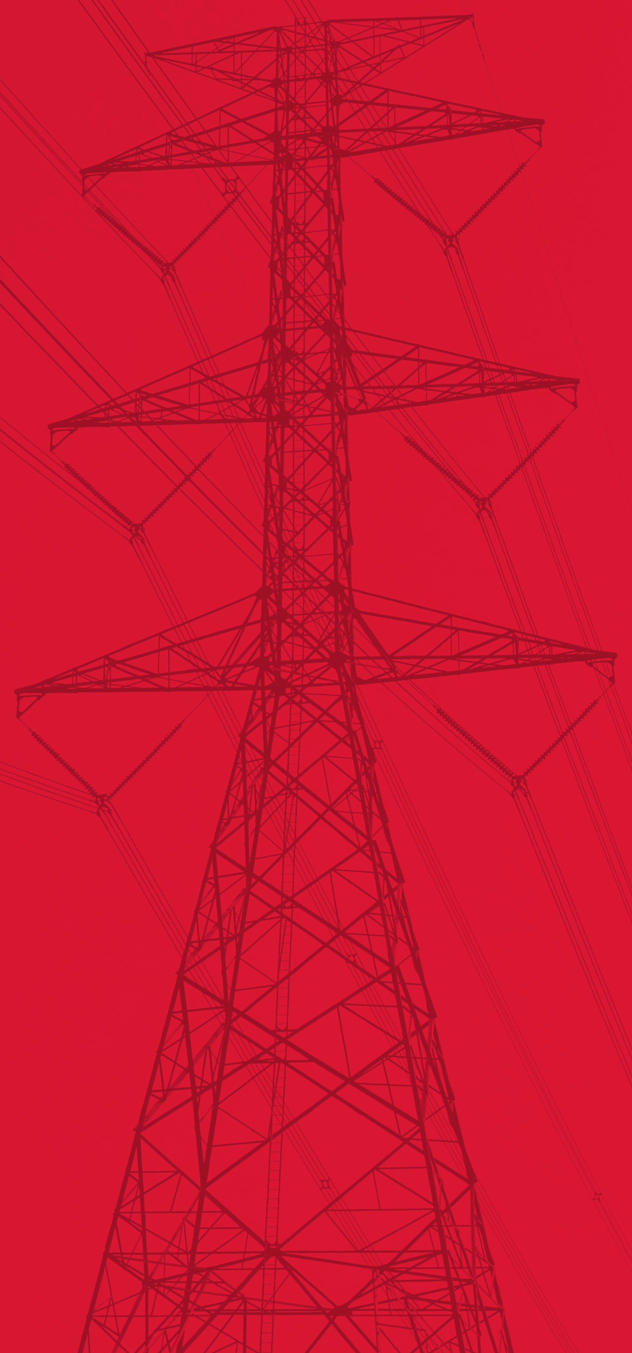
Iowa State University
College of Engineering

CYCLONE ENGINEERING RESEARCH

SPRING 2019



SPRING 2019 CONTENTS

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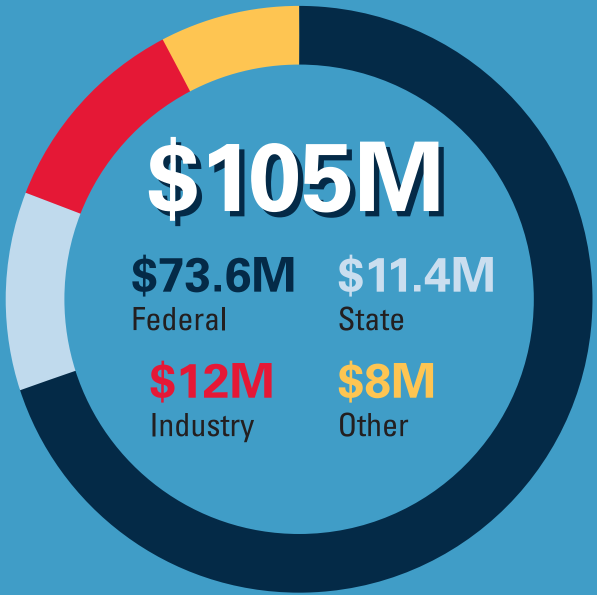
On the cover:
Energy Systems: Harvesting and managing clean energy
The needs of the growing world population, together with the need to reduce the impact of climate change, require new energy science and technologies. Iowa State University College of Engineering has research programs in energy systems that address renewable and clean energy technologies, including wind, solar and biofuels; new battery technology; efficient energy production and use; and advanced processes and materials that reduce resource demand and environmental impact.

RESEARCH EXPENDITURES



TOP NEW RESEARCH AWARDS

$1.41M "Robust real-time modeling of distribution systems with data-driven grid-wise observability"
Zhaoyu Wang, *assistant professor of electrical and computer engineering*

$1.20M "Sensor-enabled data-driven predictive analytics for modeling and control with high penetration of DERS in distribution system"
Venkataramana Ajjarapu, *professor of electrical and computer engineering*

$1.03M "Stripping antibiotic resistance with strips: Evaluating prairie buffer strips to mitigate resistance gene dissemination from manure-amended fields"
Michelle Soupir, *associate professor of agricultural and biosystems engineering*

$1.00M "A smart service system for UAS traffic management in low-altitute airspace"
Peng Wei, *assistant professor of aerospace engineering*

2019 NSF CAREER AWARD WINNERS

"Multifidelity modeling and search using adaptive field prediction"
Leifur Leifsson, *assistant professor of aerospace engineering*

"Synthesis and properties of group IV colloidal quantum wells"
Matthew Panthani, *assistant professor of chemical and biological engineering*

"Robustifying machine learning for cyber-physical systems"
Soumik Sarkar, *assistant professor of mechanical engineering*

RESEARCH EXPENDITURES BY DEPARTMENT

$7.1M	$13.7M	$9.9M	$17M	$15M	$5.3M	$25.5M	$11.5M
Aerospace	Agricultural & Biosystems	Chemical & Biological	Civil, Construction & Environmental	Electrical & Computer	Industrial & Manufacturing Systems	Materials	Mechanical

2018 NSF CAREER

7
Awards

TECHNOLOGY TRANSFER

74
Invention Disclosures

17
Patents

GRADUATE DEGREES AWARDED

336
Master's degrees

128
Ph.D. degrees

SMART ENERGY for EFFICIENT SPACE

Kristen Cetin, assistant professor of civil, construction and environmental engineering, is harnessing smart energy technologies to enhance building performance and occupant comfort.

"We're combining the power of sensors, automation, the internet of things and modeling to create data-driven, real-time energy efficiency strategies for the built environment," said Cetin.

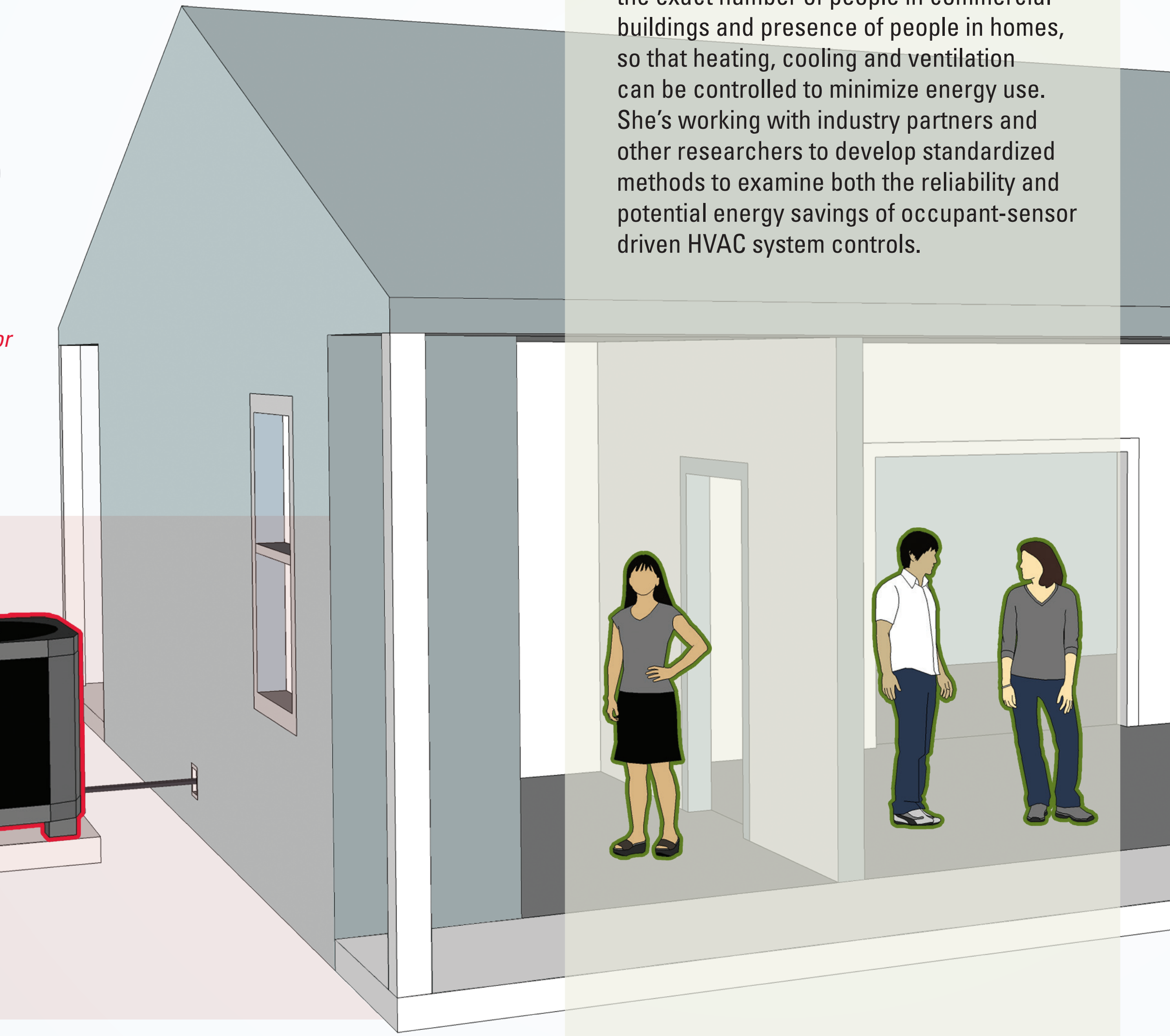
***Kristen Cetin**, assistant professor of civil, construction and environmental engineering*

ACCURATE OCCUPANT SENSING

Adjusting heating and cooling in real-time to the number of people in a building only works with an accurate count of occupants. Cetin and her research team are developing a methodology to determine the exact number of people in commercial buildings and presence of people in homes, so that heating, cooling and ventilation can be controlled to minimize energy use. She's working with industry partners and other researchers to develop standardized methods to examine both the reliability and potential energy savings of occupant-sensor driven HVAC system controls.

HIGH-PERFORMING HOME HVAC

Many HVAC systems don't get routine tune-ups to keep them working at top efficiency. Cetin is developing real-time methods to help homeowners monitor the performance of their home HVAC using data from on-unit sensors or smart meters. Giving homeowners continuous data about their HVAC system's performance may encourage them to make easy, small fixes that result in significant long-term energy savings.

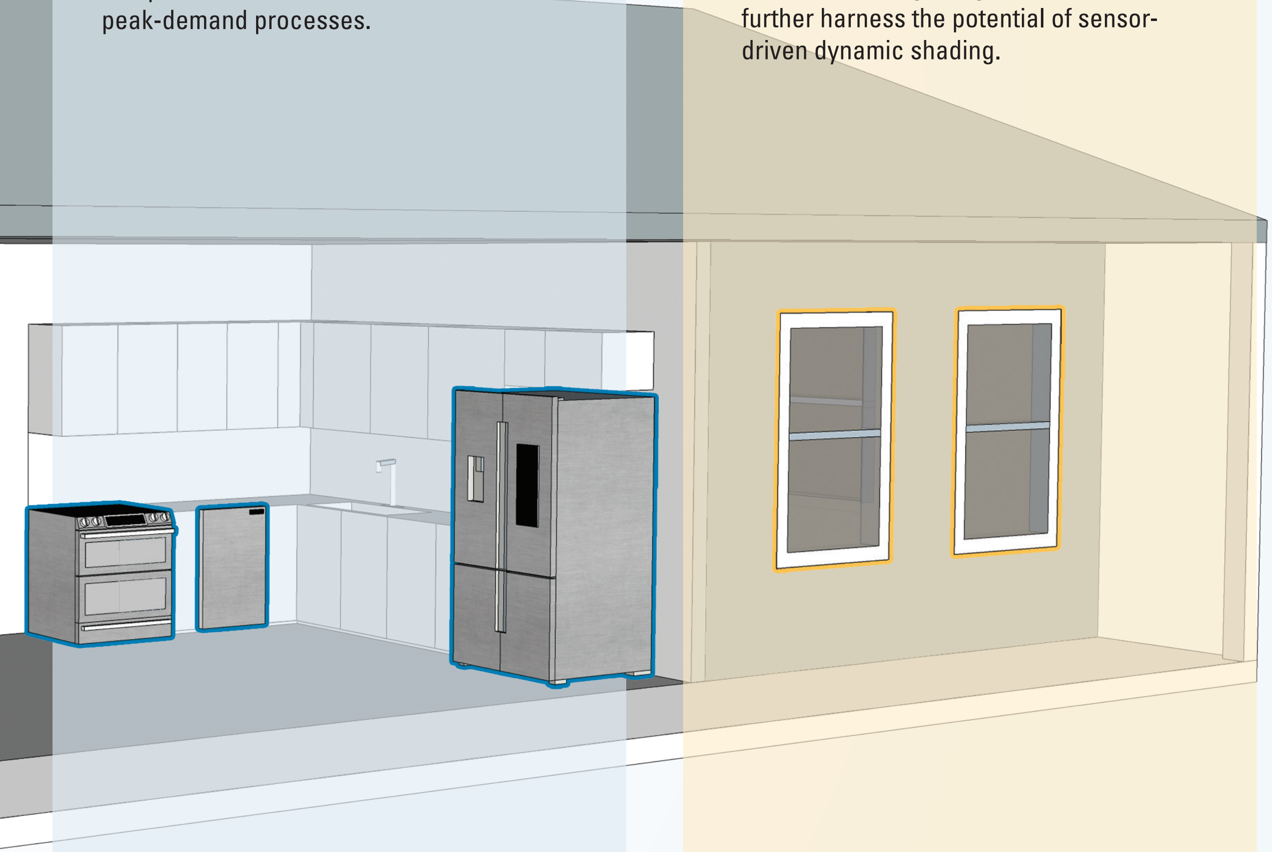


SMART APPLIANCES

Utility organizations have looked to air conditioning systems to save energy and reduce electricity demands in times of peak demand, but could household appliances like refrigerators and dishwashers also provide savings? Cetin and her team are developing analysis methodology to help determine what appliances are the best bet and provide ideas for how to automate the peak-demand processes.

AUTOMATED WINDOW SHADING

Cetin is studying how to best use dynamic window shades to conserve energy while ensuring occupant comfort. She's modeling the impact of automated dynamic window shading on energy consumption and available daylight – and conducting full-scale laboratory testing as well. What's next is integrating dynamic shading with electrochromic glazing in windows to further harness the potential of sensor-driven dynamic shading.



Real-world education for real-world engineering problems

Kristen Cetin leads a team of Cyclone Engineers working to develop classroom teaching methods that better mirror the real-word work of engineers.

"Engineers face complex problems on the jobsite. There's no single solution and many constraints," says Cetin. "Since most students go into industry, it's important that we as faculty try to understand—and adapt to—that method of thinking."

Cetin, assistant professor of civil, construction and environmental engineering, and team members, **Bora Cetin**, assistant professor of civil, construction and environmental engineering, and **Benjamin Ahn**, assistant professor of aerospace engineering, are investigating how engineering students, faculty and professionals approach "ill-structured" problems.

The researchers are observing and analyzing the problem-solving process of students, faculty and professional engineers to determine similarities and differences in techniques. From the study results, the team will develop course materials or best-practice teaching recommendations to help make the engineering classroom more like the engineering real world.

DATA-DRIVEN MODELING
for a smart, resilient grid

Zhaoyu Wang, Harpole-Pentair assistant professor of electrical and computer engineering, is using data-driven science and machine learning to bring real-time modeling to electric power systems – and to enhance system resilience in severe weather events.

Real-time, grid-wide monitoring

Wang's team is customizing machine learning algorithms currently used in photo processing and voice recognition for the challenge of working with complex power system data.

They've partnered with local utility organizations – ranging from a large, private utility to a rural co-op – to gather three years of data for more than 6,000 customers with smart electric meters.

"Power system data has many unique features, including time series correlations, along with physical constraints like specified voltage levels, and other impact factors such as weather and human behavior," said Wang. "Add to that the rise in decentralized, customer-owned renewable energy sources in the electric grid – and the task of creating usable models for the power industry is a big one."

So far, Wang's team has discovered never-seen-before load patterns for different times of the day and in different seasons. What's next is finding techniques to extend the data gathered from smart meters to the rest of system, using big-data techniques to give utilities more visibility of individual solar energy sources – and combining all these capabilities into verified software tools so utilities can monitor their systems reliably and in real time.

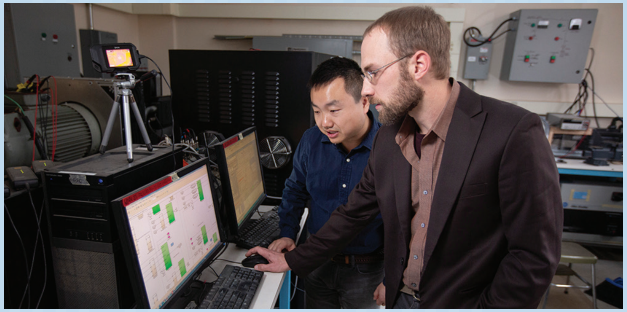
Enhanced power system resilience

Wang is also examining how data-driven strategies can help restore power systems more quickly after severe weather and other natural disasters.

"For many years, power system recovery was done based on physical checks to determine what areas were down – and experience-based recommendations of how to prioritize repairs," said Wang. "Big-data can bring a systematic approach to disaster recovery logistics, optimizing resource use and speeding up fixes."

Wang's team is investigating how distributed solar sources can offer an additional strategy to supply electricity after storms.

"When the main, centralized source of power has been disrupted by a severe event, localized solar energy may be a key way to provide emergency power while the overall system is fully restored," said Wang. "To take full advantage of decentralized, renewable power sources in the grid, we are developing data-backed models to estimate system conditions after natural disasters – and perhaps even predict after-storm scenarios."



***Zhaoyu Wang**, assistant professor of electrical and computer engineering, and **Nick David**, graduate student in electrical and computer engineering*

Catalyst for collaboration: Electric Power Research Center

The Electric Power Research Center brings together electric power researchers at Iowa State with experts in industry, national labs, state and federal agencies, and national trade associations to solve the challenges of rapidly changing power systems.

Formed in 1963, the EPRC has grown to include faculty from eight Iowa State departments, nine industrial members and other utility collaborators that work together on research in grid resilience and security, renewable power source integration, planning and risk management in power markets, meteorological modeling and more.

The EPRC also funds graduate student research and offers professional education courses to help strengthen the future of the electric power systems field.

GAME THEORY

to quantify threats of power grid cyberattacks

Threat levels for cyberattacks on the power grid are usually labeled high, medium or low. That's too qualitative and too subjective for Cyclone Engineers.

Current assessments are inadequate to account for dynamic and uncertain adversaries and the complexity of the computer controls and networks that support the grid.

Could engineers incorporate scientific methods? Computer algorithms? And given that there are attackers and defenders – just like in a soccer match – could game theory be applied to help with risk assessment, attack-defense modeling and "what-if" contingency analysis that could help mitigate any attacks?

Manimaran Govindarasu, Ross Martin Mehl and Marylyne Munas Mehl Computer Engineering Professor, is leading the National Science Foundation-funded project, collaborating with **Sourabh Bhattacharya**, assistant professor of mechanical engineering.

"We want to prove this concept is doable," Govindarasu said. "And we want to develop a software tool industry can use – one that provides a systematic way of security planning and investment."

The key will be developing models that analyze and predict threats, vulnerabilities and consequences, Govindarasu said. Of those, threat modeling is the least understood. He thinks game theory could change that.

Bhattacharya says game theory is all about quantifying how people or teams try to maximize their outcomes – whether that's scoring soccer goals or defending the power grid from cyberattacks.

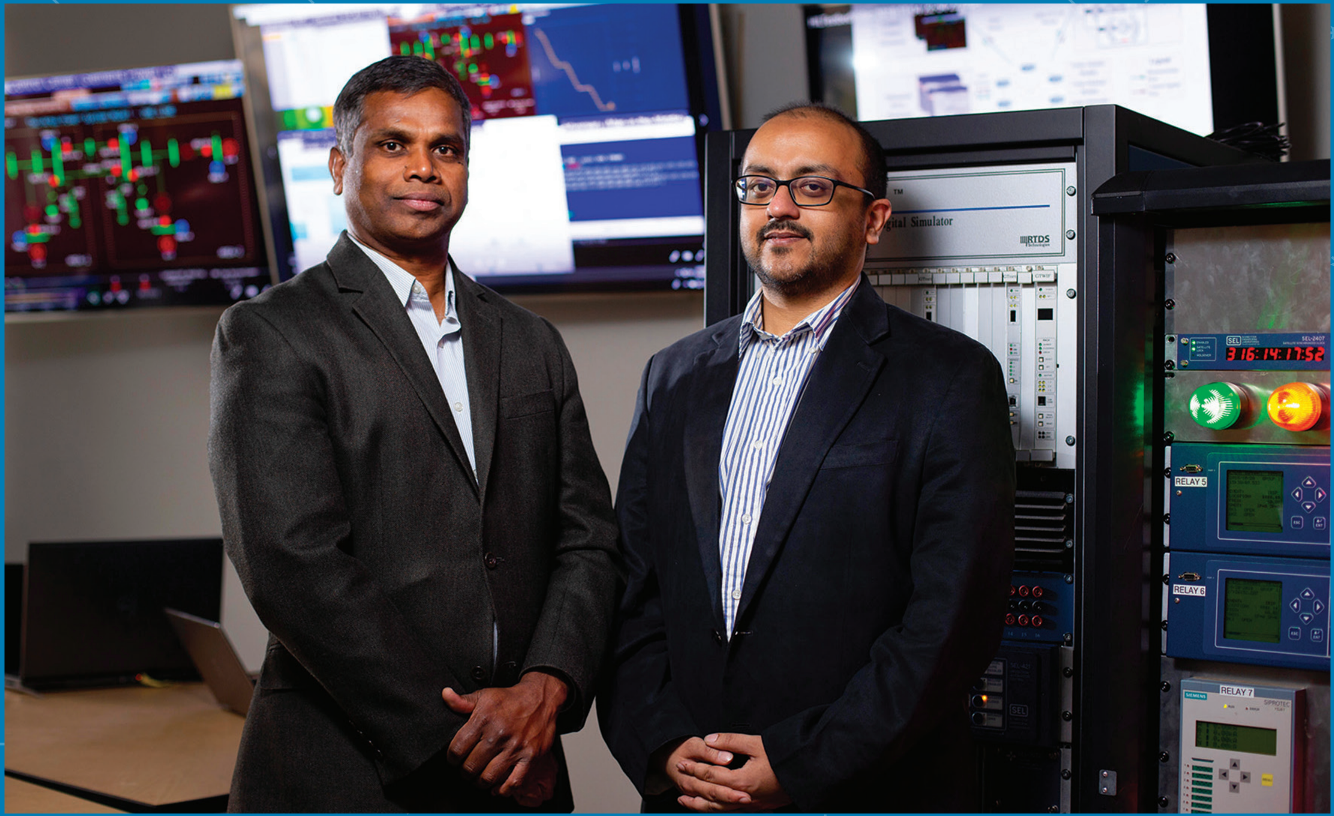
"We can use game theory tools to figure out what we can expect from such interactions," he said.

The primary tools are mathematical models that measure "optimality," or "what's the best I can do?" in any given scenario, Bhattacharya said.

In the case of the power grid, operators want to keep their computers and controls safe behind firewalls with strong authentication and access-control mechanisms. Attackers want to evade those protections and bring down the grid.

That fight against each other can be modeled to show how and where the grid is vulnerable to cyberattacks, Bhattacharya said.

"That's a powerful tool to develop strategies to protect the system," he said. "Given a fixed budget for security, it can show whether your need better locks on the 'windows' or the 'doors.'"



***Manimaran Govindarasu**, Ross Martin Mehl and Marylyne Munas Mehl Computer Engineering Professor, and **Sourabh Bhattacharya**, assistant professor of mechanical engineering*

MODEL FUTURE: OPTIMIZED ELECTRIC POWER SYSTEM PLANNING

Renewable energy offers promise for cleaner, cheaper electricity, but the variability in its production levels introduces new levels of uncertainly into the electric power system. **Sarah Ryan**, Joseph Walkup Professor in Industrial and Manufacturing Systems Engineering, is developing new stochastic optimization techniques to help electric system operators effectively plan for deeper integration of renewables.

More renewables, more uncertainty

Introducing wind and solar generation into electrical grids also introduces a new level of day-to-day uncertainty about tomorrow's weather and energy generation.

"When the amount of electricity generated by renewables was small, it was good enough to merely do conventional capacity scheduling and build in a small margin in case the wind wasn't blowing or the sun didn't shine," said Ryan. "But as the amount of renewables in the electric system grows, so does the necessity for data-driven optimization that accounts for forecast uncertainty."

Ryan is developing new models that consider a number of different energy-generation scenarios and optimizations based on the level of uncertainty.

"We classify historical weather data and see patterns in different sets of historical days that have different levels of uncertainty associated with them," said Ryan. "One major challenge is figuring out the ideal number of scenarios to consider in a model to ensure accuracy while finding a solution fast enough for use by utility operators on a day-to-day basis."

Long-term planning

Long-term electric generation and transmission capacity planning contends with significant uncertainties in changing fuel sources, costs and policy, in addition to new uncertainty associated with renewables.

Ryan is using improvements in both computing power and software tools to optimize long-term planning for the integration of electrical systems with other forms of energy. She recently examined the risk associated with electric power systems becoming increasingly dependent on natural gas fuel sources, and how that risk relates to the expanded use of renewable energy sources.

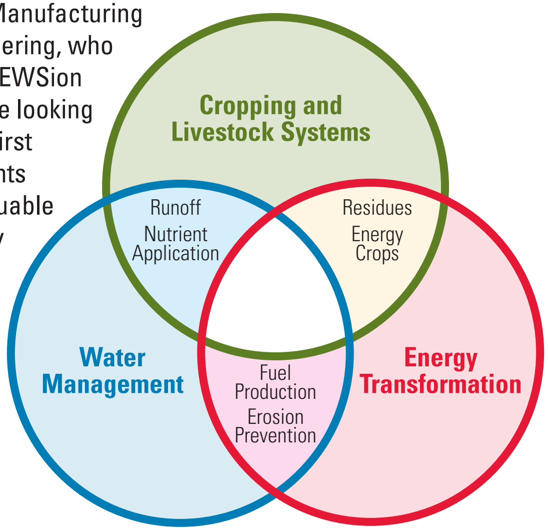
"We have a lot of power systems relying on gas to cost-effectively adjust to renewable fluctuations, and we are delivering the modeling tools to ensure the long-term reliability of this new mix of sources," said Ryan.

Preparing tomorrow's food-energy-water systems experts

Iowa State is home to a new National Science Foundation traineeship program preparing the next generation of food-energy-water (FEW) systems innovators. Open to both masters and Ph.D. students, the DataFEWSion program offers a unique focus on data-rich systems modeling at the intersection of energy transformation, water management, and cropping and livestock systems.

Faculty members from industrial and manufacturing systems engineering, agricultural and biosystems engineering, aerospace engineering, mechanical engineering, agronomy, economics, sociology and natural resource ecology and management will come together to prepare students for careers in research, policy making and bioeconomy entrepreneurship.

"Iowa State is a land grant university with a longtime strength in both agriculture and engineering – and valuable collaborations among experts in different aspects of FEW systems. It makes Iowa State the place to be if students are interested in any type of FEW career," said **Sarah Ryan**, Joseph Walkup Professor in Industrial and Manufacturing Systems Engineering, who leads the DataFEWSion program. "We're looking forward to our first cohort of students starting this valuable interdisciplinary experience later this year."



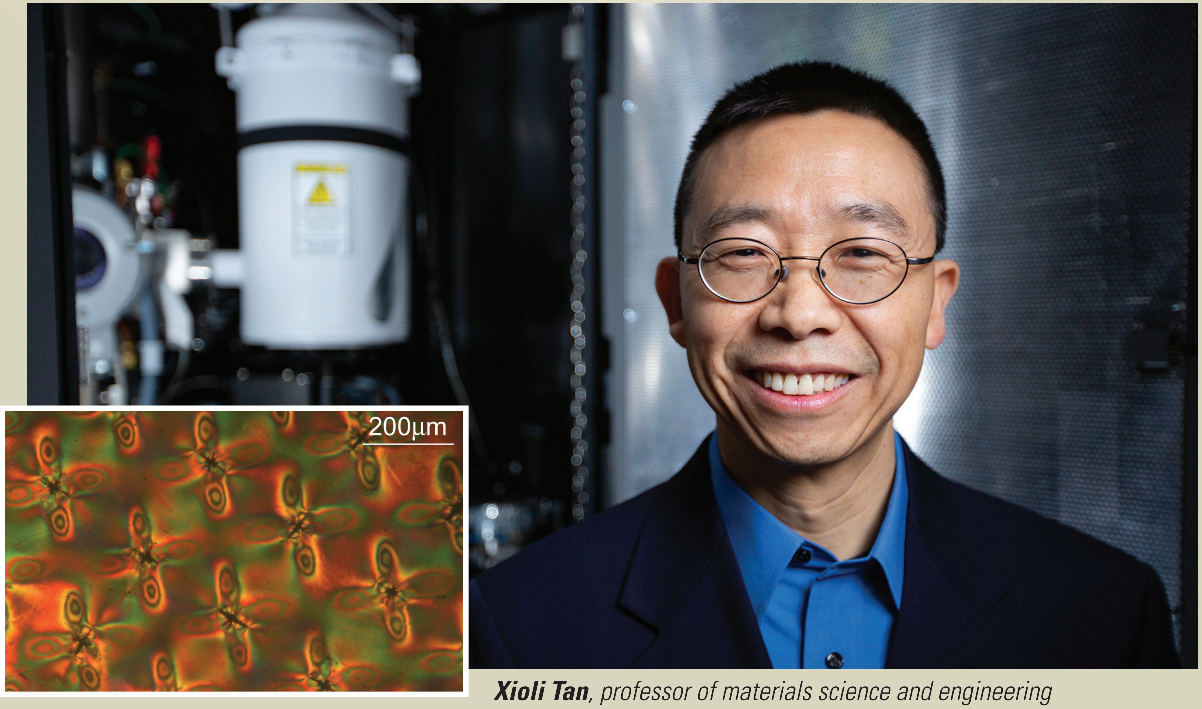
BETTER CERAMICS
Cleaner, Greener Technologies

Xiaoli Tan is creating new materials needed to solve international sustainability and environmental challenges. Tan, professor of materials science and engineering, is an expert in designing, creating and measuring new compositions of functional oxide ceramics, materials widely used in electronics.

"Our goal is to establish the interrelationships between materials' composition, microstructure, and properties, so we know what ingredients will make oxide ceramics materials with much better performance than existing ones," said Tan.

Optimizing the performance of dielectric oxide ceramics may advance improvements in the energy density of capacitors used to store solar and wind energy.

And the clock is ticking on finding new lead-free compositions of piezoelectric oxide ceramics to replace the lead-containing version widely used today in fields ranging from medical ultrasound to underwater communications.



***Xioli Tan**, professor of materials science and engineering*

"Piezoelectric materials convert mechanical energy into electrical energy or vice versa," said Tan. "When you apply force or pressure, the crystal structure deforms and generates high voltage."

Tan's research group is the worldwide leader in a technique called in situ transmission electron microscopy (TEM) to examine just how crystal structures respond to changes in pressure and voltage. Developed by Tan during his Ph.D. work, the technique includes a custom specimen holder and a specialized specimen preparation process that creates the 0.1 micron-thick, crack-free specimen required for the TEM to "see" through the sample.

"The TEM is capable of recording images at resolutions smaller than 1 billionth of a meter, so we can see even the slightest changes in crystal structure," said Tan. "The TEM at the U.S. Department of Energy's Ames Laboratory Sensitive Instrument Facility is one of the best in the nation, which makes this research possible at Iowa State."

Next for Tan is adding additional complexity to his technique, including the ability to control temperature during measurements.

"Adding in the ability to heat up or cool down samples will better simulate the realistic application conditions of oxide ceramics, such as in the high temperatures faced by electric car capacitors," said Tan. "More closely mimicking real-world conditions will help us use these materials to solve real-world problems."

DATA RECOVERY TOOLS for the BIG DATA AGE

Big data holds big potential for solving pressing problems of our time – but big data also brings the significant challenge of working with high-dimensional data sets. **Namrata Vaswani**, professor of electrical and computer engineering, is developing novel algorithms for high-dimensional data recovery.

Her algorithms can recover data from noisy or distorted measurements and are fast, online and memory-efficient. Vaswani's approach focuses specifically on exploiting the inherent structure present in the data, such as sparsity or low-rank, as well as the time dependencies of these structures in order to recover data.

"When you exploit time dependencies, or other structural properties, you can get away with less observed data or noisier data and still make meaningful conclusions," said Vaswani.

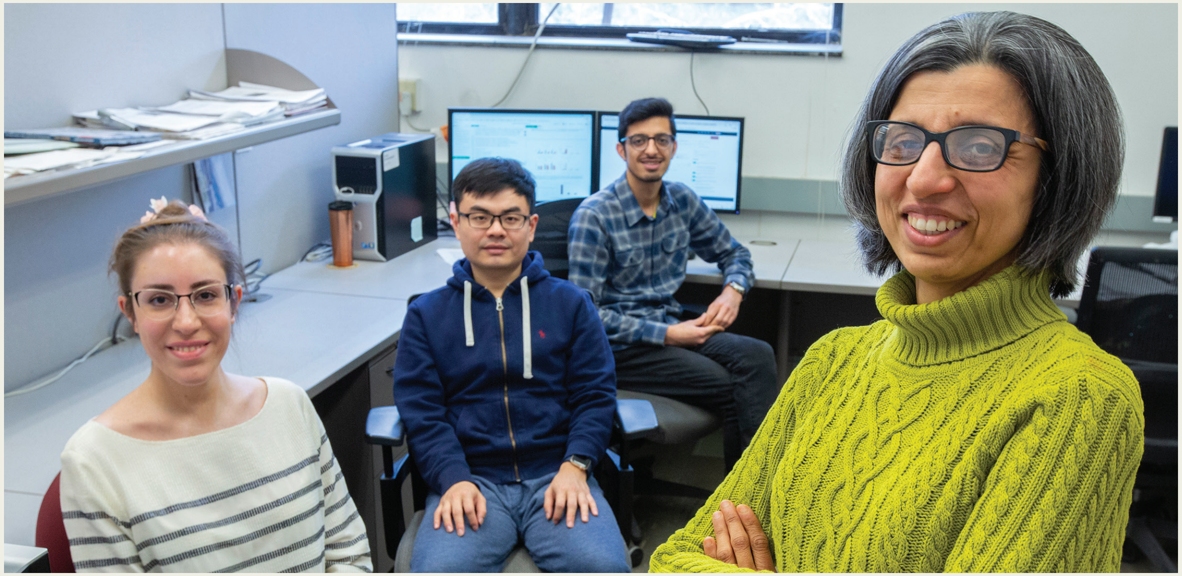
One example is functional MRI images of fast-changing body processes like a beating heart or changing brain activation. Vaswani's technique in dynamic compressive sensing was the first data-recovery method of its type to show significant sample complexity gains in functional MRI imaging. The development gives doctors better, richer data to make decisions from, while minimizing patient time in the MRI machine.

More recently, Vaswani's research group has worked on developing new tools to simplify automatic video analytics. Since all video is naturally full of data outliers in the form of foreground images blocking background images, Vaswani's expertise is uniquely suited for the task. Previous online (real-time) approaches could only process video under narrow, far-from-realistic conditions. But, Vaswani has shown the first provable solution, called Recursive Projected Compressive Sensing (ReProCS), that can handle the high amount of data outliers found in realistic video with static backgrounds.

"Moreover, ReProCS is fast and has near-optimal memory complexity, both of which are the most important factors in determining the practical usability of any algorithm in today's age of big data," said Vaswani.

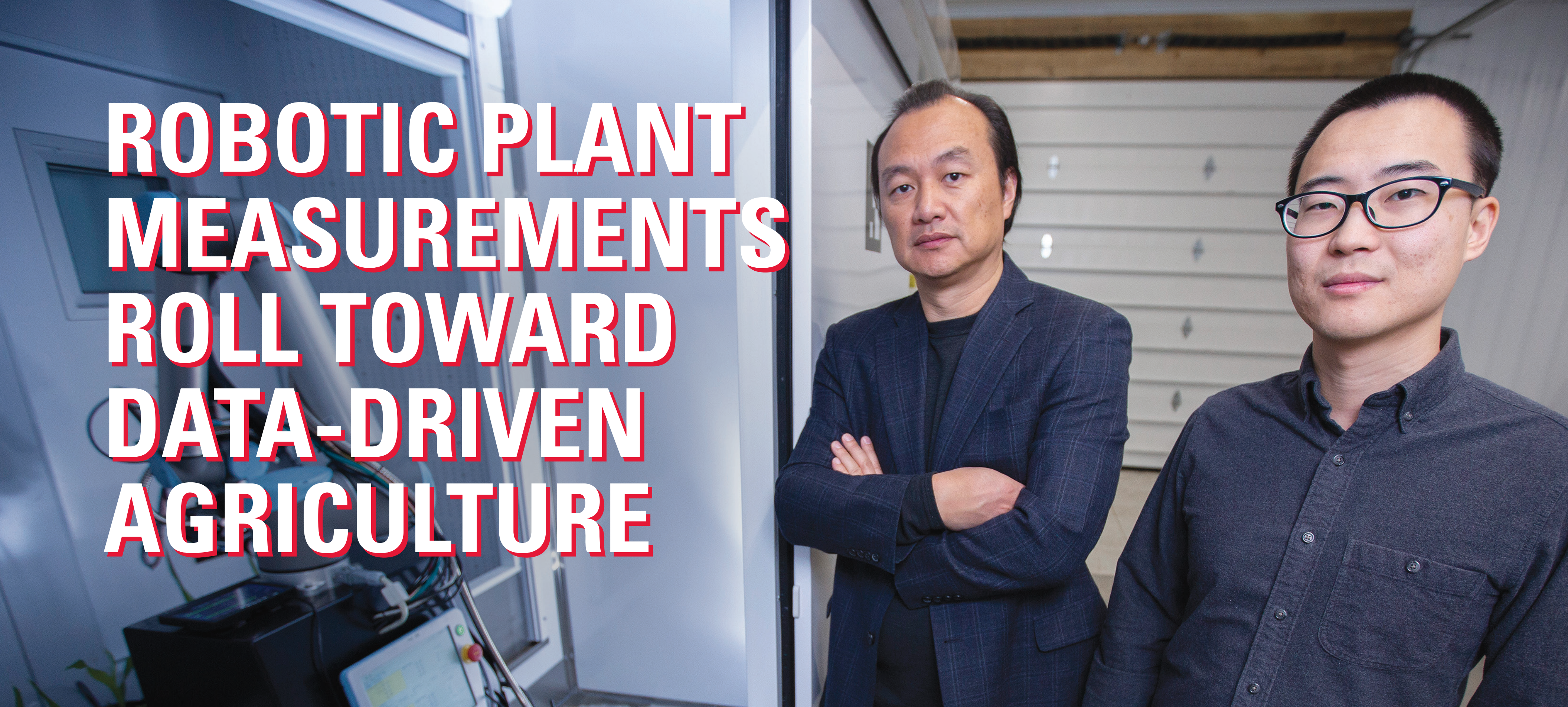
Applying Vaswani's techniques may help automated video recognition catch up with existing automated photo recognition tools – and may even help with another video challenge: improving the data quality of online video streaming services' recommendation systems, which only work as well as they can handle high amounts data outliers.

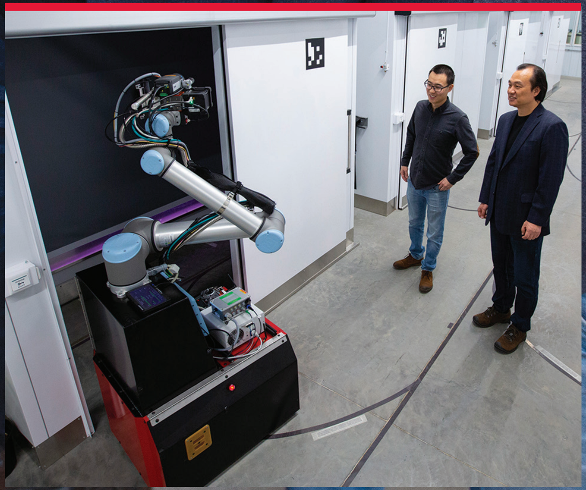
Vaswani is now working on exploiting time-varying structural properties to solve even more difficult non-linear data recovery problems often faced in "phaseless measurements" areas like X-ray imaging, optics or astronomical data. Her new algorithms will be aimed at speeding up "phase retrieval" data recovery and minimizing cost of higher-resolution measurements by exploiting structural assumptions, such as low-rank.

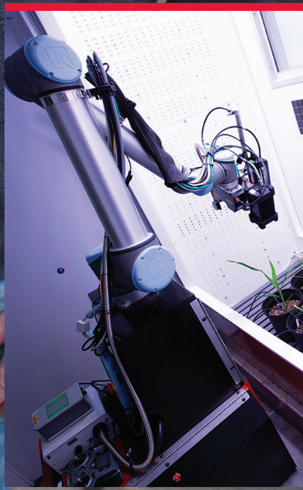


***Seyedehsara Nayer**, **Han Guo** and **Vahid Daneshpajooh**, all graduate students in electrical and computer engineering, and **Namrata Vaswani**, professor of electrical and computer engineering*

ROBOTIC PLANT MEASUREMENTS ROLL TOWARD DATA-DRIVEN AGRICULTURE







***Lie Tang**, associate professor of agricultural and biosystems engineering, and **Yin Bao**, postdoctoral research associate in agricultural and biosystems engineering*

Lie Tang's research team designs plant-measuring robots that quickly and accurately collect the plant-trait data needed for data-driven crop performance research.

"We combine intelligent robotics and sensing technologies to improve both the throughput and the quality of plant measurements, a core need in the growing field of predictive plant phenomics," said Tang, an associate professor of agricultural and biosystems engineering.

In plant sciences, genomic and environmental data is already abundant and reliable. Tang's autonomous robotic plant measurement systems supply the missing piece needed to understand the relationships between genes, growing environment and plant traits – and ultimately accurately predict how to improve crop plant yield and resilience.

Tang's robots enable better data-driven plant science from the lab to the field.

Enviratron

Tang is a co-principal investigator in a campus-wide project to create the Enviratron, an autonomous robot that measures plant growth in highly-controlled laboratory plant growth chambers.

"We installed the best sensing technologies available on a robot with an arm that reaches out and gets very close to the plants, as close as previously-used handheld measurement devices can," said Tang. "Enviratron is able to duplicate and improve on the measurements that required a lot of human labor."

The Enviratron robot rover automatically moves from growing chamber to chamber, using a 3-D camera, a hyperspectral sensor, a fluorescence detector and a Raman scattering spectrometer to measure plants under different environmental conditions. Keeping plants in their growth chambers for measurements ensures fewer outside variables are introduced – and improves data quality.

This National Science Foundation-funded project has shown some major advantages over previous plant growth and measurement techniques, opening new possibilities in plant sciences research.

Phenobots

Tang's plant-measuring robotics extends beyond the lab to the field with his Phenobots. Like the Enviratron, these field-based phenotyping robots carry measurement sensors, but face an additional set of challenges.

"Phenobots fit between crop rows, so we have less than 30 inches to fit a lot of hardware, and we must position it to take measurements of both small and tall plants," said Tang. "Add the natural variables of the field – soil conditions, weather, lighting and wind – and obtaining quality data is a difficult problem."

Tang's team has built two generations of custom rovers to address the in-field measurement tasks and demonstrated that these ground robots can capture detailed traits of corn and sorghum, including stalk size, leaf angles and more. Now Tang is using what he has learned to build a small fleet of third-generation Phenobot models that will be used by plant scientists in multiple Midwest states.

"As an engineer, I enjoy working with students to build tools and solve real-world problems, and it's been very rewarding to see how the Enviratron robot and Phenobots will help solve some important challenges in data-driven agriculture," said Tang.

Dyno-might

Construction will soon start on a $2.9 million chassis dynamometer at the Iowa State Agricultural Engineering and Agronomy Farm.

The advanced off-road vehicle testing facility, one of just a few publicly available in the world, will make possible controlled dynamic testing of complete vehicle systems and advanced traction control systems. The state-of-the-art equipment will advance Iowa State's capabilities and expertise in developing and evaluating off-road and agricultural vehicle sensing and control systems and new power train concepts, as well as providing a controlled test platform to complement field tests.

Iowa State undergraduate and graduate students will also have new opportunities to get hands-on experience in sophisticated traction, power train and vehicle chassis performance testing skills.

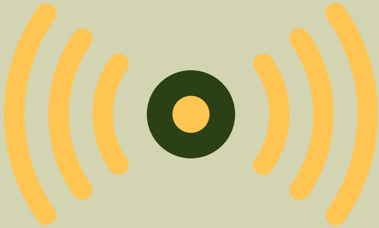
Danfoss Power Solutions has committed more than $1.8 million to the facility. The chassis dynamometer will promote resource sharing and build on existing momentum between Iowa State and Danfoss, as well as other industry partners.

"The new chassis dynamometer is a valuable addition to our research, teaching and extension programs – and it's sure to lead to the discovery of next-generation agricultural engineering technologies and better prepare the next generation of Iowa State engineers and technology students," said **Steve Mickelson**, Charles R. and Jane F. Olsen Professor in Engineering and chair of agricultural and biosystems engineering.

NEWS BITE

STORM SIMULATOR TOPS LIST

The Department of Aerospace Engineering's tornado microburst simulator tops the list of AccuWeather's natural disaster research facilities. The simulator is part of Iowa State's Wind Simulation and Testing Laboratory and creates miniature tornadoes that move across a structure to study of how different tornado parameters and different building shapes impact storm damage.



RESONANT SENSORS FOR HEALTH AND AGRICULTURE

An interdisciplinary research group led by **Nigel Reuel**, assistant professor of chemical and biological engineering, is developing low-cost, flexible resonant sensors and wireless readers for detection of enzymes, proteins, biofilms, tissue types and ions. DuPont is an industrial partner on the NSF-funded work, which has broad applications in health and agricultural fields.

MOVING AT THE SPEED OF HPC

Iowa State is now home to a new $1.6 million high performance computer cluster, with twice the computation power as previous clusters on campus. NOVA can process 1.3 petabytes of data and adds Volta GPUs, opening new doors in research ranging from machine learning to data analytics in digital agriculture and beyond. NOVA is funded by a National Science Foundation project led by **Arun Somani**, Anson Marston Distinguished Professor in Engineering, through the Major Research Instrumentation program.

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SHAKING UP COMPOSITE MATERIALS

Jaime J. Juárez, an assistant professor of mechanical engineering, is using acoustic fields to form stronger, more durable particle-polymer composite materials. His technique may be a step forward in additive manufacturing, enabling the effective simultaneous deposit of different materials on parts and products.

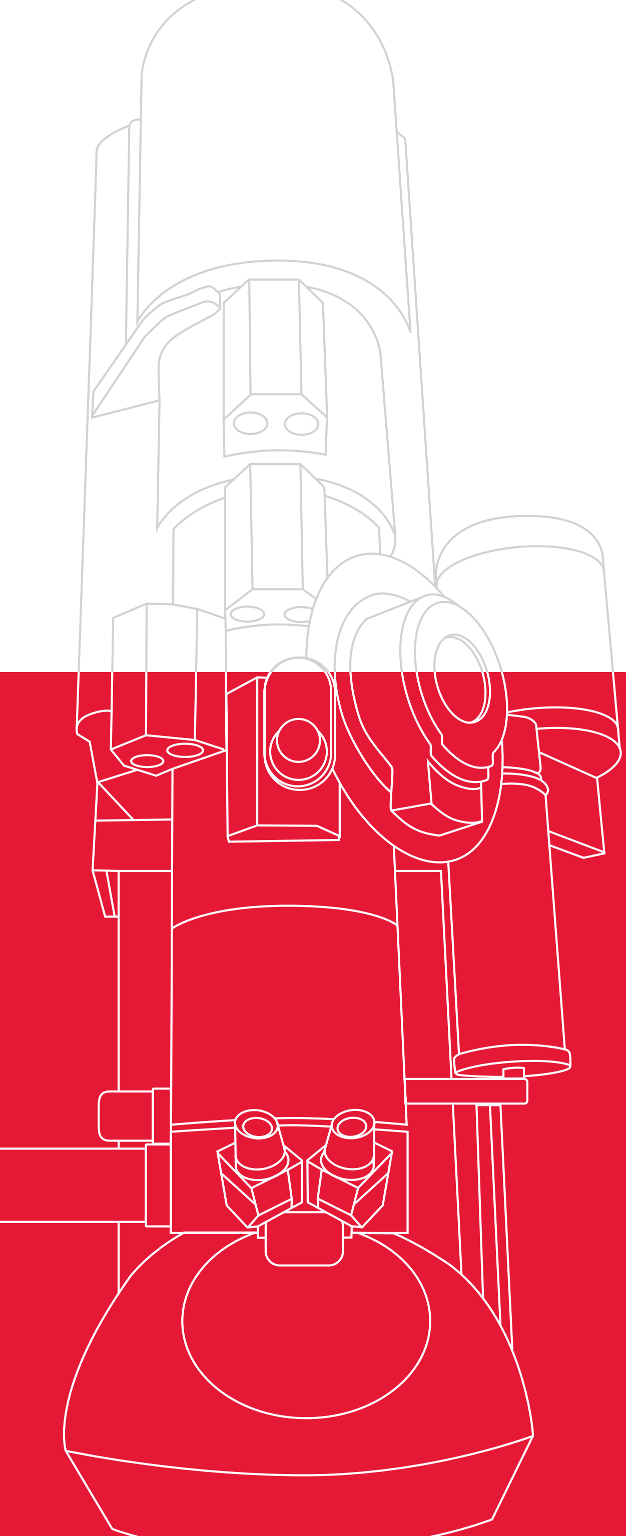
SUPPORT FOR INNOVATION

A $6 million gift from The Boeing Company will support Iowa State's Student Innovation Center and opportunities for hands-on, undergraduate research experiences. "Boeing is committed to inspiring the next generation of innovators and equipping them with the skills they need to excel in the modern workforce," said **Dennis Muilenburg** ('86 aero engr), Boeing chairman, president and chief executive officer. "The Student Innovation Center at Iowa State University will help encourage innovation on campus and in graduates' future careers, positioning them for success in STEM-related fields."

The Student Innovation Center is scheduled to open in 2020.

BACKPACK FULL OF SUNSHINE

Mechanical engineering senior **Courtney Beringer** has spent three years designing, developing and prototyping a solar panel-equipped backpack. The bag includes a removable solar panel and battery capable of charging a laptop – and is designed with all the features of conventional backpacks, including a water bottle holder. Beringer's project recently won first place in an International Textile and Apparel Association student paper competition.



IOWA STATE UNIVERSITY

College of Engineering

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Cyclone Engineers use state-of-the-art electron beam microscopy tools in facilities shared with the U.S. Department of Energy's Ames Laboratory. The Sensitive Instrument Facility is home to scanning electron, focus ion beam, scanning transmission electron (STEM) and probe-aberration corrected STEM microscopes that make it possible for us to push the boundaries of materials characterization – right here on the Iowa State campus. **Read more on page 10** about how we use electron beam microscopy to optimize the functional oxide ceramics found in many electronics.