their adviser, Francesco Monticone, assistant professor in the School of Electrical and Computer Engineering in the College of Engineering.

The theoretical work aims to expand the capabilities of metamaterials to absorb or refract electromagnetic waves. Previous research was limited to modifying either absorption or refraction, but the Monticone Research Group has now shown that if both qualities are modulated in real time, the effectiveness of the metamaterial can be greatly increased.

These temporally modulated metamaterials, sometimes referred to as "chrono-metamaterials," may open unexplored opportunities and enable technological advances in electromagnetics and photonics.

"What we demonstrate," Monticone said, "is that if you modulate both properties in time, you manage to absorb electromagnetic waves much more efficiently than in a static structure, or in a structure in which you modulate either one of these two degrees of freedom individually. We combined these two aspects together to create a much more effective system."

Doctoral student Zeki Hayran (left) with assistant professor Francesco Monticone. Photo by Eric Laine.

The findings may lead to the development of new metamaterials with wave absorption and scattering properties that far outperform what is currently available. For example, a broadband absorber has to be thicker than a certain value to be effective, but the material thickness will limit the applications of the design.

"To decrease the thickness and increase the bandwidth of such an absorber, you have to overcome the limitations of conventional materials," Hayran said. "One of the ways to bypass these limitations is through temporally modulating the structure."

The aim of Monticone's group is to open new areas of research to produce increasingly efficient practical applications.

"What we are trying to do is not incremental changes to the technology," Monticone said. "We want disruptive changes. That's really what motivates us. So how can we make a dramatic improvement to the technology, not just an incremental improvement? To do that, very often, you have to go back to the fundamentals."

The new research pushes the limits of electromagnetic wave absorption by using another degree of freedom, which is modulation in time, something not typically done in this area, but now receiving increasing research attention.

With a new theoretical underpinning in place, experimentally implementing temporal modulations of this kind is the challenge for further research. A physical experiment would first need to design a mechanism to control the modulation of absorptive and refractive qualities of a material over time, which might include laser beams or microwave components.

The ideas have direct implications for several applications, such as broadband radar absorption and temporal invisibility and cloaking. Applications could also extend to other domains of wave physics such as acoustics and elastodynamics.

"Our findings, and the exciting results by other researchers working in this area, highlight the many opportunities offered by time-varying metamaterials for both classical and quantum electromagnetics and photonics," Monticone said.

This research is supported by the Air Force Office of Scientific Research and the National Science Foundation. Additional support is provided through the Fulbright Foreign Student Program of the U.S. Department of State.

COLLABORATION GETS QUANTUM VIEW OF SUPERCONDUCTOR JUNCTION

by David Nutt

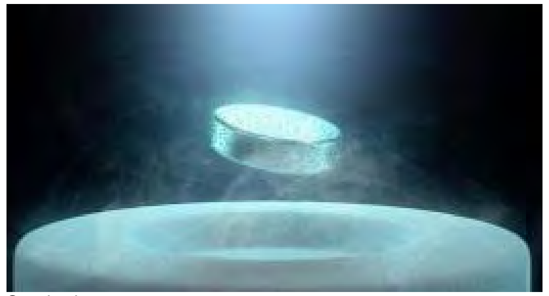
A crystal structure that combines a semiconductor and superconductor is a tantalizing prospect to create energy-efficient computers, or quantum computers, which leverage the unique quantum mechanical properties of superconductors. Superconductors carry current with little to no energy loss, while semiconductors offer the control and versatility that has made them an essential feature of transistor technology.

The challenge is how to combine the two states and ensure you get the best of both electrical worlds – and can still isolate them.

A collaboration between researchers from Cornell and the Paul Scherrer Institute in Switzerland grew a thin film, only a few atomic layers in thickness, of the one of the oldest known superconductors, niobium nitride, on top of gallium nitride, a semiconductor that in recent decades has become a vital component in optical and power electronics. For the first time, the researchers have successfully measured the electronic properties of the junction between the two materials, a crucial step toward creating hybrid superconductor-semiconductor quantum devices.

The groups' paper, "Momentum-Resolved Electronic Structure and Band Offsets in an Epitaxial NbN/GaN Superconductor/Semiconductor Heterojunction," published Dec. 22 in Science Advances. The paper's co-lead authors are Cornell doctoral student John Wright and Tianlun Yu with the Paul Scherrer Institute.

"We have vastly different electronic systems that are now coexisting in the same materials platform. Knowing more about the interface between these two materials, and the electronic properties at the interface, could allow us to design applications that take advantage of the unique electronic properties of both materials," Wright said. "Sometimes the separation between the states of the two materials is the property we would want. And sometimes we may actually want interaction between the electronic states."



Stock photo.

Cornell's team was led by Debdeep Jena, the David E. Burr Professor of Engineering and Huili Grace Xing, the William L. Quackenbush Professor of Engineering.

The Jena-Xing Lab previously demonstrated they could integrate niobium nitride with gallium nitride in epitaxial structures and, in the process, leverage thrilling quantum properties. For their new project, they wanted to understand the electronic properties of both materials independently, as well as the properties at the junction, or interface, where the materials meet.

The group used molecular beam epitaxy to grow a precisely controlled, high-quality crystalline superconducting sample only several nanometers thick – itself a significant accomplishment. Then they developed an intricate capping procedure to preserve the quality and purity of the sample and shipped it to their partners at the Paul Scherrer Institute, who used soft-X-ray angle-resolved photoelectron spectroscopy (ARPES) to measure the electronic properties both at the surface of the material, as well as deep inside it.

"Historically, niobium nitride was one of the oldest known superconductors. Still, people had failed to measure its complete quantum mechanical electronic structure," Jena said. "The experiment that was initiated with this collaboration actually succeeded in getting there."

While the Paul Scherrer Institute team performed its ARPES measurements, the Cornell group fabricated test devices at the Cornell NanoScale Science and Technology Facility and conducted its own electronic transport measurements to gain a macroscopic look at the electrons moving through the material interface and the energetic barriers they encounter there.

"The beauty of this work is that when you put gallium nitride with niobium nitride, the fundamental properties of each of these materials do not change," said research associate Betul Pamuk, who conducted the computational modeling and was one of the paper's co-authors.

The researchers were surprised to find niobium nitride's electronic states differed slightly from what the modeling and theory had suggested – a discrepancy that would have been impossible to discover without the combination of the ARPES measurements and the high crystalline quality and chemical purity of the sample they grew.

One of the superconductor-semiconductor's most promising applications is for high-quality crystalline Josephson junctions, which can enable nonlinear electrical behavior and, as a result, boost high-speed electronics and create qubits – or quantum bits – for quantum computing.

ENGINEERS MAY LEARN FROM BEES FOR OPTIMAL HONEYCOMB DESIGNS

by Krishna Ramanujan

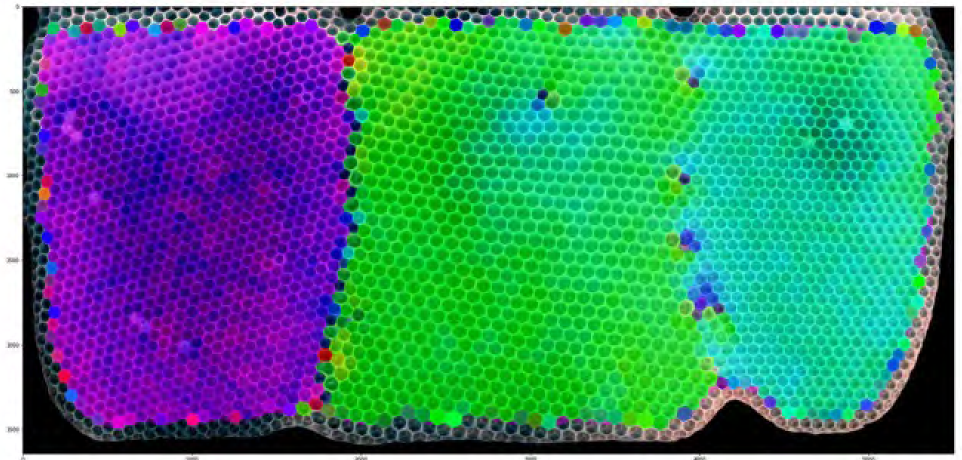
Perfect hexagonal structures inspired by honeycombs in bee nests are widely used to build everything from airplane wings, boats, and cars, to skis, snowboards, packaging and acoustic dampening materials.

Challenges arise when space constraints or repairs require engineers to keep a structure mechanically strong when linking together industrial honeycomb panels that each have cells of different sizes. High performance computers used with 3-D printers may solve this problem in the future, but could bees provide a more efficient and adaptable strategy?

A new study finds they can. It turns out that honey bees are skilled architects who plan ahead and create irregular-shaped cells and a variety of angles to bridge together uniform lattices when limited space constrains them.

Special imaging of natural honeycombs and computer modeling revealed that worker bees will change the tilt, size and geometric shapes of cells to meet different building challenges, according to the paper, "Imperfect Comb Construction Reveals the Architectural Abilities of Honey Bees," published July 26 in the Proceedings of the National Academy of Sciences.

"In this fundamental study, we looked at a naturally evolved system which solves similar challenges in a near-optimal manner," said Kirstin Petersen, assistant professor of electrical and computer engineering in the College of Engineering and a co-author of the paper.



Cells marked with different colors to show their orientations reveal how different patches in the comb are built with a consistent tilt when the bees merge two patches. Note that irregular five- and seven-sided cells are also used along the merge lines. Image provided by Petersen/Napp.

"Understanding how evolution can lead to these organisms that have architectural tricks gives us insights into how you can build structures that are multipurpose, strong, and resilient to different environmental perturbations," said first author Michael L. Smith, Ph.D. '17, assistant professor of biological sciences at Auburn University, who began this work while he was at Cornell.

Bees are known to build two types of hexagonal honeycomb cells: small ones for rearing worker bees and larger ones for rearing drones, the male reproductive bees. A challenge – and some forethought – arises when the bees must link lattices made of smaller cells with the larger ones, because the geometries don't allow for a seamless fit. One issue is that bees don't remodel their cells. "Whatever action they take in one place effectively decides what's going to happen later," Petersen said. Also, for honey bees, wax is the most expensive material energetically, Smith said.

"When they build something out of wax, they're being as frugal as possible," said Smith, who is also an affiliate member of the Max Planck Institute of Animal Behavior at the University of Konstanz in Germany.

As a result, the bees employ other shapes – pentagons or heptagons – in order to link together panels of perfectly hexagonal drone and worker cells. Along with building cells of different shapes, the bees also build irregular-sized cells, and sometimes even combine multiple types of irregular cells. The authors refer to these pairs and triplets of irregular cells as "motifs" and show that particular combinations occur more often than expected by chance.

Sometimes the bees will switch from building one type of cell to the other, but they make that change gradually, over multiple cells, which suggests they are thinking ahead, Petersen said.

In the study, Smith set up 12 colonies in the field with frames that lacked the usual wax and wire inside, so the bees could build natural honeycombs without guides. At the end of the season, the researchers took specially lit images and then wrote a custom software to automatically identify, sort and measure the vertices, angles, sizes and geometries of thousands of cells. Coauthor Nils Napp, assistant professor of electrical and computer engineering in the College of Engineering, developed a theoretical computer model that allowed them to analyze configurations, and test optimal ways cells might fit together in a continuous manner under the space constraints. They used the model to ask, how much better could the bees do? "And it turns out, not that much better," Petersen said.

More than 200 years ago, Swiss entomologist Francoise Huber suggested that bees might use intermediate cells to merge a honeycomb together, but he lacked the modern tools to measure thousands of cells and validate his idea.

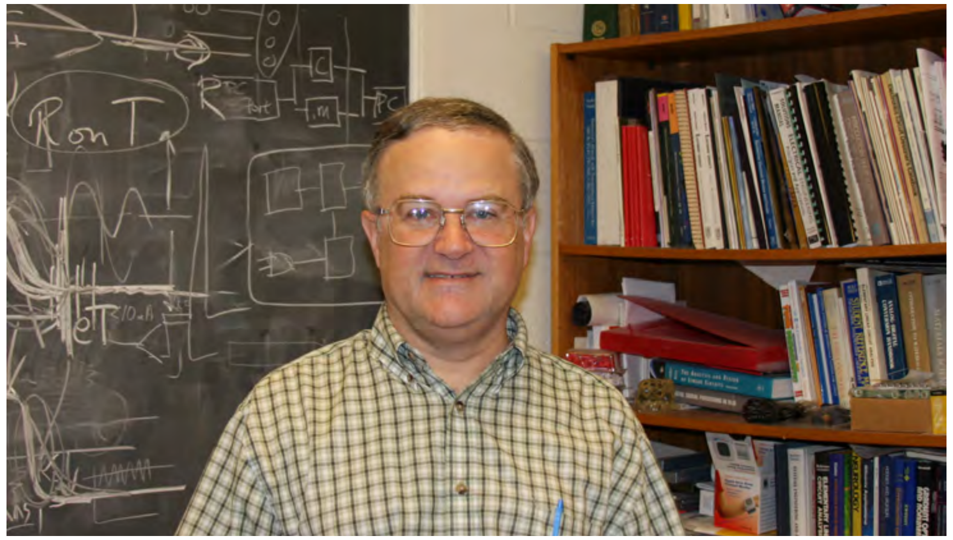
"It really required these tools to rigorously show that," Smith said. "So it's not surprising that no one has done this before."

In future work, the researchers may explore if honeycombs are optimized for mechanical strength and test the breadth of the bee's architectural repertoire.

The study was funded by the Simons Foundation, the National Science Foundation, the German Research Foundation, a Packard Fellowship for Science and Engineering, and GETTYLABS.

ECE ALUM, FACULTY MEMBER HONORED BY THE CORNELL TRADITION

by Eric Laine



John Belina '75, M.Eng. '75. Archive photo.

The alumni-supported program called The Cornell Tradition has established the John Belina Cornell Tradition Fellowship in recognition of Belina's many years of dedicated service and commitment to its student fellows.

Belina, who served in various capacities in the School of Electrical and Computer Engineering from 1982 until his retirement in 2018, has requested this fellowship be awarded each year to a Cornell Tradition fellow who serves in a leadership role in Cornell Residential Life.

The Cornell Tradition coordinates the efforts of outstanding undergraduates who are committed to paid work, service, and academic achievement. Total membership is approximately 500 fellows, most of whom are chosen through the regular Cornell University admissions process. Rising sophomores and juniors can apply to the program during their spring semester. Each year, Cornell Tradition Fellows contribute more than 50,000 hours of work as well as 40,000 hours of service in their campus, local, and home communities.

Belina is a longtime supporter of The Cornell Tradition. He has served on numerous award selection committees, presented awards to seniors at the annual recognition event, and recommended students to The Cornell Tradition who he believed would be a good fit. Belina has positively impacted many students in The Cornell Tradition through his connections in Residential Life and in his work in the College of Engineering, where he was a beloved teacher for almost 40 years. Belina is also an alumnus of Cornell ECE, earning his bachelor's degree in 1974 and his M.Eng. in 1975.

Read more ECE news at **ece.cornell.edu**

MOHAMED ABDELFATTAH

Mohamed Abdelfattah joined ECE as an Assistant Professor at Cornell Tech. His research interests include deep learning systems, automated machine learning, hardware-software codesign, reconfigurable computing, and FPGA architecture.

"My research lies at the intersection of computer hardware and machine learning," he said. "I investigate methods to codesign algorithms, software and hardware to optimize the efficiency of emerging applications powered by machine learning. On the hardware side, I focus on reconfigurable computing with devices like FPGAs, especially in the datacenter setting. On the algorithms and software side, I have been working on automated machine learning (AutoML) methods to enable neural networks on constrained mobile devices. My overarching goal is to design the next generation of computers that are powerful yet efficient to power machine learning applications."

"I was always fascinated by electronics. During my undergrad, I was eager to understand how these integrated circuits worked. I took many courses on semiconductor technology and analog electronics but then quickly fell in love with digital electronics, and particularly FPGAs. More recently, machine learning has completely captured my imagination but further progress is blocked by the availability of computer resources. This is why I'm motivated to work on the next generation of computers, to enable further progress in machine learning."

"Having worked in industry (Intel and Samsung) for the past 6 years, I am excited about working with students again. I look forward to creating collaborations with both academic researchers and industrial partners, and I hope to take full advantage of open-ended academic research in pursuing ideas that are not necessarily tied to short-term industrial goals. I am also excited about being part of both the Computer Systems Lab and the Tech campus in NYC, both with an amazing roster of world-class researchers."

KARAN MEHTA

Karan Mehta received B.S. degrees from UCLA in Physics and Electrical Engineering in 2010, and completed his Ph.D. in Electrical Engineering and Computer Science at MIT in 2017. Following stints as a postdoctoral fellow and senior scientist in the physics department at ETH Zurich, Karan Mehta joined Cornell ECE as an Assistant Professor in January 2022, leading a group working at the intersection of photonics, atomic physics, and quantum technologies.

"Individual atoms in the void form nearly ideal, noise-free systems for quantum technologies ranging from computation to precision sensing," he explained. "As fundamentally attractive as they are though, controlling individual atoms practically, particularly at scale, is hard. Our lab, the Photonics and Quantum Electronics Group, explores techniques broadly at the boundary of atomic physics and scalable classical photonics/electronics. This leads us to explore new photonic materials and devices, together with the light-matter interactions enabled by their interface with atomic systems, in pursuit of precise and scalable quantum technologies."

"I was bowled over by the beauty of optics when I first properly learned electromagnetism. It's also hard not to be fascinated by quantum mechanics, and these turn out to be wonderfully related — both in terms of the basic physics, and in technology too, in ways that have evolved in interesting and impactful ways over decades. It's been a pleasure to continue to see and pursue some exciting opportunities while understanding these areas better."

"Building up a group is an exciting challenge, and in research I'm always looking to find new directions to pursue. I look forward to being able to do this together with the great students, staff, and faculty here at Cornell."

Faculty profiles by Chris Dawson

ANNA SCAGLIONE

Anna Scaglione M.Sc.'95, Ph.D. '99 has rejoined the faculty of Cornell Engineering as a professor of electrical and computer engineering. The last time Scaglione was an ECE faculty member, the first iPhone had just been unveiled and the term "Smart Grid" had just been defined by the U.S. Congress in the Energy Independence and Security Act of 2007.

In the intervening years, Scaglione's expertise and research areas have expanded beyond signal processing for information networks to include intelligent cyber-physical infrastructure for secure, resilient energy delivery systems. With a particular interest in helping to create the next generation power grid, Scaglione is based at the Cornell Tech campus in New York City.

"I don't think New York City has been as ambitious as San Francisco and Silicon Valley in their use of technology for the betterment of the lives of its citizens," Scaglione said. "I am really concerned about what the city is going to do about recharging electric vehicles, as well as how renewables and electric storage will be deployed effectively in such a dense place. I want to be part of the discussion about how to make all of these things happen."

Scaglione is affiliated with the U.S. Dept. of Energy's Integrated Data Frameworks Group, which performs research and development on software and methodology for improving the security, quality, and usability of analysis tools for scientific and applied data. As the group's website notes, "Her current research focuses on studying and enabling decentralized learning and signal processing in networks of sensors. She also focuses on sensor systems and networking models for cyber security in critical infrastructure and for the demand-side management and reliable energy delivery and in other aspects at the intersection between intelligent infrastructure, information systems, and social networks."

Scaglione is thinking beyond the mere technological challenges of making the electric infrastructure of New York City more secure, resilient, and sustainable. "Ultimately, researchers, policy-makers, and planners have to understand how structural changes affect productivity, the appeal of the city, and the lives of the people living there," she said. "I hope I can play a role in the transition and direct my more applied work in this direction."

Scaglione's years of research leave her uniquely suited to address head-on some of the most daunting challenges facing New York City as it strives to create an energy infrastructure that can incorporate offshore wind- and solar-generated power, to support a growing number of electric vehicles, and to protect its infrastructure from hackers.

Scaglione is thrilled to be back at Cornell and in New York City, where her work can have an immediate impact. "New York needs innovation," she said. "It's a good thing for a city to think about how it can change for the better for its citizens, and I am excited to be a part of these changes."

ECE faculty based at Cornell Tech meet for dinner with Director Apsel. From left to right: Professor Anna Scaglione, Professor Alyssa Apsel, Associate Professor Mert Sabuncu, Assistant Professor Mohamed Abdelfattah, and Professor Daniel Lee. Photo provided.

LANG TONG IS BUILDING INTELLIGENCE INTO ENERGY MANAGEMENT

by Chris Woolston

It's going to take a lot of energy to power the country and the world through the next decade, let alone the next century or beyond. Light bulbs, electric cars, city power grids—the energy has to come from somewhere, and it has to be delivered with levels of efficiency, reliability, and resilience that are currently out of reach.

Lang Tong, the Irwin and Joan Jacobs professor of engineering at Cornell University, is trained as an engineer, but he's taking a wide-ranging approach to energy that draws on economic theories as well as ohms and resistors. With the support of a new $1.4 million ARPA-E grant from the U.S. Department of Energy, he's working with Khurram Afridi, associate professor of electrical and computer engineering, and assistant professor Francesco Monticone to explore new technologies to wirelessly charge electric vehicles as they speed down the highway, a potentially crucial step to a more sustainable future.

The explosive growth of electric vehicles promises to bring new challenges to the grid, Tong says. He notes that such vehicles were practically non-existent just a decade ago, but they could soon account for 20% of new purchases. "If every house has an electric car, that would be one of the biggest sources of energy consumption," he says. "It's one of the most interesting aspects of the future of the power grid."

The ARPA-E project, "Field-focused load-leveled dynamic wireless charging system for electric vehicles," could make it more feasible to power the electric vehicle revolution without overloading the grid, says Afridi, the project leader.

"THE ONLY WAY THAT ELECTRIFIED TRANSPORTATION CONTRIBUTES TO DECARBONIZATION AND CLIMATE CHANGE MITIGATION IS IF THE POWER FOR THE CAR COMES FROM CLEAN ENERGY."

Afridi explains that most people today charge electric vehicles in the evening when they come home from work, putting a simultaneous strain on the system at a time of day when the sun is not providing much power. If charging systems were embedded within the road, vehicles could be powered on demand. "Essentially the car is receiving continuous, constant power," Afridi says.

A charging station for electric and hybrid cars in the Hoy Parking Garage. Photo by Robert Barker (UREL).

"You're cruising on the energy from the system instead of storing it. It's almost like an electric railway."

Tong's role in the project is to develop artificial intelligence tools to ensure that wirelessly charged vehicles would draw a relatively constant load from the grid. Afridi and Monticone are working on daunting technical details. The proposed technology would use high-frequency electric fields to deliver 50 KW of power over a distance of 12 cm, which is roughly the clearance of a typical electric car. Afridi's lab has already developed a prototype system that can deliver 2.5 KW over that distance; scaling that power by a factor of 20 will be a major challenge and, hopefully, a significant milestone.

Afridi notes that when he started investigating this sort of technology in 2014, the best anyone could do was deliver 5 W of power over 1 mm of distance to wirelessly charge cell phones.

Monticone's main task is figuring out a way to keep the electricity confined to the charging pad and the engine, not shooting out the sides of the car or, worse, into the passengers. "It's crucial to direct the fields—and the energy they carry—in the desired direction," he says. To accomplish that, he plans to design a new type of charging plate using patterned metal sheets. "It will allow us to 'sculpt' the electric field between the charging plates, making the wireless energy delivery most efficient," he says.

If successful, such technology could greatly reduce the need for batteries while increasing the range and efficiency of electric vehicles. For electric vehicles to be broadly adopted, however, the electric grid has to be modernized.

"The transportation system and the electric power system consume two-thirds of total energy," Tong says. "Merging these two would represent a huge infrastructure challenge. You would either have to build new power plants or tap into renewables. The only way that electrified transportation contributes to decarbonization and climate change mitigation is if the power for the car comes from clean energy."

There are enormous technical and economic challenges in integrating solar and wind power everywhere to meet the emerging power demand from electrified transportation. To this end, Tong says, implementing smart digital technology is the key. Along with smart homes that manage energy consumption to match the lifestyle of residents, we need a smart power grid that integrates efficiently and reliably distributed energy resources such as the rooftop solar, behind-the-meter battery, and smart EV charging at home, in public parking facilities, and mobile charging on the road.

Tong has come a long way from his earlier career as a researcher. When he joined Cornell, he worked on wireless communications and networking. Making communications possible anytime and anywhere was the goal. While the science and engineering of wireless communications are compelling, the social and societal impacts of such ubiquitous communications have become more complex.

During a sabbatical at UC Berkely in 2008, Tong decided to devote his research effort to renewable energy. Over the past 14 years, his Digital Energy and Power System group has endeavored to make anytime anywhere renewable integration a reality by focusing on three pillars of smart grid technology: system optimizations under uncertainty, data analytics and machine learning, and engineering economics of renewable energy. From wireless communications to wireless charging with renewable energy, Tong says, electrical engineers will play a critical role in the energy transformation we will see in the 21st century.

Lang Tong, the Irwin and Joan Jacobs Professor of Engineering. Photo by Eric Laine.

SUSTAINABLE ENERGY FOR A HIGH-POWERED WORLD

by Jackie Swift

How the High Frequency Power Electronics Group incubates environmentally positive innovations

Associate Professor Khurram Afridi and Ph.D. students Maida Farooq and Firehiwot Gurara in the High Frequency Power Electronics Group lab. Photo by Eric Laine.

As global warming increases and countries seek to lower carbon emissions, finding ways to access sustainable energy is paramount. Associate Professor Khurram Afridi and his lab, the High Frequency Power Electronics Group, are at the forefront of this quest to create methods and technologies that will harness the energy we need through environmentally positive innovations.

Afridi has garnered attention recently for his work on wireless recharging of electric vehicles while they are in motion. His research in this area has the potential to revolutionize transit in years to come. But electric vehicle recharging is not the only impactful project focusing on energy and sustainability coming out of the High Frequency Power Electronics Group. Several lab members are working on research projects with similarly far-reaching potential.

"Maida Farooq and Firehiwot Gurara are both working on the forefront of high frequency power electronics," Afridi said. "They are developing new power electronic technologies appropriate for MHz-frequency operation while also addressing important societal problems. Firehiwot and Maida are role models for the next generation of engineers driven by the passion to improve lives."

Smaller, Cooler, More Efficient UPSs to Keep Data Centers Humming

As the world moves more and more to online applications—everything from cloud computing to Bitcoin and block chains—data centers are growing both in importance and in energy consumption. To make data centers more dependable and sustainable, Ph.D. student Maida Farooq has turned her attention to the systems that funnel energy to the servers.

"With the rise of artificial intelligence and machine learning and the shift to a cloud-based system, data has been growing exponentially over time," Farooq says. "All that data is stored in the servers, and so the storage requirement is growing in proportion to the data. It's projected that data centers will be consuming most of the energy of the planet in the coming years. Obviously all those servers will need power supplies."

Data centers count on Uninterruptable Power Supplies (UPSs), which supply power to critical loads by decoupling the servers from direct reliance on the power grid. A UPS will take power from the grid and process it so that it is smooth and acceptable for the servers. In addition, if an outage should happen, the UPS will continue to supply uninterrupted power via its built-in battery. "If we didn't have UPSs, then data would be lost when servers lose power," Farooq says.

Current UPSs have a number of problems, Farooq explains. One is their insatiable need for power. Another is their size; they take up a lot of space in the server racks that could better be utilized for the servers themselves, saving the data centers money. On top of that, the heat generated by all those UPSs means data centers need an inordinate amount of cooling. "If we are able to make more efficient, smaller UPS systems, we will be able to save a lot on energy consumption," Farooq says.

Farooq has set her sights on reducing the size of the UPS by decreasing the size of the energy storage elements—the inductors and capacitors—inside it. "Their size scales down when we increase the frequency of the switches," she says. "But it's not that straightforward. The switches typically used are silicon based, and silicon-based transistors are not able to switch that fast. They have a lot of parasitics that come into play."

Side views of the proposed high power density online UPS prototype built in the lab, capable of achieving a power density of 26.4 W/in^3. Image provided.

Parasitic capacitance and inductance—when unwanted capacitance and inductance effects are formed in a circuit—are essentially unavoidable in electronic devices. However, the recent emergence of gallium nitride (GaN) semiconductors has introduced a possible solution. "GaN devices are very good at switching at high frequency because they have much lower parasitics," Farooq explains. "They allow us to switch much faster, and by doing that we can envision a way to miniaturize the UPS."

Using GaN switches, though, is only the beginning of Farooq's UPS redesign. When switching to higher frequencies, the layout of the circuit board, and the control of the UPS, has to be compatible as well. "We can replace silicon switches with GaN switches in the circuit boards currently on the market, but they still won't be able to switch at high frequencies because the way things are placed is not compatible with high frequency operation," she says. "We need a new topology."

Online UPS inside a chassis for testing under practical conditions of a data center. Photo provided.

Working with Afridi, and following the preliminary work of her collaborator Danish Shahzad Ph.D. '21, Farooq created a new UPS circuit topology and associated controls that are compatible with high-frequency operation. The new circuit topology utilizes half-bridge structures comprised of GaN switches instead of the four-quadrant structures comprising silicon switches which made high-frequency operation challenging. The novel control approach developed by Farooq enables the new UPS topology to deliver high quality power. The result is a smaller, much more efficient UPS that needs much less cooling.

"The innovative work that Maida is doing in UPS design will have direct impact on our ability to sustainably scale data center workload," said Afridi, "making it possible for everyone on the planet to have access to information."

The researchers have created a lab prototype and are now working with UPS manufacturing companies to test it. After that, Farooq will work on further topological innovations that will allow her new UPS design to work on different line voltages across the world. "In Japan, for instance, you have low line voltage, while in Europe you have a very high line voltage," Farooq says. "I want to explore online UPS topologies that can support universal input voltage while allowing usage of GaN switches to enable miniaturization via high-frequency operation. This will enable us to deploy the online UPS anywhere in the world."

A Solar Cookstove that Generates and Stores Electricity Via Waste Heat

As part of her graduate work, Ph.D. student Firehiwot Gurara is co-designing a solar cookstove that can also generate electricity for applications like lighting or phone charging. The system, which is funded by the Cornell Atkinson Center for Sustainability, concentrates solar energy for cooking and also has a thermoelectric generation unit which extracts the waste heat from the stove and uses it to generate electricity for the electrical applications. In addition, a thermal and electrical storage unit allows for energy storage so that a user can cook food even at night, as well as store energy for the electrical applications.

"Firehiwot's work on the solar cookstove and the conversion of its waste heat into useful electricity has the potential to change the quality of life of millions of people around the world," Afridi said.

Gurara is working on the electronics for the system, while a group of students from Professor Zhiting Tian's lab in the Sibley School of Mechanical and Aerospace Engineering are creating the cookstove itself. "We're still in the initial prototype stage," Gurara says. "I've designed the power converter to accommodate the power requirements of both energy storage and charging and lighting devices. We've tested the electronic system, but it still has to be refined to integrate with the cookstove system."

Designing the power converter required Gurara to juggle a number of key design considerations. These included handling the thermoelectric generators' wide input voltage range caused by variations in temperature, as well as managing the wide output power requirement for battery and loads. The space constraint in the stove itself proved a challenge, as well.

Gurara hopes the cookstove will provide an alternative energy source for people in regions or situations where the electrical grid infrastructure is nonexistent or underdeveloped, she says. "Over 3 billion people don't have access to clean cooking, for example," she explains. "This especially impacts the health of women in developing countries, who suffer a lot from indoor air pollution caused by using wood and other biomass-based fuels for cooking. I'd like for the system to be applicable for them, but the thermal generators are a bit expensive, so the work needs a lot of modifications before that can happen."

The project began back in late 2019, when Gurara and her colleagues sent out surveys to contacts in India, China, and Pakistan to assess the energy demands for specific applications, willingness to pay, and challenges related to energy or electricity access for people in those regions.

"The survey was not conclusive, since it only involved a few people from each country, but it helped us with narrowing down the areas of application," she says. "We identified cooking as a major challenge, especially for people in rural areas where they don't have access to the electrical grid or sometimes even to other energy sources. And the application is not just limited to energy access in developing countries but could also be used in parks in the United States, for instance, where there is no convenient access for cooking or for phone charging."

Once they had started the project, Gurara, Tian and undergraduate mechanical engineering student Mike (Quanhuan) Liao participated in the National Science Foundation's Innovation Corps (I-Corps) program, which helps academic inventors learn about entrepreneurship and the ins and outs of founding a startup business. As part of the I-Corps experience, the researchers conducted phone interviews with people from Pakistan, Ghana and Ethiopia, to understand the challenges they have with traditional biomass-based cooking, as well.

Gurara originally came to Cornell as an undergraduate transfer student interested in power electronics. The chance to work on sustainability related projects, among other things, drew her to the university. She joined Afridi's lab, then stayed on after graduating to pursue a Ph.D. in Electrical and Computer Engineering.

"I really like that Cornell has such a collaborative environment," she says. "Professor Afridi is also very supportive. He's one hundred percent committed to making sure we succeed at whatever we're doing. That's the main reason why I'm here."

THE SOUND OF FUSION

How a big bang in the basement of Grumman Hall contributes to a future of fusion energy

by Eric Laine

When the COBRA fires, the sound is startling.

The COBRA (Cornell Beam Research Accelerator) pulsed-powered generator delivers one million amperes of current in a 100-nanosecond BANG that reverberates through the Laboratory of Plasma Studies (LPS) in the basement of Grumman Hall.

The massive electric discharge is routed into a vacuum chamber where it annihilates the substance contained there, a puff of gas or an array of wires, breaking it down into ions and electrons, a state of matter known as a plasma. In an instant, the plasma is squeezed, or pinched, by a similarly massive magnetic field in a process called a Z-pinch for the axis orientation of the squeeze.

"Plasmas tend to be unstable. They don't want to go where you want to push them," said David Hammer, the J. Carlton Ward, Jr. Professor of Nuclear Energy Engineering who leads the Multi-University Center of Excellence for Pulsed-Power-Driven High-Energy-Density Science. "It's like squeezing a balloon, and the balloon goes out between your fingers. That's what a plasma does as well. So, developing a configuration of plasma that can be squeezed by a magnetic field is very important to the field of magneto inertial fusion."

Continued...

This set of four images is the extreme ultraviolet self-emission of an imploding aluminum wire array situated between a dynamic magnetic mirror formed by a pair of twisted electrodes. Starting from thebottom left in clockwise direction, each image was taken 10 nanoseconds after the preceding one. Imaging by Chiatai Chen.

FEATURE STORY

LPS researchers are not working at a scale that would produce fusion energy here below populated classrooms, labs and offices in Grumman Hall, though hearing the COBRA fire might make it seem like they are. Similar experiments are conducted at the Sandia National Laboratories in Albuquerque, New Mexico, at a much greater scale using proper fusion fuel. The work in LPS is aimed at developing diagnostic tools and testing processes that can later be scaled up at the national labs.

A variety of instruments are used to measure what's happening inside the vacuum chamber, but none produce results quite as spectacular as the cameras. During one pulse, which lasts less than a millionth of a second, a bank of synchronized cameras take a set of pictures, each 10 nanoseconds apart, showing a rapidly growing instability in the plasma.

"You see the plasma going unstable as the pictures show the plasma coming down to a very tight pinch," Hammer said. "These measurements are fundamental to knowing what causes the plasma to do the motions that it does. Understanding the motions that we see with those cameras is a fundamental aspect of what we're working on."

Jay Angel, a fourth year Ph.D. student, is developing a novel diagnostic to make measurements of the magnetic fields being produced in plasma expanding in a vacuum using a technique called Zeeman spectroscopy. Diagnostic techniques he develops can be used to show whether a particular method of experimentation will produce favorable results in labs working at greater scales than LPS. "Every diagnostic will work within its own limits," Angel explained, "What I'm doing is finding the limits."

Angel worked on biomedical imaging techniques at Boston University College of Engineering where he earned his master's degree on laser speckle rheology, which is shining a laser on blood as it coagulates to get real time information about clotting coefficients—basically how fast your blood clots. He appreciated working on a project with a goal that provided some societal benefit, which is a feature that drew him to fusion research as well.

"About a month after I applied to Cornell, Dave Hammer reached out to me," Angel said. "As soon as he said 'fusion' I was like, wow, that seems like possibly one of the best fits for the goal of improvement for humanity. It was hard to even imagine another research topic that could beat it."

Ph.D. student Jay Angel prepares the vacuum chamber for the next experiment. Photo by Eric Laine.

Angel's work in LPS takes advantage of his experience with various imaging techniques, many of them using lasers. Analyzing the images captured by magnetically squeezing plasma sometimes produces more questions than answers. "There's a lot of things we still don't understand that happen on our machines," Angel said, "and if you scale it up, it's even more complicated."

But he's focused on the larger ambitions of fusion energy. "Whether my diagnostic works or not is not that important in the big picture," he said. "I'm still spending every day working on plasma physics, looking at how things work, determining how a diagnostic could apply in various scenarios. We're working towards fusion."

Chiatai Chen, fourth year Ph.D. student in LPS, agrees. "My work is trying to contribute to the understanding of some of the physics required to make nuclear fusion happen," he said. Chen is studying whether it's possible to improve the confinement of a very hot and dense plasma with what's called a magnetic mirror.

While Angel sends COBRA's electrical energy through a puff of gas to generate plasma, Chen drives the current through an array of wires which implode in the process. A magnetic mirror is formed simultaneously by the twisted electrodes to confine the plasma. Confining the plasma with this magnetic mirror can allow it to reach a higher temperature and density, and high density and temperatures are what you need to achieve fusion, Chen explained.

"Here in LPS at the scale we're working at," Chen said, "the temperatures and densities are still too low for fusion. So the motivation behind this project is to demonstrate a method for containing and compressing the plasma that could be scaled up to a larger system at the national labs that might actually produce fusion energy."

Chen speaks from experience, having spent more than two years as a research scientist at Lawrence Livermore National Laboratory after earning a B.A. in physics from the University of California at Berkeley.

"I was working on things completely unrelated to plasma," Chen said, "but even though I wasn't working on it personally, I was exposed to it." At Livermore, the plasma experiments were similar, but instead of driving an electric current through a wire array to create a plasma, they were doing inertial confinement fusion using a very powerful laser.

"That's where I got interested in high energy density plasma physics, and that's why I decided to change my research direction," Chen said. "I was hoping to get an opportunity to participate in research work that one day will lead us to fusion energy. And that's why I came to Cornell LPS."

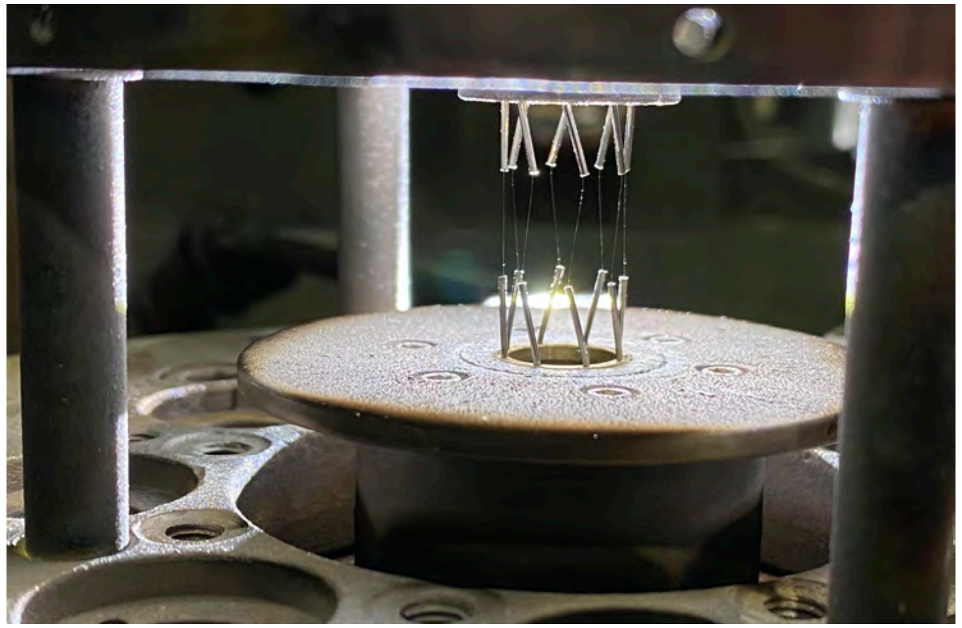
The student researchers in LPS are supported by a staff of technicians who maintain the complex and mostly decades-old equipment, often machining their own parts as needed, and who help set the stage for the experiments. "COBRA experiments are a team effort," Angel said. "The lab just wouldn't operate without them."

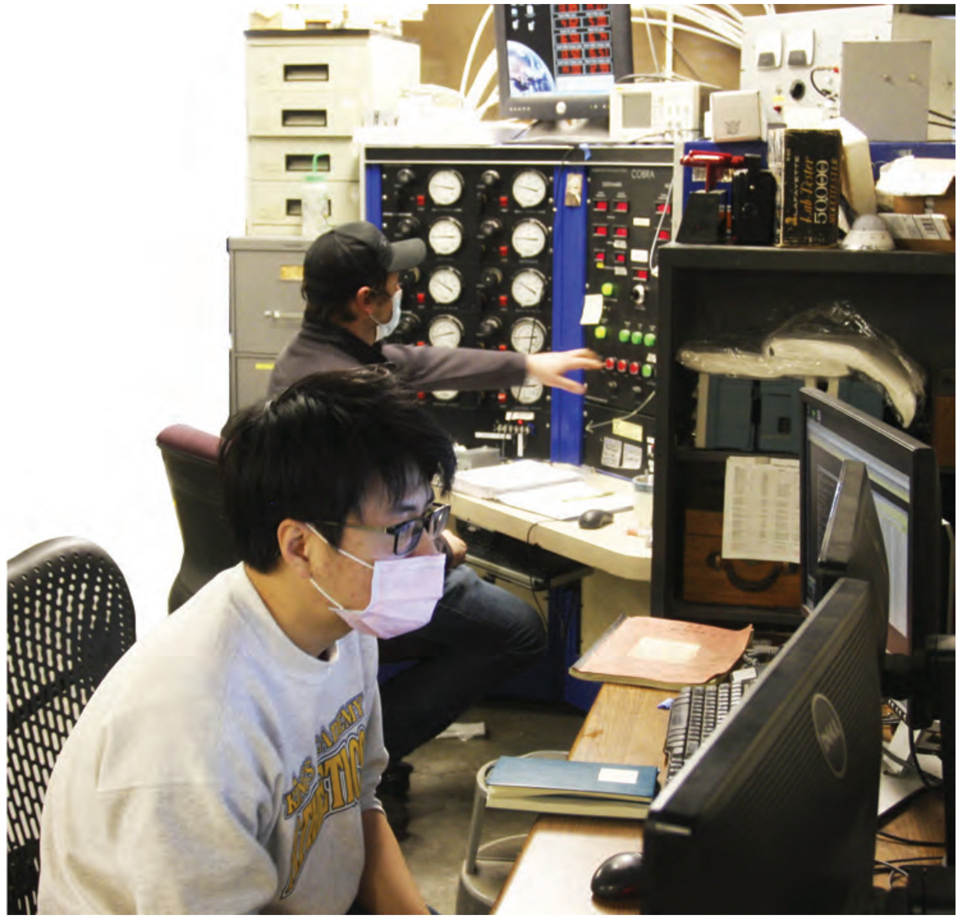
"It can take three or four days, up to a week, to set up all the diagnostics including the optics, the mirrors, the lens, making sure the lasers are going in the right direction, and the cameras are looking at the right angles," Chen explained. "The experiment itself happens in less than a second—boom—and the cameras capture it."

The excitement in LPS is palpable to those who visit, whether it's coming from the epic discharges of the million-amp COBRA, or from the possibilities contained in the research. "Having a limitless source of energy, if we can make nuclear fusion a reality, is something that really excites me," said Chen.

That's the mission of LPS: to understand the fundamental physics underlying plasma with the ultimate goal of discovering a way to generate a controlled fusion system that produces nuclear reactions safe to harness for energy production. The work is supported by the United States Department of Energy and the National Nuclear Security Administration's Stewardship Sciences Academic Programs.

Learn more at lps.cornell.edu.


A look inside the vacuum chamber prepared for a COBRA shot. Eight 17-micron diameter aluminum wires are threaded through stainless steel tubes twisted to act like a magnetic coil. Photo by William Potter.


Ph.D. student Chiatai Chen and LPS equipment technician Dan Hawkes (background) await the results of a COBRA shot. Photo by Eric Laine.

PREPARE THE GRID NOW TO POWER ELECTRIC VEHICLES

Advice for policymakers based on a collaborative pilot program

by Eilyan Bitar and Polina Alexeenko

Less than 2 percent of all cars sold in America today are electric, but that will soon change. The internal combustion engine's firm grip on American transportation is loosening and for the first time a vision of an all-electric vehicle future is coming into clear focus. It's a vision that may become reality in a matter of decades, and one driven by declining battery costs, progressive policy, consumer demand and the world's largest automakers.

Volvo says it will make only electric vehicles by 2030 and General Motors has announced plans to go all electric, completely phasing out gasoline powered vehicles by 2035. Officials in California intend to ban the sale of new vehicles powered by internal combustion engines by the same year. Sensing a looming shift in the market, many other automakers like Ford and Volkswagen are investing heavily to expand their electric car offerings.

But even with this great momentum, the transition to an all-electric car future won't be possible without careful planning and coordination with the power grid and the companies that manage its operation — a reality made all the more pressing in light of deadly power outages in Texas following a winter freeze.

Today, most people charge their electric cars when they come home in the evening — when electricity demand is typically at its peak. If left unmanaged, the power demanded from many electric vehicles charging simultaneously in the evening will amplify existing peak loads, potentially outstripping the grid's current capacity to meet demand.

To accommodate the increase in that demand, utilities and grid operators—operating as they do now—would need to build new power plants to produce enough power and expand transmission and distribution infrastructure to carry that power from the generators to the electric vehicle chargers. In states like Texas and California, where the transition to electric vehicles is accelerating rapidly, these enhancements to the grid infrastructure would cost tens of billions of dollars. And they would take decades to complete. To minimize these costly upgrades, utilities must rethink how they manage demand.

Timing is everything. Very often, EV owners don't need their cars charged immediately after they park at home or at the office—just within a reasonable window of time before they expect to leave. In an effort to tap this flexibility, many utilities have begun to offer electric car owners time-of-use rates, where the price of electricity varies over the course of a day, being cheapest during off-peak hours.

While this might seem like a sensible approach, it won't solve the peak load problem posed by EVS, and may make matters worse. At best, time-of-use rates will encourage some electric car owners to charge during off-peak hours. At worst, such incentives will synchronize electric car charging patterns, as many EV owners will program their vehicles to begin charging simultaneously at the start of the off-peak pricing period—a phenomenon that has been observed in a number of utility run trials. At moderate to high levels of electric car adoption, time-of-use rates may ultimately backfire — creating new demand spikes in the middle of the night, because of their synchronizing effect on EV power demand. A greater degree of coordination is needed.

"UTILIZING CUSTOMER FLEXIBILITY, THE SMART CHARGING SYSTEM WAS HIGHLY EFFECTIVE IN SHIFTING THE MAJORITY OF EV CHARGING LOADS OFF-PEAK."

To more effectively manage the charging times of electric cars on their power distribution networks, some utilities are exploring the possibility of directly controlling the electric car chargers. This may seem invasive, but could be one essential tool to minimizing strain on the grid — and saving electricity customers billions of dollars.

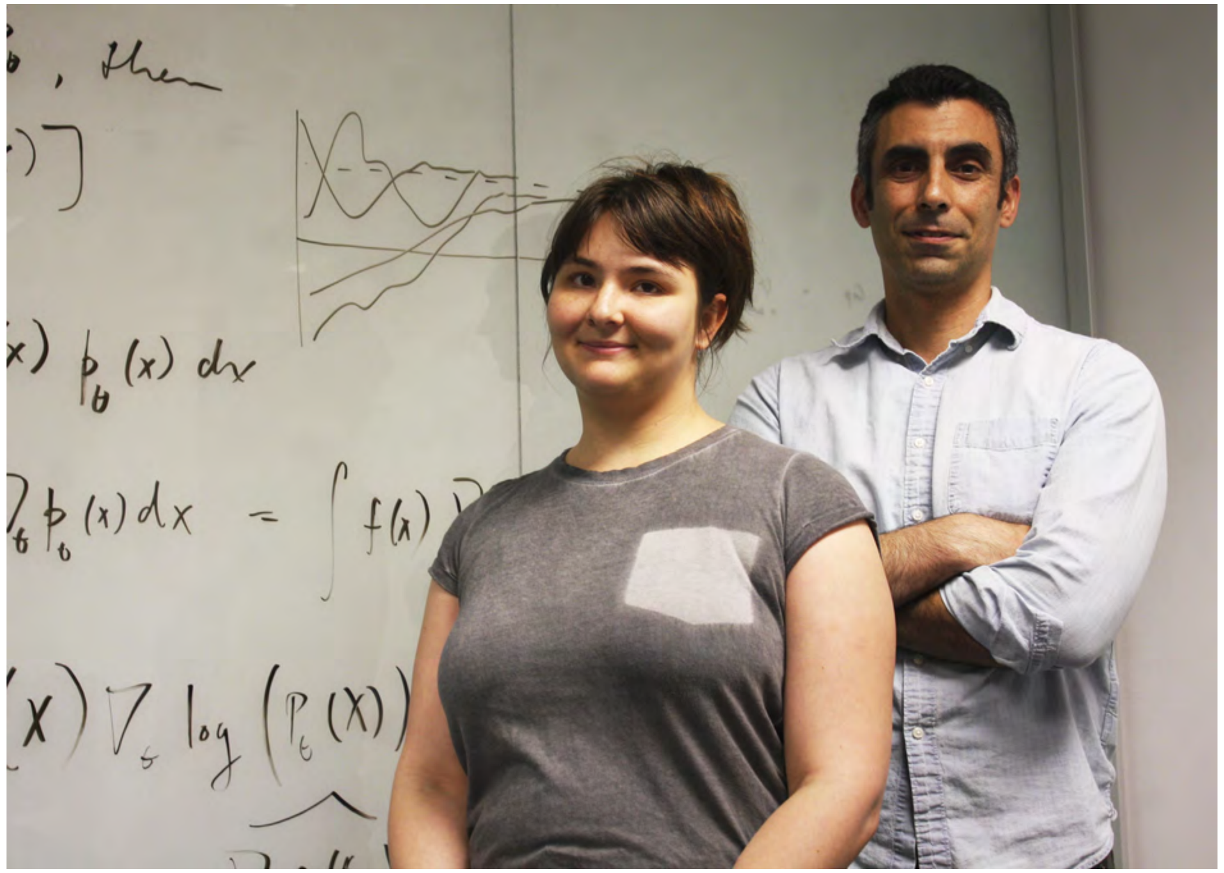
As part of this effort, utility company New York State Electric and Gas, in collaboration with our research team at Cornell University, piloted a new approach to dynamically controlled charging, where electric car owners can use their smartphones to specify how long they intend to leave their vehicles plugged in by selecting from a menu of "deadlines" that offers lower electricity prices the longer they're willing to delay the time required to charge their cars. After customers select their preferred deadlines, a smart charging algorithm actively controls the power being drawn by their electric cars in real-time to minimize overall strain on the grid, while ensuring that every customer's car is fully charged by its deadline. Customers get their energy when they need it and the utility can optimally coordinate the delivery of that energy to avoid spikes in demand. Everyone benefits.

Under the proposed coordination mechanism, we found that customers were frequently willing to engage in optimized charging sessions, allowing the smart charging system to delay the completion of their charging requests by more than eight hours on average. Utilizing the flexibility provided by customers, the smart charging system was also shown to be highly effective in shifting the majority of EV charging loads off-peak to fill the night-time valley of the aggregate load curve. Customer opt-in rates remained stable over the span of the pilot study, providing empirical evidence in support of the proposed coordination mechanism as a potentially viable "non-wires alternative" to meet the increased demand for electricity driven by the growing adoption of EVs.

The ability to actively control the charging of electric cars at scale also has long-term implications for the decarbonization of the transportation sector and the capacity to fuel this transformation by clean renewable electricity. One challenge limiting the large-scale grid integration of renewable energy resources, like wind and solar, is the intermittency in their supply of power. Through optimized charging, electric cars can be used to balance that intermittency by acting like a giant battery—absorbing renewable power when there's a surplus, and injecting some of that power back into the grid if it's needed at a later time, a concept known as "vehicle-to-grid." Such coordination would give rise to a symbiotic relationship between electric cars and renewables, where electric cars are used to buffer the intermittency of renewables, and renewables supply clean power to electric cars.

EVs are coming. Market forces and government policies will ensure they become part and parcel of Americans' lives. The question now is whether the grid will be ready.

A version of this op-ed originally appeared in the Albany Times Union on April 21, 2021. www.timesunion.com



Polina Alexeenko (left) is a fifth year Ph.D. student advised by Eilyan Bitar (right), associate professor and the David Croll Sesquicentennial Faculty Fellow in Cornell ECE. Photo by Eric Laine.

FOCUS ON PASSION, WORK ON SOLUTIONS

by Eric Laine

Dan Miller '78 offers advice for making an impact in a changing climate

Dan Miller '78 is managing director of The Roda Group, a Berkeley, CA based clean tech venture capital group he co-founded with fellow Cornellian Roger Strauch '78. Roda's portfolio includes carbon capture company Svante, energy storage company Gridtential, and water technology company Axine. Dan co-founded TCSI corporation which became a leading provider of telecommunications software. Before that, he designed communication satellite payloads at Hughes Aircraft (now Boeing) Space & Communications.

Dan received his B.S. in electrical engineering from Cornell and his M.S. from Stanford, and he's served on the Cornell ECE Advisory Council since 1995. Dan is a leading advocate for the need to take urgent action to address climate change including putting a price on carbon.

Photo provided.

What role do you think climate change plays in motivating engineering students today?

I think it plays a large and growing role. Students today are quite aware of the threat of climate change — often more aware than their parents — and they know it is their life that will be impacted. So more and more of them are looking to see how they can use their talents to help address the biggest problem facing the world.

What are the top skills ECE students need to make an impact?

When it comes to climate change, we need all skills. Of course, we need engineering skills to develop and deploy renewable energy and energy efficiency systems, but we also need people skilled in architecture, agriculture, labor relations, physics, meteorology, veterinary sciences, psychology, communications, and on and on. In other words, Cornell University is the perfect place to bring people together in a multi-disciplinary way to tackle climate issues!

The Roda Group focuses investments on technologies to address the consequences of climate change. Which of Roda's many current investments do you feel has the most potential for real impact?

One company that I'm particularly excited about is Svante Inc. Svante has developed a carbon capture system based on solid sorbents that can be structured into filters that capture CO2 (the traditional approach uses liquid sorbents). Svante systems is used to capture CO2 from hard-to-decarbonize industrial sectors such as cement and steel production, which account for about 25% of all emissions. Svante's sorbent material will also be used in Direct Air Capture systems that suck CO2 out of the air.

How did you come to serve on the board of Gridtential?

Gridtential developed a new "Silicon Joule" battery architecture that replaced lead grids in traditional batteries with plated silicon wafers that function as the anode and cathode. This leads to batteries that have high depth of discharge, rapid charging and discharging, long cycle life, can operate over a wide temperature range, and are highly recyclable.

I met the person who would become the CEO of Gridtential at a Cornell event 10 years ago, and that started a discussion that resulted in The Roda Group investing at that very early stage, when it was a three-person company. Now Gridtential is producing and licensing its battery technology and announcing partnerships with battery manufacturing and automobile companies.

How is Gridtential's approach to energy storage and battery technology unique?

Gridtential leveraged the growth of the solar energy business to make their advanced batteries affordable. Gridtential replaced the lead grids in traditional batteries with silicon wafers, but those wafers used to be very expensive. However, because of the amazing growth of the solar photovoltaic market, the price of silicon wafers has plummeted resulting in wafers that cost about what the original lead grids cost. Also, because Gridtential did not change the basic battery chemistry, manufacturers of traditional batteries can switch production to Silicon Joule batteries with only moderate changes to their factories.

How would you describe your role on the ECE Advisory Council?

I've been a member for over 20 years, and I see my role as giving an alumni and business perspective on issues facing the school. One issue that I have been pressing for many years is how climate change will impact all of our lives, and the need for the school and Cornell at large to focus on solutions.

What advice do you have for ECE students looking for careers with the kinds of companies that The Roda Group invests in?

Focus on what you are passionate about and work on solutions that will make the world a better place. An engineering education teaches you much more than details of a technology or formulas for calculating things; it teaches you how to look at problems and how to use systems thinking to come up with solutions. That is more valuable than detailed technical knowledge.

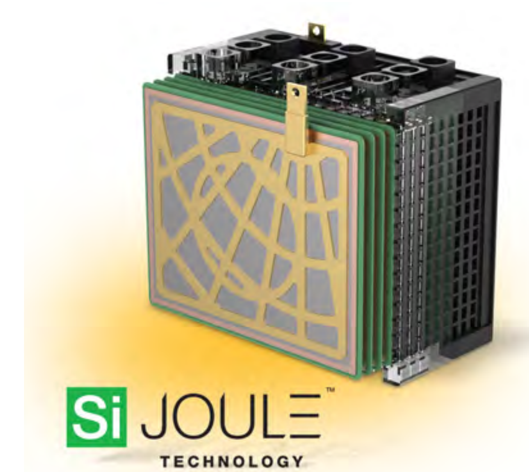


Image of the Silicon Joule 24V U1 deep-cycle Gen2 battery, courtesy of Gridtential. Silicon Joule lead batteries are 99.3% recyclable with the potential to perform comparably to lithium batteries at low-cost.

DOING SOMETHING

Meet the ECE undergrad leading the Campus Energy Conservation team

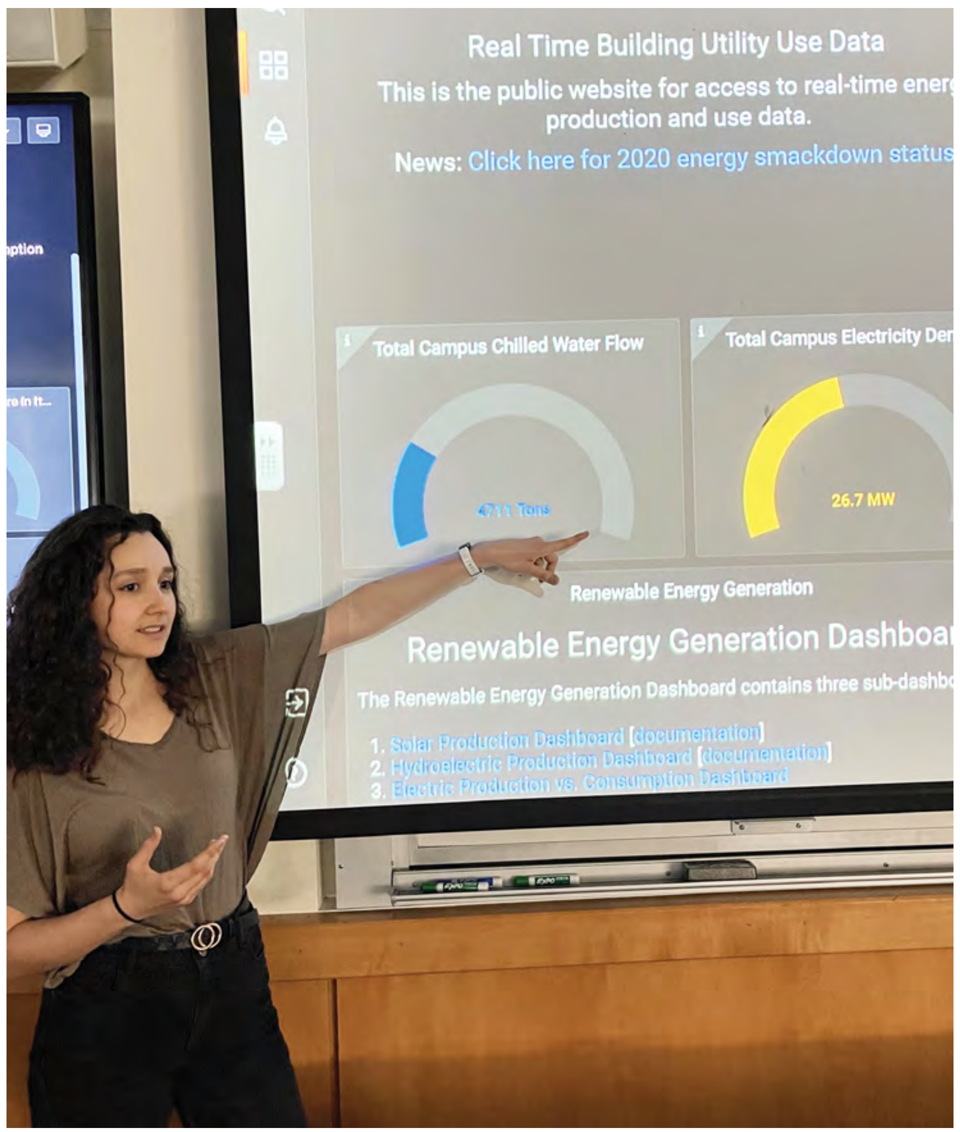
by Eric Laine

I don't personally like complaining about things if you're not going to do something about them," says Andrea Miramontes Serrano '24.

Within weeks of arriving on campus from her home in Madrid, Spain, Miramontes Serrano was outlining actions the university could take to reduce plastic waste in an article for The Cornell Daily Sun. The mandatory quarantine imposed by the still-growing COVID-19 pandemic in August 2020 forced Cornell Dining to make difficult choices about how take-out meals were provided to students, and the result was a lot of disposable plastic.

"Reading about the university's Platinum STARS rating, I envisioned Cornell as highly sustainable," Miramontes Serrano recalled, "but one of the first things I saw was the abundant waste." She heard a lot of people complaining about it too, and writing the article, "Plastic Film and Nasty Dumps: Can Cornell Live Up to Its Reputation of Sustainability?" was one of the first ways she decided to do something.

The article caught the attention of Kimberly Anderson, Sustainability Engagement Manager for Cornell's Campus Sustainability Office. "Several departments had been discussing waste impacts because of operational changes due to the pandemic, so her article was timely," Anderson said. She noted that Miramontes Serrano, who was already working with Cornell Dining to implement waste-reduction solutions, was eager to partner on sustainability efforts and had ideas on how to do it. Ultimately, the Sustainability Office hired Miramontes Serrano as a Sustainability Student Engagement Coordinator in August 2021.



Andrea Miramontes Serrano delivers a presentation on the campus energy dashboard, the EMCS portal. Photo provided.

To create more opportunities for students to get involved in the decarbonization of Cornell, Miramontes Serrano founded the Campus Energy Conservation (CEC) team. "As part of her joint role on Engineers for a Sustainable World (ESW) and within our office, Andrea created the new CEC team where students can partner with Cornell departments like Energy & Sustainability and Environment, Health & Safety to create and implement projects aimed to reduce energy consumption on campus through structural and behavioral changes," Anderson said.

The CEC team is working on enhancing the campus energy dashboard, the EMCS portal. The portal provides real-time building utility data for the Ithaca campus, and is used by staff, faculty, and students for a variety of academic and operational purposes. "Cornell is one of the few institutions that allows public users to visualize campus energy consumption data," Miramontes Serrano said. "Other institutions are now using it as inspiration for their own energy modeling and research."

> **"OFTENTIMES WE THINK OF SUSTAINABILITY AS A TOPIC. I SEE IT AS THE DUTY THAT WE HAVE FOR THOSE WHO WILL COME AFTERWARDS."**

The team has also submitted a proposal under a Sustainable Campus Energy Reduction Grant to retrofit spaces on campus that currently do not have centralized control systems, and whose HVAC energetic demand is particularly high, beginning with spaces in Hollister Hall. Additionally, they're working on a new initiative focused on inventorying ultra-low freezers in campus labs, quantifying the freezers' energy consumption, and identifying opportunities for improvement. The team found one freezer, a device from 1987 which is among the oldest on campus, consuming at least 28-35kWh per day—as much as a single-family household.

Miramontes Serrano and her team represent a growing number of students dedicated to improving Cornell's standing as an environmentally focused institution. "Our student team increases our capacity to do living lab sustainability projects at Cornell," Anderson said. "They help generate momentum amongst students, project teams, and student organizations to partner with our office and advance sustainable campus operations, engagement, and education at Cornell."

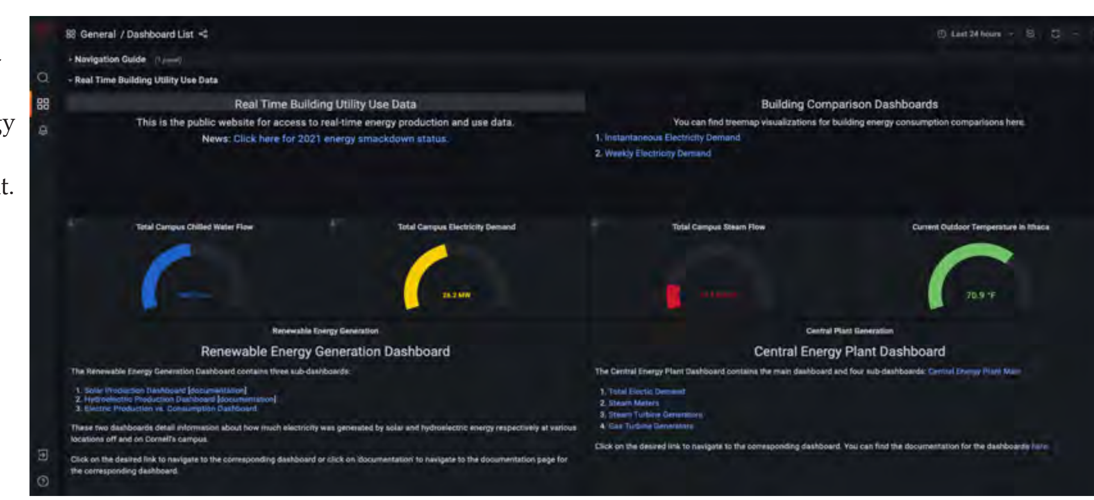
Miramontes Serrano was interested in sustainable development long before coming to Cornell. "I thought that to understand energy, I would have to understand electricity," she said. "And in order to understand electricity, I had to understand what kinds of devices and operations are involved when you work with electricity, what you can do with them, and how to build them."

Majoring in electrical and computer engineering seemed like a perfect fit. "A big thing for me was, if I ever have an idea, I want to be able to make it happen," Miramontes Serrano said, "I want to know how a system is made. I want to see how the sensors are installed in the walls, and what the connections are. ECE represents the fundamentals of what technology is right now." She's putting her enthusiasm and technical background to work conducting research on energetic self-sufficiency, microgrid applications and distributed energy resources through a Laidlaw Research Fellowship.

Asked if the School of Electrical and Computer Engineering was doing enough to incorporate sustainable energy issues into its curriculum, Miramontes Serrano took a high-level view.

"It would be appropriate for Cornell to weave more sustainable topics into all of its common classes, not just engineering," she said, adding that facing the challenges resulting from climate change can't be limited to a classroom project or an academic discussion.

"Oftentimes, we think of sustainability as a topic," Miramontes Serrano said. "Whereas I personally see it as the duty that we have for those who will come afterwards."



Screen shot of the EMCS portal in May 2022.

FACULTY AWARDS & HONORS

Jayadev Acharya, assistant professor, received a Google Research Scholar award in the category Machine Learning and Data Mining for his proposal "Information-Constrained Statistics and Federated Analytics."

Khurram Afridi, associate professor, appeared on WAMC's The Academic Minute in April 2022 speaking on wireless charging of electric vehicles. Afridi was also invited to write a comment article related to the area of electrified transportation in the February 2022 issue of Nature Electronics. He also received a Cornell Engineering Research Excellence Award and will serve as ECE's next Director of Graduate Studies starting July 1.

David Albonesi, professor, received the Fiona Ip Li '78 and Donald Li '75 Excellence in Teaching Award. Albonesi was also honored with the Class of 1972 Academic Innovation award.

Eilyan Bitar, associate professor, was an invited speaker at "Leveraging Grid Edge Integration for Resilience & Decarbonization," part of a briefing series hosted by the Environmental and Energy Study Institute.

Hsiao-Dong Chiang, professor, had his company, Global Optimal Technology, rank #2 overall in the ARPA-E Go Competition Challenge II. The main drive for the competition is to encourage the development of a robust optimal power flow solver. His team is expected to receive an award of $420,000.

David Delchamps, associate professor, received the Kenneth A Goldman '71 Excellence in Teaching Award.

Amal El-Ghazaly, assistant professor, received the Michael Tien '72 Excellence in Teaching Award. El-Ghazaly also received the Zellman Warhaft Faculty Commitment to Diversity Award from Cornell Engineering.

Zygmunt Haas, emeritus professor, was elected Fellow of the Association for Computing Machinery.

Debdeep Jena, David E. Burr Professor (ECE, MSE), was identified by Clarivate as one of the "world's most influential researchers," recognized for producing multiple highly-cited papers that rank in the top 1% by citations for field and year in the Web of Science.

Bruce Land, senior lecturer, was approved for emeritus status.

José Martínez, the Lee Teng-hui Professor, has been promoted to senior associate dean for diversity and academic affairs. Martínez has served as associate dean of diversity and academic affairs since January 2020 and will have an expanded portfolio of responsibilities in overseeing faculty development, appointments and performance, among other responsibilities.

Francesco Monticone, assistant professor, received the Franco Strazzabosco Young Investigator Award from the Italian Scientists and Scholars in North America Foundation (ISSNAF), which honors the best young Italian researchers working in the US. Monticone, whose family is from Ghemme, Italy, won the award presenting his work on applied electromagnetics and electrical engineering.

Kirstin Petersen, assistant professor, received a Cornell Engineering Research Excellence Award for her work on intelligent robotic systems focusing on robot collectives inspired by swarms in nature and applied to autonomous construction, smart materials, and agriculture.

Mert Sabuncu, associate professor, received the Michael Tien '72 Excellence in Teaching Award.

Huili Grace Xing, William L. Quackenbush Professor (ECE, MSE), has been elevated to an IEEE Fellow by the Institute of Electrical and Electronics Engineers. Xing also serves as Associate Dean on Research and Graduate Studies for the College of Engineering.

Zhiru Zhang, professor, received a pair of honors from the Association for Computing Machinery's (ACM) Special Interest Group on Design Automation (SIGDA). Zhang received the Best Paper Award at ACM/SIGDA's 30th International Symposium on Field-Programmable Gate Arrays (FPGA 2022) for the work titled "RapidStream: Parallel Physical Implementation of FPGA HLS Designs." Zhang has also been recognized by the ACM/SIGDA Technical Committee on FPGAs and Reconfigurable Computing, electing his DAC'06 paper titled "An Efficient and Versatile Scheduling Algorithm Based on SDC Formulation" to their Hall of Fame.

TRENDING ON SOCIAL MEDIA

Cross-college researchers unravel mummy bird mystery

By David Nutt, Cornell Chronicle, April 6, 2022

(L-R) Carol Anne Barsody, master's student in archaeology, Hunter Adams, lecturer in electrical and computer engineering, and ECE student Jack Defay '22 scan a mummified bird from Cornell's Anthropology Collections with smart phones that, in combination with open-source technology, will result in a 3D model of the mummy – a low-cost method of artifact digitization that could be easily replicated by other institutions. Photo by Ryan Young (UREL).

Visit the ECE website for the latest faculty and student news, awards and spotlights.

ece.cornell.edu/ece/news

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Ph.D. Student Awards and Honors

Joseph Casamento (Jena-Xing Lab) was selected to join the 2021-2022 cohort of NextGen Professors, a career-development program focused on preparing Cornell graduate students and postdocs for faculty careers across institutional types.

Nick Cebry (Batten Research Group) was the lead teaching assistant for this summer's CURIE Academy, a week-long project-based program to promote engineering education in an interactive and inclusive space for high school girls.

Reet Chaudhuri (Jena-Xing Lab) won the 2022 Cornell ECE Outstanding Ph.D. Thesis Award for his thesis, "Integrated Electronics on Aluminum Nitride: Materials and Devices." He said "A major highlight has been my discovery of the long-missing undoped GaN/AlN 2D holes, which enabled the p-channel III-nitride transistors to break the GHz-speed barrier."

Phillip Dang (Jena-Xing Lab) won the Best Oral Presentation Award at the Materials Research Society Spring meeting, 2021. Dang studies growth and characterization of spin-orbit materials and quantum states including the Integer Quantum Hall Effect (IQHE) and the Meissner Effect in superconductors.

Yu Gan and **Mingyu Liang** (Delimitrou Group) had their paper "Sage: Practical & Scalable ML-Driven Performance Debugging in Microservices" receive an IEEE Micro Top picks Award for the 12 most influential architecture papers from 2021 based on importance and potential for long-term impact.

Sophia Handley (Jena-Xing Lab) won Best Presentation at the 2021 Gulf Coast Undergraduate Research Symposium (GCURS), hosted annually by Rice University. GCURS provides current undergraduates the opportunity to present their original research discoveries to scholars from around the world.

Zeki Hayran (Monticone Group) was awarded a 2021 Optics and Photonics Education Scholarship by SPIE, the international society for optics and photonics, for his potential contribution to the field of optics and photonics. Hayran was also selected as one of only 10 recipients of the 2021 IEEE Photonics Society Graduate Student Scholarship, and he took second place in the OSA Early Career Best Poster Competition at the Waves in Time Varying Media Conference.

Austin Hickman (Jena-Xing Lab) recently earned his Ph.D. from Cornell Engineering and formed a startup company, Soctera, Inc., which was awarded an NSF Phase I STTR grant. Soctera is developing next generation power amplifier technology based on the aluminum nitride platform.

Nikita Lazarev (Zhang, Delimitrou Groups) had her paper "Dagger: Efficient and Fast RPCs in Cloud Microservices with Near-Memory Reconfigurable NICs" receive an IEEE Micro Top picks Honorable Mention.

Jon McCandless (Jena-Xing Lab) won a Best Student Presentation Award at the Electronic Materials Conference (EMC) 2021.

Kunal Shastri (Monticone Group) was a finalist in the student paper competition of the Metamaterials 2021 International Congress of Artificial Materials for Novel Wave Phenomena. His paper, "Bandwidth limits for wide-field-of-view achromatic metalenses," advances the Monticone Group's work on ultra-thin flat lenses.

Sreyam Sinha Ph.D. '20, postdoctoral researcher, and **Sunak Maji** (Afridi Group), are co-authors of the paper "Comparison of Large Air-Gap Inductive and Capacitive Wireless Power Transfer Systems," which won a Best Presentation Award at the IEEE Applied Power Electronics Conference 2021.

Aaron Wilhelm (Napp Lab) won the 2021 ECE Outstanding Ph.D. Teaching Assistant Award. Aaron works with assistant professor Nils Napp researching high-accuracy localization for low-cost mobile robots. He was the TA for ECE 3140 Embedded Systems.

John Wright (Jena-Xing Lab) published his paper on the experimentally determined band structure of GaN/NbN interface in Science Advances.

ECE DAY 2022

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ECE STUDENTS LEARN BY DOING

In fall 2021, a team of engineering students set to work on repairing the Bill Nye Solar Noon Clock atop Rhodes Hall. Under the guidance of ECE senior lecturer Joe Skovira, Ph.D. ’90, M.Eng. student Kristin Lee, ECE major Smith Charles ’23 and their team designed a replacement control system, developed new software, and added redundancies for stability and backup. Read the full story at ece.cornell.edu/ece/news.

Bill Nye ’77 chats with Smith Charles ’23 in the Maker Lab in Phillips Hall. Photo by Ryan Young (UREL).