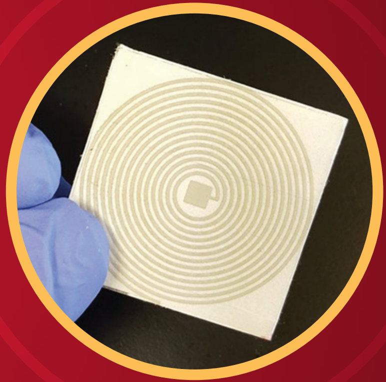
CYCLONE ENGINEERING RESEARCH

FALL 2020



New sensors for closed systems

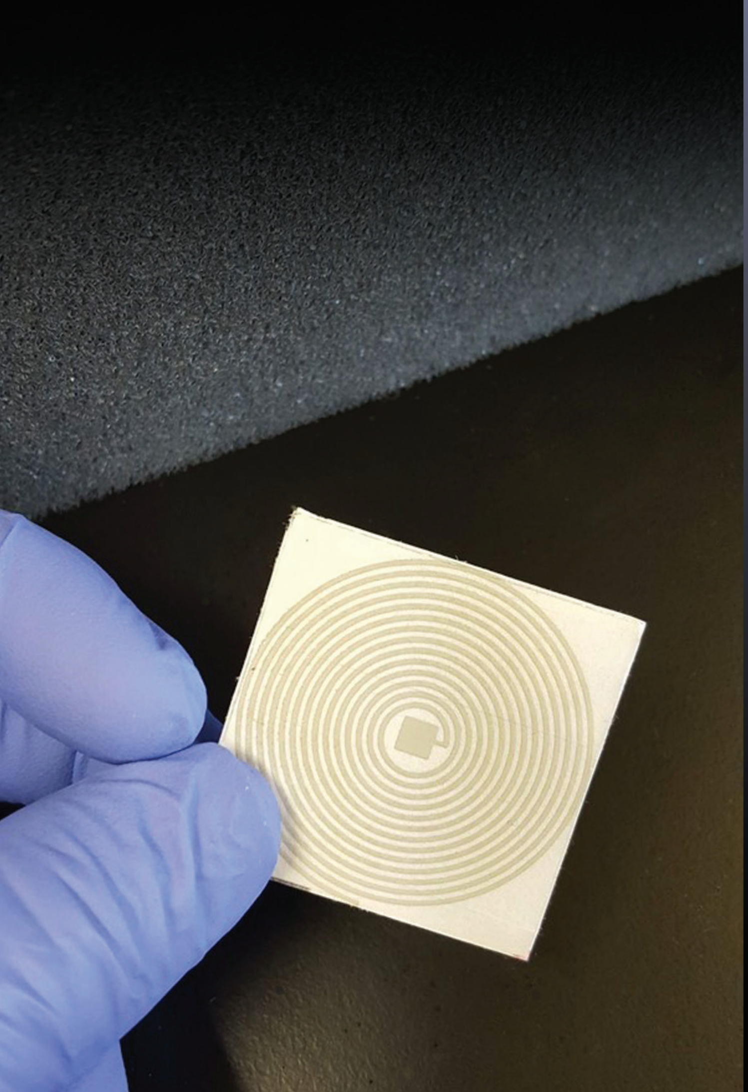
Filling the gaps in graduate student professional skills education

Precision conservation at the food-energy-water nexus

IOWA STATE UNIVERSITY
College of Engineering

On the cover:

Cyclone Engineer **Nigel Reuel** is leading development of an at-home, closed, contact-free diagnostic sensing system that could be used to quickly test for COVID-19 or other outbreaks.



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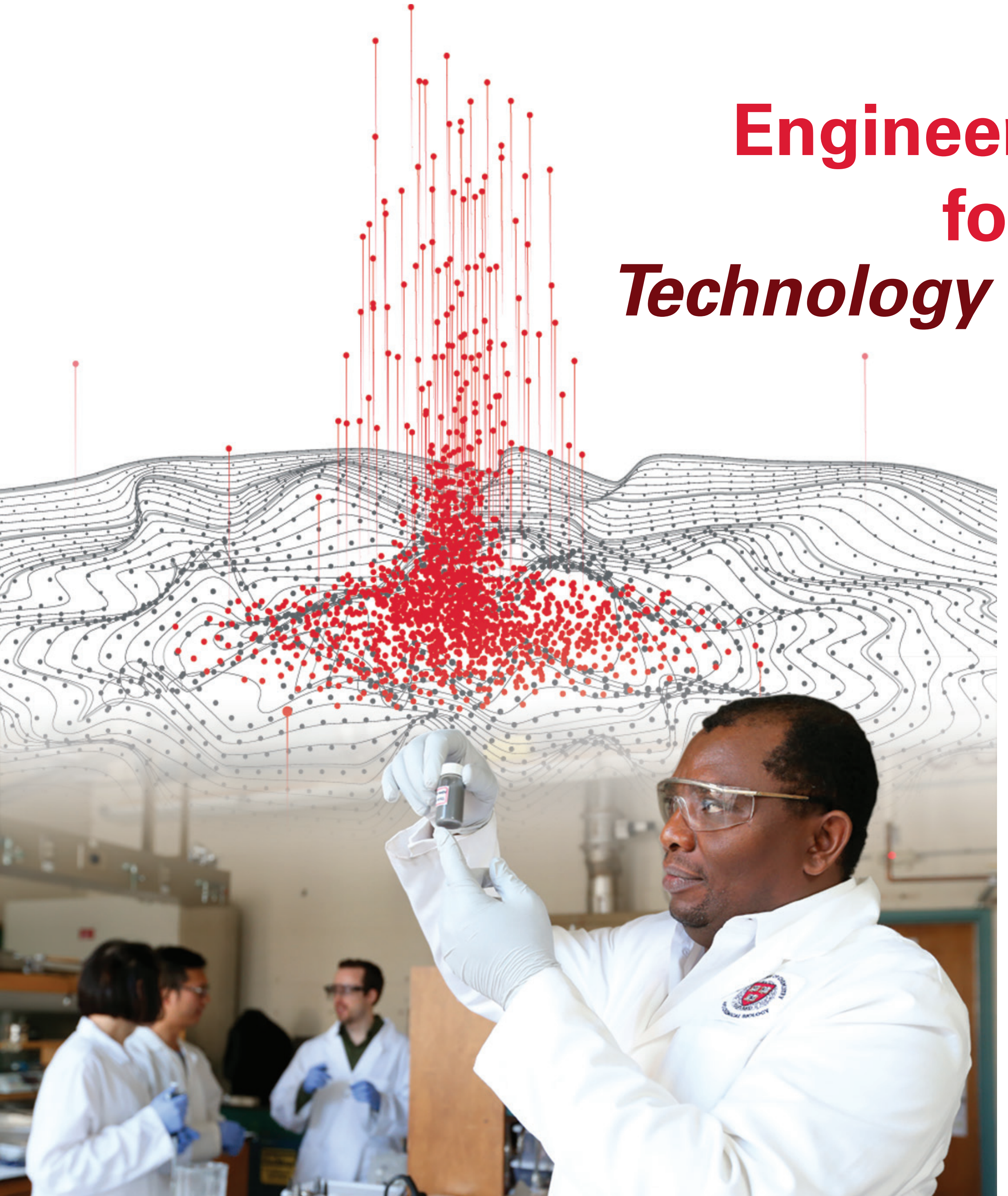
W. Samuel Easterling
James L. and Katherine S. Melsa Dean of Engineering

Arun K. Somani
Associate Dean for Research
Anson Marston Distinguished Professor
Philip and Virginia Sproul Professor

Editor: **Breehan Gerleman**
Contributing Editors: **Madeline McGarry**, **Sierra Hoeger** and **Martha Haas**
Photography: **Christopher Gannon**
Graphic Designer: **William Beach**
collegerelations@iastate.edu
www.engineering.iastate.edu/research

Engineering innovations for a better world: *Technology transfer success*



Top 100

Iowa State University is once again listed among the top 100 worldwide universities granted U.S. patents during a calendar year. Iowa State has made the list every year since 2013 when the rankings began.

The Iowa State University Research Foundation Inc., which processes and holds patents tied to Iowa State research, is tied for No. 77 on the 2019 list. The list is compiled by the National Academy of Inventors and the Intellectual Property Owners Association.

31 patents

Researchers associated with the College of Engineering were awarded 31 patents in the last year for innovations ranging from heat-free solders, bio-based asphalts, plant phenotyping systems and more.

A patent was awarded last year for liquid-metal particles invented by ***Martin Thuo*** *(foreground), associate professor of materials science and engineering, and* ***Ian Tevis*** *(back right), former postdoctoral associate, that can be used for heat-free soldering and other applications.*

SENSORS FOR CLOSED SYSTEMS OPEN UP POSSIBILITIES IN BIOTECH

Ask **Nigel Reuel** about his research and you start to hear a pattern in how he describes his goals: “merging,” “collaborating,” “tying together,” “multidisciplinary.” Look at his career, and you see how he’s combined industry experience with in-the-lab creativity to create engineering innovations.

“When I was at DuPont, one of my roles was a technology scout, looking around for the best ideas that would be useful for core businesses, and I started to see that many other companies were looking to university professors as well to develop the next wave of innovation,” said Reuel, assistant professor of chemical and biological engineering. “I realized where I could really push innovation and bring together teams of strong players would be joining academia.”

Since coming to Iowa State, Reuel has succeeded in becoming the “entrepreneurial professor” he set out to be.

New sensors for biotech

Reuel’s research focus is sensors for closed systems and sits at the intersection of chemical engineering, biology and materials science. His group has made key discoveries for unmet needs across biotechnology.

Reuel has developed new types of resonant radio-frequency sensors to wirelessly monitor soil enzymes, deformation in soft materials, wounds and even sweat rate under firefighters’ PPE.

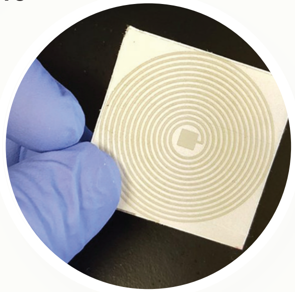
“We’ve created novel methods in coating sensors with enzyme substrates to quantify hydrolytic enzyme activity in closed systems, along with first demonstrations of non-powered devices – all while reducing costs and size of sensor readers,” said Reuel.

The group has also gone to the nanoscale to take on the big challenge of measuring activity of industrial enzymes widely used as biocatalysts. Reuel uses the natural fluorescence and surface sensitivity of single walled carbon nanotubes in modular sensors to measure enzyme activities on their native substrates.

Supporting the group’s work is an expertise in rapidly prototyping proteins used for sensors and new algorithm and hardware development for sensor reading and data processing.

Startup delivers shortcuts

“With these four core research areas in place, we are now in the exciting phase of combining them to make innovations in diagnostics, pharmaceuticals and precision agriculture,” said Reuel.



New resonant sensors for closed systems

So far the group has made 12 technology disclosures, seven of which are in patent prosecution, and two licensed by Reuel’s National Science Foundation-awarded startup, Skroot Laboratory Inc., which is incubating on the north side of the Iowa State campus in the Carver Co-Lab.

Skroot’s flagship product is a sensor system that attaches outside of bioreactors and provides real-time, contact-free monitoring of cell density. The product is a shortcut (skrót is Polish for shortcut) for critical process measurements that are currently done by manual sampling.

“It has been exciting to watch the technology grow and rapidly flourish outside of the academic lab. These sensors are on real reactors, providing real data, and real value to customers to reduce cost of therapies and improve speed to market,” said Reuel. “It has also been great to hire talented students as they graduate from Iowa State to stay and build the company. I see many other startups coming from my academic group on the near horizon."

Tomorrow's innovators

Reuel is as set on mentoring the next generation of innovators as he is on creating innovations. He encourages all students in his group to participate in entrepreneurship training and do external co-ops so they can "speak both languages" of industry and academia.

According to Reuel, Iowa State offers students and faculty researchers a uniquely fertile ground to develop new ideas and products.

"Iowa State is very supportive and has facilities and incubating space both on campus and very near to campus," said Reuel. "Plus federal grant resources and boot-strapped startup funds go really far in this lower-cost part of the country, so you can move faster and hit your milestones with greater success than I experienced and witnessed in higher-cost 'hub' cities. Fellow faculty and students here are fantastic. We really do live in 'fields of opportunity' as the state tourism slogan goes."

Mail-in, fast-scan tests for COVID-19

No long line, no medical staff in full protective gear, no waiting. **Nigel Reuel** is leading development of an at-home, closed, contact-free diagnostic sensing system that could be used to quickly test for COVID-19 or other outbreaks

Reuel's team envisions a low-cost, mail-safe, fast-scan platform built around his closed sensing systems that use paper-based resonant sensors. Also key to the approach is a "toehold switch" that detects target RNA genetic material, triggering production of "reporter" proteins that change the frequency of the sensor's signal.

The finished product will likely involve a multilayered assembly on thick paper. The top layer would hold collected samples, middle layers would contain the toehold switch and bottom layers a printed, coiled resonant circuit.

Testing would be as easy as taking your own sample, putting in an envelope and dropping it in the mailbox or collection center. Electronic readers then scan the sensor in the never-opened envelope and automatically text, email and record results.

Reuel said his idea would address several urgent testing problems: "This approach off-loads the burden of diagnostics from health workers, eliminates the increased use of limited personal protective equipment, and provides a better response to outbreaks."

FILLING THE GAPS:
In graduate student professional skills education

Could graduate students build more than just research skills during their thesis projects? An interdisciplinary project led by Cyclone Engineer **Shan Jiang** aims to address this question through the first of its kind Graduates for Advancing Professional Skills (GAPS) program.

Meeting real-world needs

GAPS was inspired by a recently conducted survey of Iowa State University graduate STEM students. An overwhelming majority of the survey respondents considered project and time management to be the most important skills to have for thesis and future career research.

While graduate students are familiar with working in an academic research setting, Jiang says grad students rarely have the opportunity to practice professional skills in a "real-world" setting. STEM companies and recruiters agree.

"On the other hand, all graduate students are working on their thesis," said Jiang, assistant professor of materials science and engineering. "The idea with GAPS is to integrate project management training with thesis research by treating the 'thesis' as a project."

GAPS provides a solution by creating learning communities and introducing a one credit semester-long training course to graduate students in STEM, helping students gain project management skills using their thesis topics as example projects.

Working together on a better way to work

GAPS will mirror the work environment students are bound to experience in their future careers by blending online and in-person instruction. Participants will work through a process to charter a project, follow a timeline, collaborate with teams and communicate with stakeholders before presenting their findings at a poster symposium.

"There's no company where you can deliver a product from the bench side to the marketplace with just one person's work," said Jiang. "You have to work hand in hand with a number of teams. That's why project management becomes really important because of how you synchronize your efforts with the other players, communicate your ideas and understand what the project needs are."

Evidence-based template

The research team itself is collaborative and interdisciplinary, led by Jiang, assistant professor of materials science and engineering, and including **Gül Okudan-Kremer**, C.G. (Turk) and Joyce A. Therkildsen Department Chair in Industrial and Manufacturing Systems Engineering; **Ann Gansemer-Topf**, associate professor in Iowa State's School of Education; **Nigel Reuel**, assistant professor of chemical and biological engineering; and **Qing Li**, assistant professor of industrial and manufacturing systems engineering.

GAPS will be piloted over the course of five semesters and be comprised of approximately 20 students per term. After the piloting stage, an advisory board will determine the success of GAPS by eliciting feedback from students and faculty.

Jiang hopes GAPS can become a template for other universities and academic institutions to adopt.

"All of us engineering educators want our students to sail through their theses smoothly – and have the professional skills training that will make them more effective researchers," Jiang said. "I think by designing this type of program properly and synergizing the effort between students and faculty, we'll offer evidence-based recommendations for other STEM grad program."

“The idea with GAPS is to integrate project management training with thesis research – by treating the thesis itself as the project to be managed.”

Shan Jiang
assistant professor of
materials science and engineering

Left to right: Gül Okudan-Kremer, Shan Jiang, Nigel Reuel, Ann Gansemer-Topf and Qing li. Photo taken February 2020.

Data-based face coverings

When the problem of mask shortages emerged during COVID-19, Cyclone Engineers turned to the core engineering principle of data-driven problem solving to help out.

An interdisciplinary team of researchers with expertise in materials science and engineering, industrial and manufacturing systems engineering, and textiles and clothing studied the best methods to make protective face masks using 3-D printing. The team examined multi-layer design, functional requirements, sterilization methods, and stiffness and strength of gaskets to determine how to make cost-effective masks that adhere to regulations and best protect the people wearing them.

The team’s preliminary research suggests a first layer of a 3-D printed gasket, a second layer of waterproof nonwoven fabrics, and the third layer of nonwoven fabrics similar to a paper towel.

The team initially planned to create masks for medical personnel, but as the shortage of medical-grade masks eased – and the need for non-medical grade masks grew – the team has shifted its focus to developing recommendations for masks for everyday use.

Mai Zheng, assistant professor of electrical and computer engineering

Storage systems keeping data safe

Building blocks of modern life

Storage systems are the fundamental computing building block of our modern lives – and like physical building blocks, computer storage systems must function well in fair weather as well as sudden disturbances to keep data safe.

"Storage robustness is crucial to systems ranging from financial institutions, where downtime can result in millions of dollars lost, to scientific computing, where the generated data advances any number of challenges facing humanity," said Zheng.

The problem of system robustness and crash consistency is decades old, but creating realistic test crash events isn't easy and the task grows ever more difficult as storage technology becomes more complex. Zheng will address the longstanding problem by creating a new flexible, scalable framework for thoroughly testing the crash consistency of many different storage systems.

Measure, model, make automatic

Zheng plans a three-part approach. He'll design a comprehensive suite of benchmarks that can be used to drive storage stacks to vulnerable states and measure crash consistency. Next, he'll leverage virtualization technology to model and generate realistic crash events for triggering vulnerabilities.

Zheng's team will also create a crash consistency exploration engine that will enable automatic testing. And all work will be done in partnership with leading industry storage system makers to ensure tools are useful to real-world challenges.

"My belief is that storage systems should never lose data, no matter what happens. Combined together, these developments and collaborations are a crucial step toward the goal of truly robust storage systems," said Zheng.

Next-gen data protectors

"Tomorrow's advances in storage systems will only be possible with an inclusive next generation of engineers, so I'm excited that my CAREER project also includes targeted education and outreach," said Zheng.

Zheng will develop a dedicated storage system course at Iowa State to give students in-depth knowledge and techniques in storage hardware, software and optimization. Zheng will also work with established Iowa State programs designed to increase diversity in STEM, including Science Bound and IINSPIRE-LSAMP.

Tom Mansell, assistant professor of chemical and biological engineering

Engineering probiotics to fight illness

Eat your cure

Our gut microbiome – a collection of complex and varied microbes – is important to our health far beyond our digestive tract.

We know that too much "bad" bacteria can make us ill, but the opposite may also be true. Engineering "good" bacteria could be key to fighting illness.

Mansell seeks to overcome one big challenge of introducing new good bacteria into the gut environment: When we eat foods rich in live cultures or take a supplement that introduces probiotics into our gut, then the probiotics themselves need something to feast on if they are to multiply and remain in place.

Engineering unique pairs

Mansell's CAREER project will create a two-step strategy so that probiotics can be successfully introduced – and flourish.

His team will first create new prebiotics, nutrients that are not normally found in the gut, and genetically modify probiotics so that they can use these unique energy sources. Step two will be introducing these engineered probiotic-prebiotic pairs to the gut to create an environment where the probiotics can thrive.

Disease fighting from the inside out

When probiotics grow strong on a steady diet of custom-paired prebiotics, they can be engineered to add disease-fighting capabilities.

"Probiotics may someday be able to make the drugs right in the gut, providing a pain-free way to deliver protein-based drugs that now require injections, to deliver anti-inflammatory agents or to secrete antimicrobial peptides to cure infection," said Mansell.

Inspiring future problem solvers

Mansell's CAREER project also includes the development of an interactive lab that will show high school and undergraduate students first-hand the competition between engineered gut bacteria and native gut bacteria. Inspired by games like Pokémon Go, the activity will assign certain attributes to each strain, then allow students to predict the outcome of the culture "battle."

Mansell's group will also create an interactive educational module about the microbiome to be featured on LearnGenetics.com, a popular web resource used by teachers and students.

In this together:
Collaborative networks create community resilience

Cyclone Engineer **Cristina Poleacovschi** studies how to build community resilience during challenges like natural disasters or economic shocks.

Poleacovschi's research suggests steps to increase shared resilience – even in unprecedented community challenges like the COVID-19 pandemic:

Strong public-private collaborations

Partnerships between public and private organizations make large-scale investment in infrastructure possible and help local business competitiveness and retention. Ideally, these partnerships are formalized, long-term and include continuous assessments of local industries' and community members' needs – and focus on quality of life.

Empower many stakeholders

Collaboration between public officials, like mayors and chambers of commerce, and empowering as many community stakeholders as possible is key to generating and working toward common goals. The more partners, the more shared knowledge, learning and impact.

Protect the most vulnerable

During community challenges, vulnerable populations are often most at risk. So, prioritize development strategies that address the most vulnerable by emphasizing community context and using local resources. Assuring that all citizens are protected is critical for preventing the amplification of inequalities during challenges – and inclusion in solutions builds local capacity and resilience.

Bridge between communities

In the midst of a challenge, communities rely on local bonds like family, friends and civic groups, but building connections with neighboring communities and institutions is needed for long-term recovery. Creating relationships with "different" organizations and communities creates a fluidity of ideas and resources that help protect all communities from future challenges.

"Of course, collaboration and decentralized power in place prior to a challenge is the best strategy to support community resilience, but these approaches are useful no matter when you start them. Encouraging the immediate development of these approaches after a challenge offers a hopeful trajectory for a community's future," said Poleacovschi, assistant professor of civil, construction and environmental engineering.

Beyond batteries:
New energy systems for a sustainable future

Incremental improvement is the goal of most battery research programs, but **Cary Pint** isn't looking to build on existing ways of doing things. He's out to create new systems of energy storage for a sustainable future.

"My background brings together diverse experiences in both academia and industry and across many different disciplines. That allows me to approach these problems in new and unique ways – and I've built a multidisciplinary research team that does the same," said Pint, Charles Schafer (Battelle) Chair in Engineering and associate professor of mechanical engineering.

Integrated energy storage

Among other innovations to improve batteries, Pint's team has designed a new class of Li-ion batteries that look and feel like carbon fiber reinforced composites but store energy like conventional batteries, opening the door to future transportation and electric grid storage systems. They've collaborated with NASA and others to consolidate on-board batteries into the structural parts – such as in CubeSat satellites.

The team has also used their expertise in batteries to forge new directions beyond energy storage. They've shown that reconfiguring components in a battery allows it to harvest, rather than store energy, leading to textiles that can harvest energy efficiently from human movement. They have also used their battery expertise to transform carbon dioxide from the atmosphere into valuable carbon nanotubes that are sought for applications from next-generation electronics to new durable composite materials.

Energized entrepreneurship

Pint has a knack for turning research outcomes into commercial ventures. One example of this is SkyNano Technologies where Pint is the co-founder and chief technology officer. SkyNano is manufacturing high-valued carbon materials from carbon dioxide emissions using a low-cost electrochemical process developed in Pint's lab.

With support from the National Science Foundation's SBIR/STTR and Department of Energy's Carbon Utilization Program, among others, SkyNano is paving the way to technological materials for future batteries, tires, electronic devices, and more from the carbon polluting our atmosphere.

With all of this, Pint is just getting started: "Moving to Iowa State and working with researchers here in areas ranging from energy to agricultural sciences will not only enable us to accelerate our pace of innovation, but extend our advances in new directions" Pint said.

All about (data) connections:
Precision conservation at the FEW nexus

Amy Kaleita, professor of agricultural and biosystems engineering, works at the intersection of food, energy, water and land use systems on data-driven precision conservation.

Where there's good soil and water data, she uses it, where there's gaps in the data, she creates new models to estimate variables, and where there's neither existing data nor a good model, she designs new sensing systems. And in all cases, Kaleita says she focuses on the connections – between complex natural systems, land uses and more – to protect our land and water.

Connecting overlapping priorities

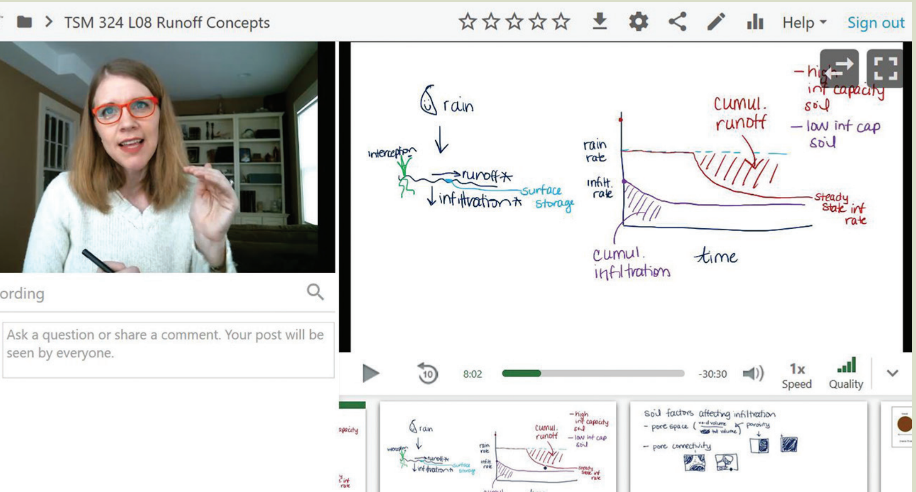
"My research philosophy is 'having it all': Agricultural production and environmental quality are not opposing objectives and both systems can be optimized to maximize benefits to both.

"But one of the challenges of conversation and land-use questions is that there are always multiple demands and multiple systems, so it's important to really understand the ways each complex system connect to each other – and the ways that stakeholders connect to the systems, so we can balance priorities."

Connecting right questions to right data

"Data-driven conservation decision making is only useful if that data matches the scale of the question. For example, there's a lot of great real-time data on nutrient concentration in streams. But if your question is much smaller-scale, like how to manage nutrients on a single farm, a sensor on a farm's tile line with weekly or season trends would give more actionable info.

"I'm particularly interested in finding innovative ways to bridge the gap in scale between what data is already available, what additional measurements we can do, and what's useful for decision-making more locally."



LEADING THE WAY ONLINE

When the COVID-19 pandemic made it a necessity to shift all coursework online at Iowa State University, **Amy Kaleita** already had a library of resources at her fingertips and a wealth of experience to help her colleagues make the transition.

Connecting big-picture goals & localized data

“Precision conservation looks at very specific subsets of localized data – like Iowa’s high-resolution LiDAR datasets that show how water flows through and across a single field and sensing systems that monitor soil or the chemical makeup of water leaving the field. Super localized data can help us understand a snapshot in time and place.

“But I look beyond that snapshot to the bigger picture and to the future. Modeling helps us investigate what would happen if we did something different locally, say, added a buffer or prairie strip in this one area – and what might the big-picture, downstream, long-term benefits might be.”

Connecting collaborators

“We are usually looking at multiple measures at a time and developing more and more integrated ways to model these. That requires building great collaborative relationships with people who have expert-level knowledge about sub-parts of the systems.

“Working across disciplines at Iowa State is not only possible, but encouraged. In my research program, I’ve worked with great collaborators in my own department and across campus. Our teams are making progress on problems shared by a lot of people and with the potential to impact a lot of people.”

Kaleita got her start with teaching courses online in 2007 when she went on maternity leave in the middle of a semester. She filmed a series of lectures ahead of time, which were combined with question-and-answer sessions and other hands-on course materials during her leave.

Her early introduction to online instruction meant she was more than up to the task when moving online this spring. But Kaleita knew her tried-and-true resources and best practices might be useful to others who were shifting quickly to remote instruction. So she helped to quickly orchestrate a workshop with other faculty in her department to prepare.

“In the early days, things were changing so fast, but since Iowa State had already embraced a wide range of online learning opportunities for students, we had a good foundation. We could all look at each other and say ‘we can do this’ – and we did it.”

| C Y C L O N E   E N G I N E E R I N G |

NEWS BITES

Read the latest on Cyclone Engineers' groundbreaking research in advanced materials and manufacturing, engineered medicine, engineering education, energy systems, resilient infrastructures, secure cybersecurity and autonomy, and more at

news.engineering.iastate.edu

Mini brains on a chip

Long Que, associate professor of electrical and computer engineering, **David Jiles**, Anson Marston Distinguished Professor of Engineering, and **Donald Sakaguchi**, Morrill Professor and expert in neuroscience, are creating synthesis technique to make "mini brains" on a chip, to make possible new studies on transcranial magnetic stimulation and drug treatment in neurodegenerative disorders. The team is developing a chip-based microfluidics platform for rapid formation of 3D in vitro culture models of the nervous system.

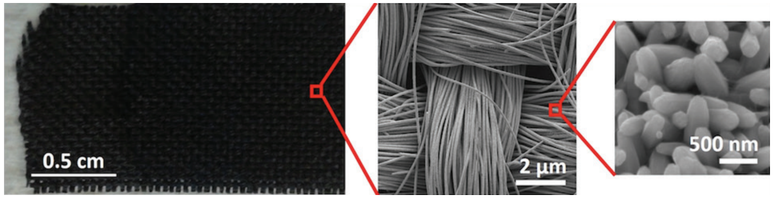
Fitbit for plants

Liang Dong, professor of electrical and computer engineering, is developing a Fitbit-like tracker that will monitor crop fields at almost single-plant resolution. Combining these wearable plant sensors with soil and water sensors, Dong and his interdisciplinary research team will create a cyber-physical system to help farmers precisely manage water and fertilizer use and increase crop productivity.

***FactorAnalysis Podcast:** news.engineering.iastate.edu/fitbit/*

Wiping away microbes

Sonal Padalkar, assistant professor of mechanical engineering, develops electrochemical deposition techniques to grow metal-oxide nanomaterials on cheap, lightweight, flexible cloth and paper. The zinc oxide, cerium oxide and copper oxide nanoparticles on the fabric or paper puncture the cell walls of bacteria, making for an effective, chemical-free disinfecting wipe.



More than sum of its parts

Matt Frank, John B. Slater Professor in Sustainable Design & Manufacturing, collaborates with John Deere to advance hybrid manufacturing techniques. Frank works with teams at John Deere's Ames Technology Innovation Center in Iowa State's Research Park and at other locations to combine computer numerical controlled machining with additive manufacturing, like 3D printing.

"Combining the strengths and diminishing the weaknesses of the two systems is a real force multiplier, making it possible to reduce cost and lead time in delivery prototypes and production solutions," said Frank.

Steady lines in a storm

Partha Sarkar, professor of aerospace engineering, is predicting how and why power transmission and bridge support cables "gallop" in high winds, causing outages and structure damage. Using five years of wind tunnel experiments on cable vibrations in high winds, Sarkar's team is now creating a wind-load model and methodology that can be used to identify vulnerability to cable galloping – and enable engineers to find solutions to dampen runaway cables.

Iowa State University
College of Engineering
4100 Marston Hall
533 Morrill Road
Ames, Iowa 50011-2103

New major in environmental engineering

Iowa State launched a bachelor of science degree program in environmental engineering major this fall. The new degree, part of the Department of Civil, Construction and Environmental Engineering, offers students the engineering and science knowledge necessary to pursue successful careers in environmental engineering and related professions – in both the public and private sectors – to help address critical challenges related to land, air and water quality.