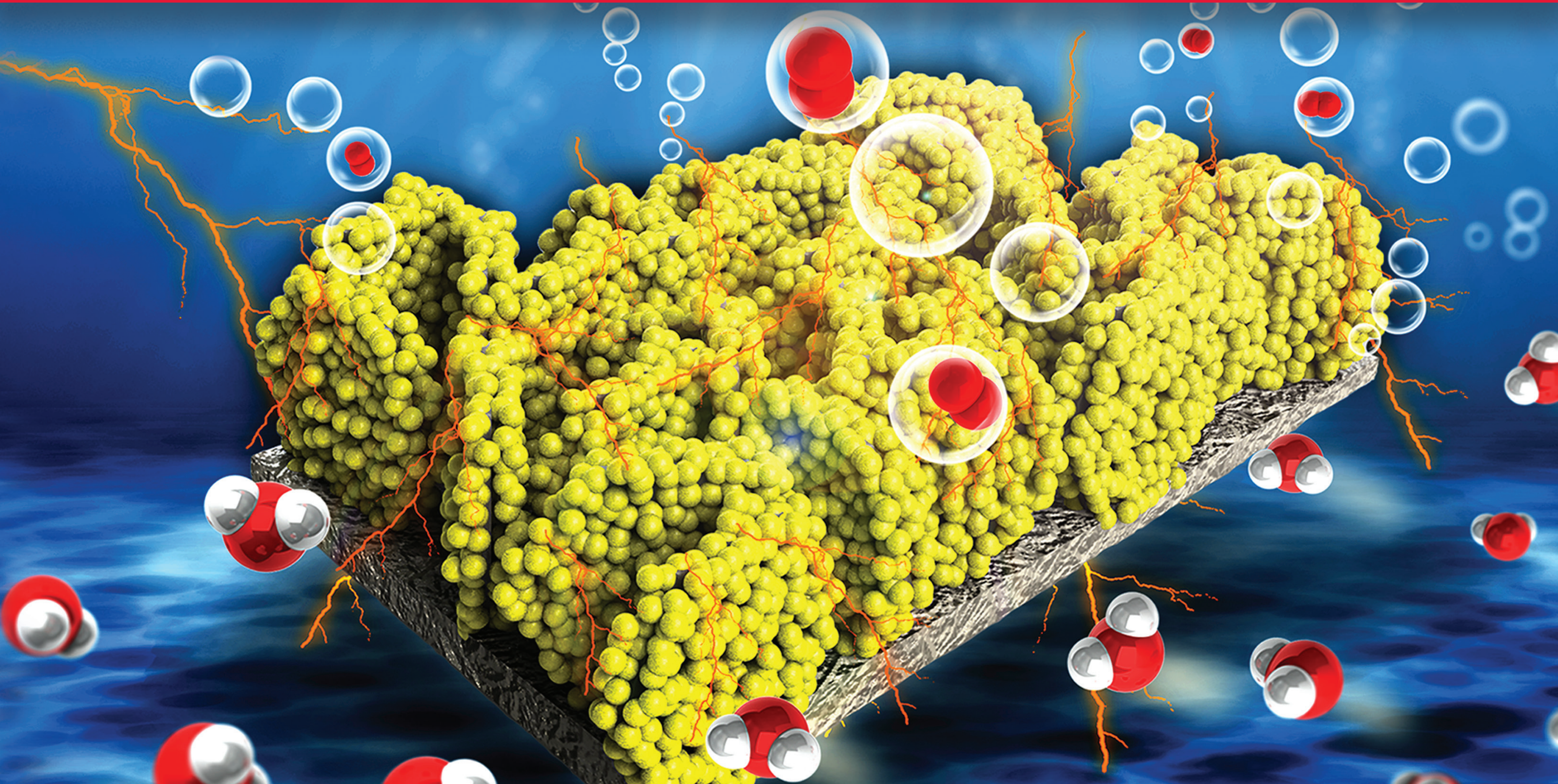
IOWA STATE UNIVERSITY
College of Engineering

# CYCLONE ENGINEERING RESEARCH

FALL 2017



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***On the cover:*** *Shan Hu, assistant professor of mechanical engineering, is developing new catalysts made of iron-oxide nanostructures that convert light into fuel faster and cheaper than other leading catalysts.*




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# NEW RESEARCH STRATEGIC PLAN IDENTIFIES AREAS OF EXCELLENCE

Preparing the next generation of engineers and pursuing groundbreaking research requires transformational thinking, bold actions and diverse partnerships. Grand challenges need great minds that create solutions to make the planet a better place. Dean **Sarah Rajala** (pictured right) and Associate Dean for Research **Arun Somani** (pictured left) have outlined new strategic objectives to guide the College of Engineering research enterprise for the next five years. The research plan aligns with a new overall college strategic plan that was recently unveiled.

"Our research program emphasizes a collaborative, interdisciplinary approach that delves into initiatives aligned with our signature research areas, bringing together the exceptional capabilities and expertise of talented faculty, staff and students," Somani says. "Our research portfolio to date has been far-reaching and successful – but with our new strategy, we are going to focus on high-impact research by investing primarily in existing and emerging areas of excellence." (See box for list. Read more about our resilient infrastructure research on pages 6-9, and learn about other areas of excellence in upcoming issues.)

### Investment in existing and emerging areas of research excellence

- Advanced materials and manufacturing
- Energy systems
- Resilient infrastructures
- Engineered medicine
- Engineering education
- Secure cyberspace and autonomy

During the past year, Somani led a working team of engineering faculty members charged with planning how best to position the research program for the future. In addition to identifying the six areas of research excellence, the group also made recommendations for graduate student recruiting, faculty retention and how to emphasize a collaborative learning environment that enables students to reach their fullest potential.

"Our pursuit of excellence means strategically investing in our research program to reach new heights, and continuously striving to be leaders in transforming the results of scientific research into engineering accomplishment," Rajala says. "Our new strategic objectives will help us better define our strengths and enhance an already successful research enterprise."

# BUBBLING WITH RENEWABLE FUEL:
## NANOSCALE CATALYST SPLITS HYDROGEN FROM WATER QUICKLY AND EFFICIENTLY

At the macroscale, rust is a common, everyday material. But at the nanoscale, it might hold the promise of sustainable clean energy. **Shan Hu**, an assistant professor of mechanical engineering, is developing new catalysts made of rust nanostructures that convert light into fuel faster and cheaper than other leading catalysts.

"Rust, or iron oxide, is an excellent example of how seemingly ordinary materials show very unusual, useful properties when we make them into nanostructures," says Hu. "At the nanoscale, iron-oxide becomes photosensitive, able to absorb sunlight and convert it into electrons. That opens up the door to many new possibilities."

*Shan Hu, assistant professor of mechanical engineering*

One such possibility is using iron-oxide nanostructures to drive hydrogen out of water in a process called water splitting. Driving, or "cranking," hydrogen from water is a first step in using hydrogen as a renewable fuel source, but the process comes with many challenges.

"Typically, these types of reactions happen really slowly, reducing how many electrons transfer from the iron-oxide to the water and crank out the hydrogen," says Hu. "So, we developed a new type of nanoparticle catalyst to speed up and improve the reaction."

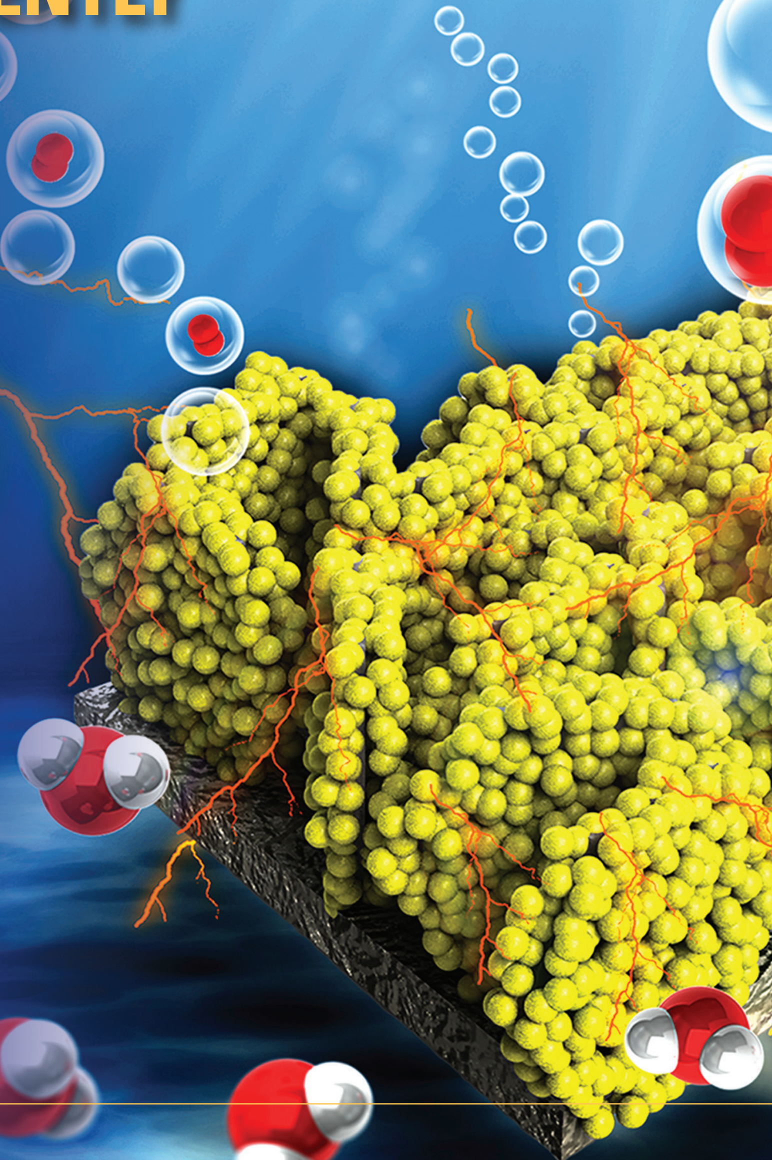
Hu and her research team found that their new nanoscale iron-nickel catalyst can beat the performance of ruthenium, a benchmark water-splitting catalyst material. And, replacing the scarce and expensive ruthenium with abundant and cheap iron and nickel helps reduce costs.

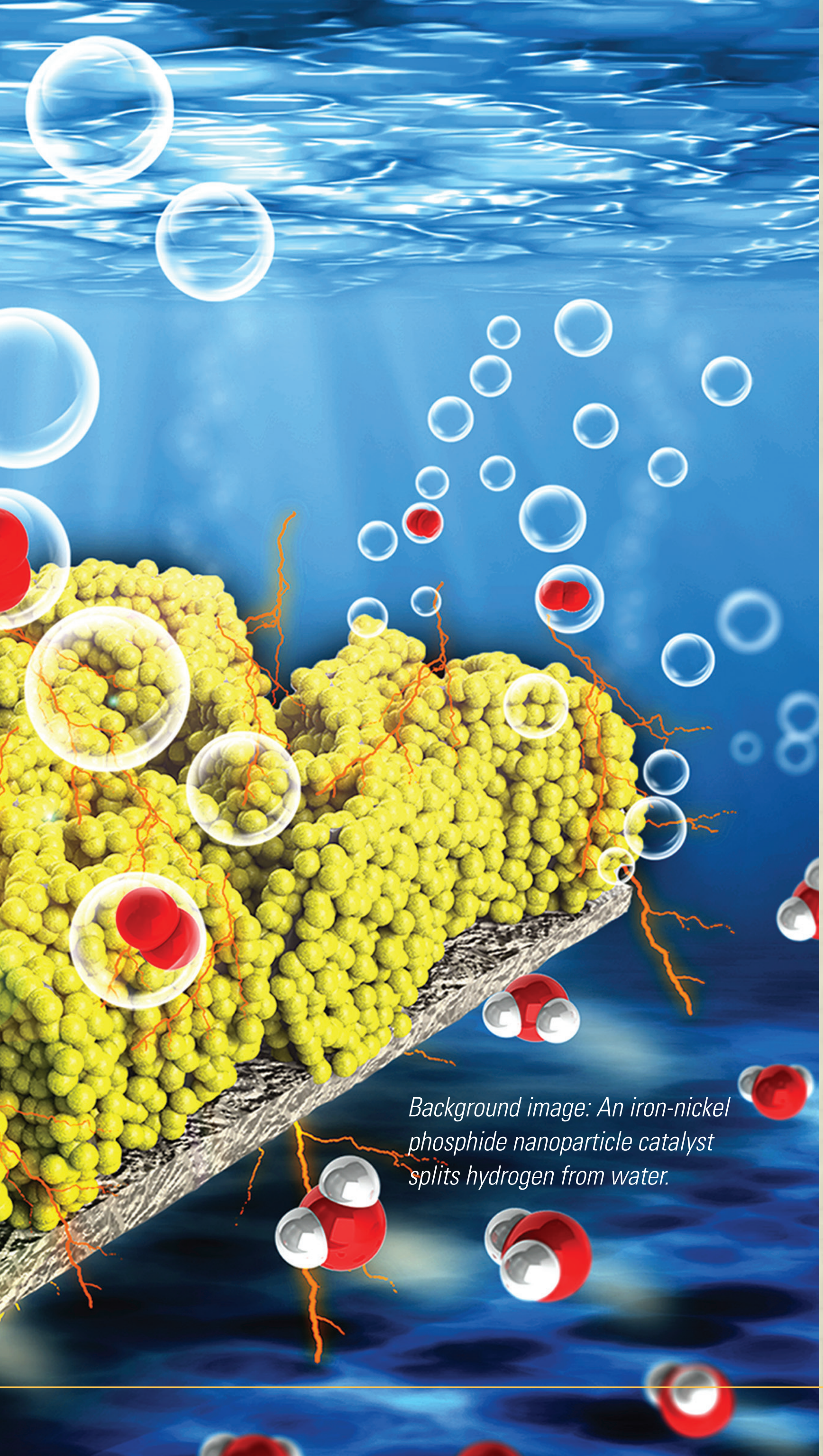
Hu's catalyst also requires less voltage to activate the reaction than other water-splitting processes.

"Usually this type of reaction requires 1.5 or 1.6 volts to crank the hydrogen, but our new catalyst does the job with only 1.2 volts, a huge energy savings," says Hu.

After making the breakthrough in water splitting, Hu has now turned her attention to harnessing the potential of nanostructures in other areas.

"We have a lot of big challenges facing society – energy needs, illnesses – just to name two. The never-seen-before abilities of nanostructures may be the new piece of the puzzle we need to solve our pressing problems," says Hu.





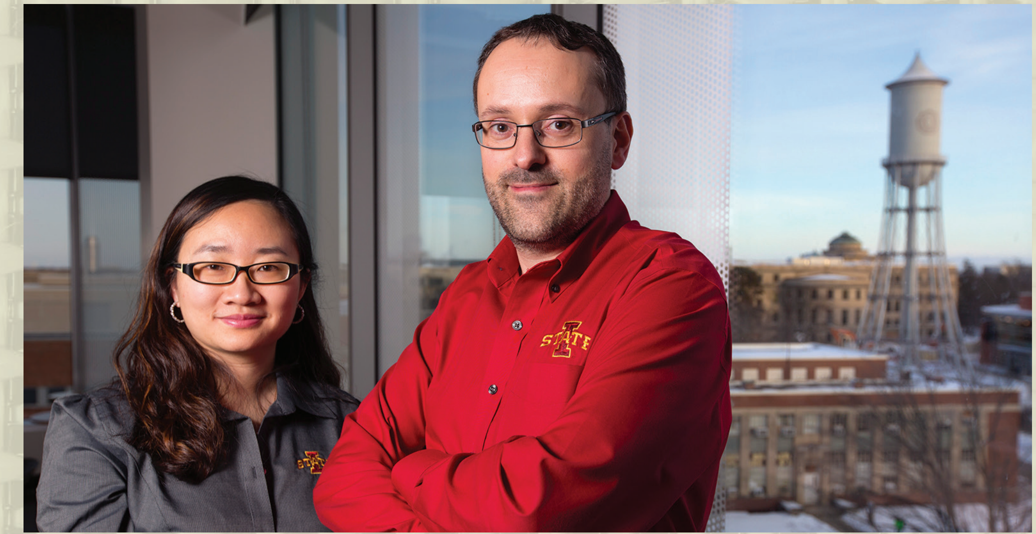
*Background image: An iron-nickel phosphide nanoparticle catalyst splits hydrogen from water.*

# NEW NYLON, NEW POSSIBILITIES

Cyclone engineers **Zengyi Shao** and **Jean-Philippe Tessonnier** created a new type of biobased nylon that outperforms nylon created from petroleum chemicals. Shao and Tessonnier, both assistant professors of chemical and biological engineering, combined their expertise in biocatalysis and chemical catalysis to design a hybrid biomass-to-nylon process that integrates fermentation and downstream upgrading. This hybrid process offers many advantages: the entire conversion is performed under near-ambient conditions, the fermentation broth is converted directly without any purification and the fermentation broth provides the reagents for the second step of the process.

What's more, the final product, bio-advantaged nylon-6,6, has an extra double chemical bond in its backbone, which can be used to tailor the material's properties in all kinds of useful ways. The double bond is an anchoring point to add extra molecular chains that can make the biobased nylon hydrophobic, antistatic, antimicrobial, flame retardant and more.

"We're making new molecules that will enable development of new products not possible before using traditional petroleum-based nylon," says Tessonnier.



# DATA DRIVEN: SMART SYSTEMS FOR TRAFFIC MANAGEMENT

Cyclone engineers are using big data to make big improvements to road safety and traffic management. **Anuj Sharma**, associate professor of civil, construction and environmental engineering, and a team of researchers are using continuous traffic data streams – video, traffic volume, speed, backups, weather and more – to build automated, real-time traffic management tools.

With support from a $1 million grant from the National Science Foundation, the team is working with the Iowa Department of Transportation to develop new traffic models, computer algorithms, user-friendly computer displays and information visualizations that will help traffic management operators make decisions and take actions to keep vehicles moving smoothly.

Ultimately the goal is to build a system that can use machine learning to detect – and even predict – traffic problems. Fast responses to traffic troubles like crashes, stalled cars or bad weather will help improve the safety of motorists and workers by reducing response times and rapidly slowing or re-routing traffic in trouble spots.

"When there's a crash, every second is critical," says **Neal Hawkins**, associate director of Iowa State University's Institute for Transportation and adjunct lecturer in civil, construction and environmental engineering.


*Cyclone transportation researchers use the Realtime Analytics for Transportation Lab as a testing ground for emerging traffic data analytics.*

# MIDDLE GROUND: EXAMINING FARM FIELD DRAINAGE TO DEVELOP BALANCED AGRICULTURAL PRACTICES

**Matt Helmers**' (pictured second from left) mission is to put the "middle ground" in managing agricultural land. Crops need enough but not too much water in the soil. Agricultural producers seek to get just the right amount of nutrients to plants, without the excess traveling elsewhere.

"The overall goal of my research in water quality and drainage flow is to look for ways to maintain agricultural productivity while reducing our environmental footprint," says Helmers, who is a professor of agricultural and biosystems engineering. "Better understanding of how water drains from fields will help us design balanced agricultural practices for the future."

Helmers collects subsurface data on both the volume of water that drains from cropland and the nutrient content found in water samples. The team combines current information with more than 25 years of historical drainage data to help form a clearer picture of the amount of water needed for best crop production, how much and when extra water is available for capture and irrigation reuse, and amounts of nutrient movement.

"No other state has the wealth of data that we do on drainage and water quality," says Helmers. "That positions Iowa State University well to answer current questions and make predictions about agricultural water needs under the changing rainfall patterns we expect to see in the future."

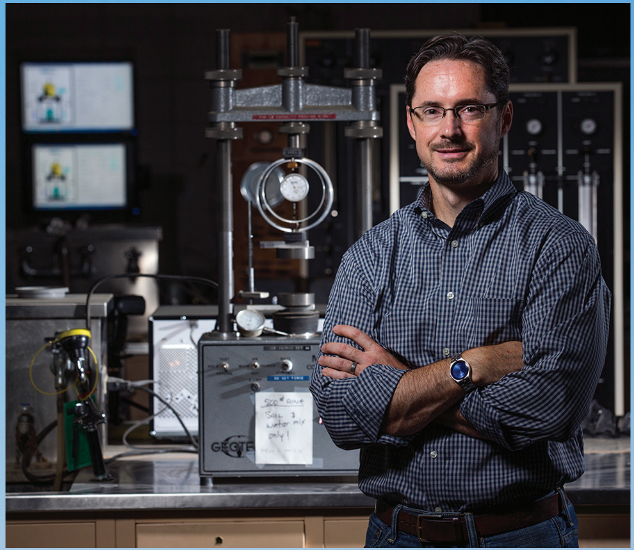
# FIRM FOUNDATIONS: REFINING PILE DESIGN MODELS FOR EARTHQUAKE-RESISTANT BUILDINGS

Many researchers say they want to shake up their fields of study. Iowa State engineer **Jeramy Ashlock** means it. Ashlock, the Richard L. Handy Professor of Civil, Construction and Environmental Engineering, studies how building and bridge foundations interact with soil during earthquakes and structural vibrations.

In research funded by an National Science Foundation CAREER award, Ashlock and his team are conducting full-scale field tests of the dynamics of piles, large steel or concrete foundations that are driven into the ground to support structures. They will test piles with a large servo-hydraulic shaker that applies random and multi-frequency excitations like those of an earthquake and record the physics of what happens.

Ashlock will use the experimental results to refine computer models that civil engineers use to help make pile design decisions. To accurately capture how the pile responds in reality, researchers must account for many complex variables: vertical, horizontal and lateral movement – along with the pile's effects on the soil beneath it, around it and even soil far away from the pile.

"Measuring and modeling pile performance is an incredible challenge," says Ashlock. "In our study, we're ratcheting up the complexity and examining real-world conditions to verify some of the phenomena we have observed in simplified, scale-model centrifuge laboratory tests. Knowing more about real-world pile conditions will make it possible for us to recommend real-world design improvements for buildings and bridges."



*Jeramy Ashlock, Richard L. Handy Professor of Civil, Construction and Environmental Engineering*

# MODERN GRID: LINKING U.S. ELECTRICAL SYSTEMS TO MOVE RENEWABLE ENERGY AND INCREASE RELIABILITY

**James McCalley** is working with researchers from across the nation to find ways to tie the United States' largest – but separate – electricity grids together. In a study that is part of a U.S. Department of Energy $220 million Grid Modernization Initiative, McCalley and his Iowa State University research team are building computer models simulating 15 years of grid improvements and operations to study the best ways to generate renewable power and transmit it to and from the major eastern and western U.S. grids.


*Iowa State's James McCalley describes computer models showing the effects of tying the country's major power grids together. Photo by Werner Slocum, NREL/DOE.*

McCalley's team is evaluating four different designs, ranging from maintaining existing limited cross-grid capacity to creating a new macrogrid that establishes connections between the West Coast and the Midwest.

Models indicate that there is good reason to connect and modernize the county's largest energy grids.

"There are two main drivers for benefits of 'cross-seam' transmission," says McCalley, an Anson Marston Distinguished Professor of Engineering and the Jack London Chair in Power Systems Engineering in the department of electrical and computer engineering. "That's wind energy moving from the middle of the U.S. to the coasts and sharing the capacity between regions for reliability purposes. In Iowa, about 35 percent of our electricity is renewable energy. If we want the rest of the country to be at 35 percent renewable energy, this is what you want to do."

# EDUCATING TOMORROW'S ENGINEERS:

## EXAMINING HOW, WHY AND WHEN NEW TECHNOLOGY TOOLS IMPROVE ENGINEERING EDUCATION

**Benjamin Ahn**'s research goal is to identify the best educational approaches for educating new generations of engineers, using technology tools available today.

"The next generation of engineers will face new challenges, and we have new technology tools to help educate and prepare students," says Ahn, assistant professor of aerospace engineering. "But technology is only as good as how we use it. Understanding what techniques work best, and why, is the first step to offering evidence-based best practices that develop outstanding future engineers."

Ahn studies three approaches that can help improve educational experiences for undergraduate students in engineering.

### Technical content mastery

Ahn is investigating how technology can help engineering students master the technical content in their fields. He is studying how students in large-enrollment foundational engineering courses use and respond to instructional videos. Some initial findings are surprising (videos any length between 1 and 20 minutes are played and completed at the same rate), while others match expectations (videos are most watched in the few days before exams). Ahn will use his research results to make evidence-based recommendations for how instructors can use video to facilitate student learning in engineering courses.

"Improving how we teach technical courses is hugely important because the classes form the foundation of an engineer's knowledge, and large-enrollment courses can be particularly challenging for students, including those who are underrepresented in engineering. Engagement and success in first- and second-year courses is key to engineering student retention," says Ahn.

### Polished professional skills

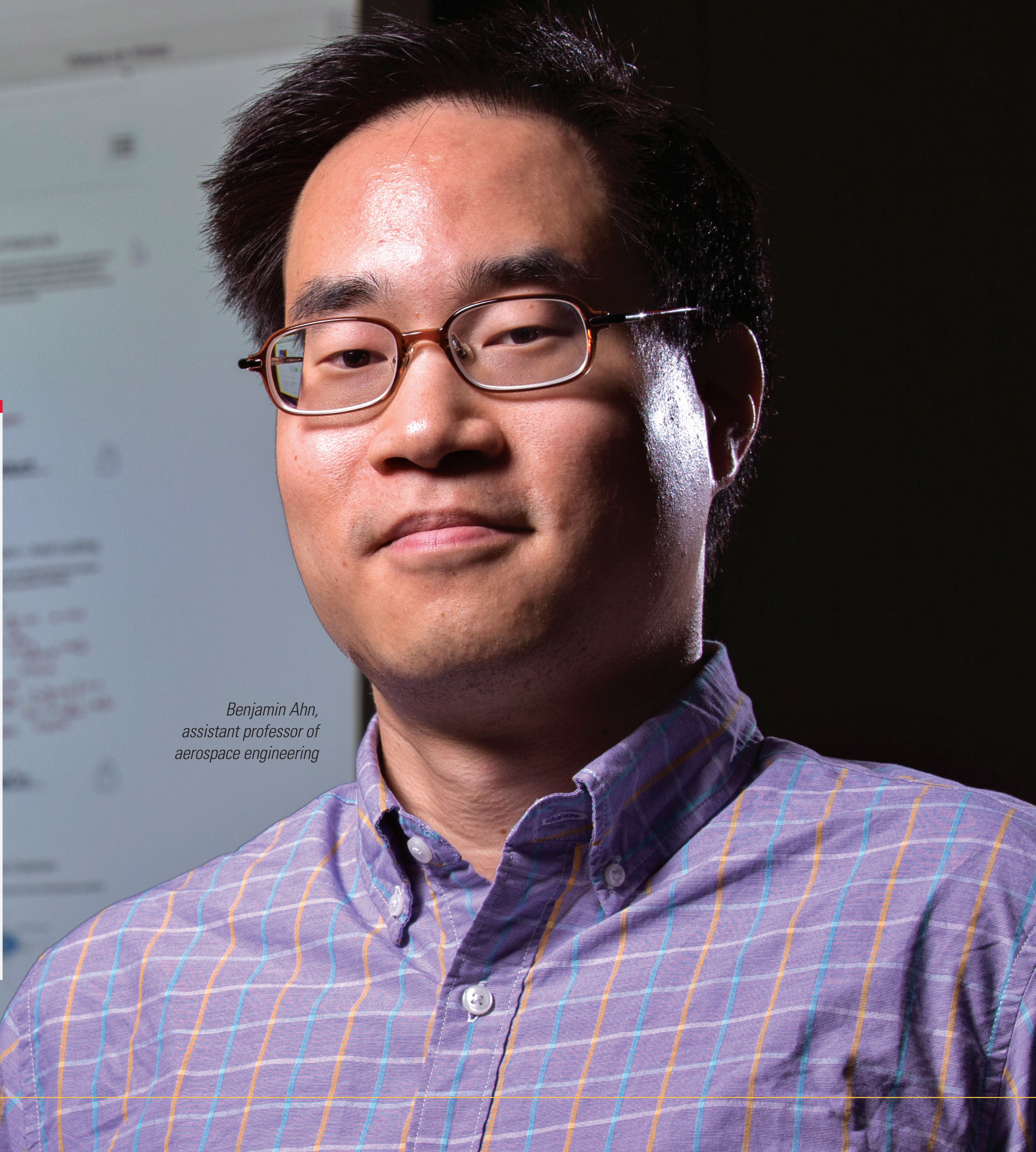
Knowing technical engineering content is a must, but in today's globalized, collaborative world, it's no longer enough. Tomorrow's engineers will need exceptional skills in teamwork, particularly working with those in different disciplines and from different cultures. Ahn is also studying how to best instill and assess students' professional skills.

"Professional skills cannot be taught or measured on paper, so I'm particularly interested in using technology and hands-on practice to convey information and conduct real-time, holistic assessments of students' development in systems-level thinking, communication, ethics and all the skills our future engineers will need," says Ahn.

### Valuable research mentoring

"Successful engineers apply and generate new technical content to help expand their fields, so giving students practice in undergraduate research experiences is a must," says Ahn. "And one of the most important aspects to high-quality research experience is receiving mentoring from more experienced engineers."

Ahn is pioneering the use of technology to better understand what parts of complex mentoring relationships are key to creating positive student experiences. He is developing new ways to measure mentoring practices and understand effects of positive mentoring on student outcomes, all with an eye on creating a research-based mentoring training program.



*Benjamin Ahn, assistant professor of aerospace engineering*

# AT-HOME DISEASE TESTING:
## DESIGNING MICROFABRICATED-PAPER SENSORS FOR BIOMARKER DETECTION

Imagine testing for cancers, hepatitis and tuberculosis as quickly, easily and inexpensively as today's home pregnancy tests and blood glucose monitoring strips. Cyclone engineer **Meng Lu** is using the power of microfabrication to create state-of-the-art, on-demand diagnostic technology.

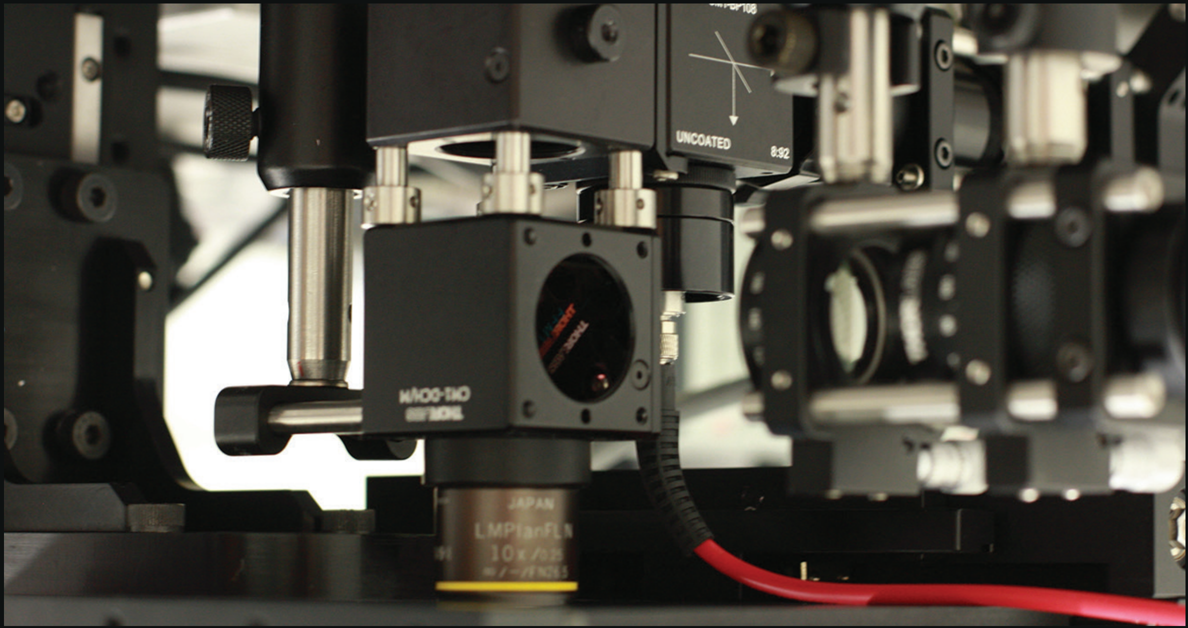
Lu, an assistant professor in both electrical and computer engineering and mechanical engineering, says the key to creating an at-home disease sensor is altering a common at-home material: paper. In a project supported by a National Science Foundation CAREER Award, he is developing the first sensor that uses engineered paper to combine the two parts of biomarker detection – sample preparation and detection – into one small sensor.

"Normal paper is made up of a random arrangement of cellulose fibers. By microfabricating the cellulose nanofibers into controlled structures, we can use paper's natural ability to move and filter liquids to separate out just the biomarker molecules we are interested in testing. Microfabricating atoms also allows us to create unusual optical responses not found in everyday paper."

The technique, called optofluidic paper, offers significant advantages over traditional diagnostic tests. Lu's sensor will be able to test for multiple biomarkers at the same time, just by building several different types of nanostructures of atoms into one paper test strip. And optofluidic sensors detect biomarkers at very low concentrations, enabling earlier disease detection – and perhaps allowing patients to avoid more invasive tests.

Lu will pair the sensor with a small, portable, inexpensive device that quickly measures optical feedback from the engineered paper and turns it into easy-to-read results.

"We will engineer the paper to adhere to

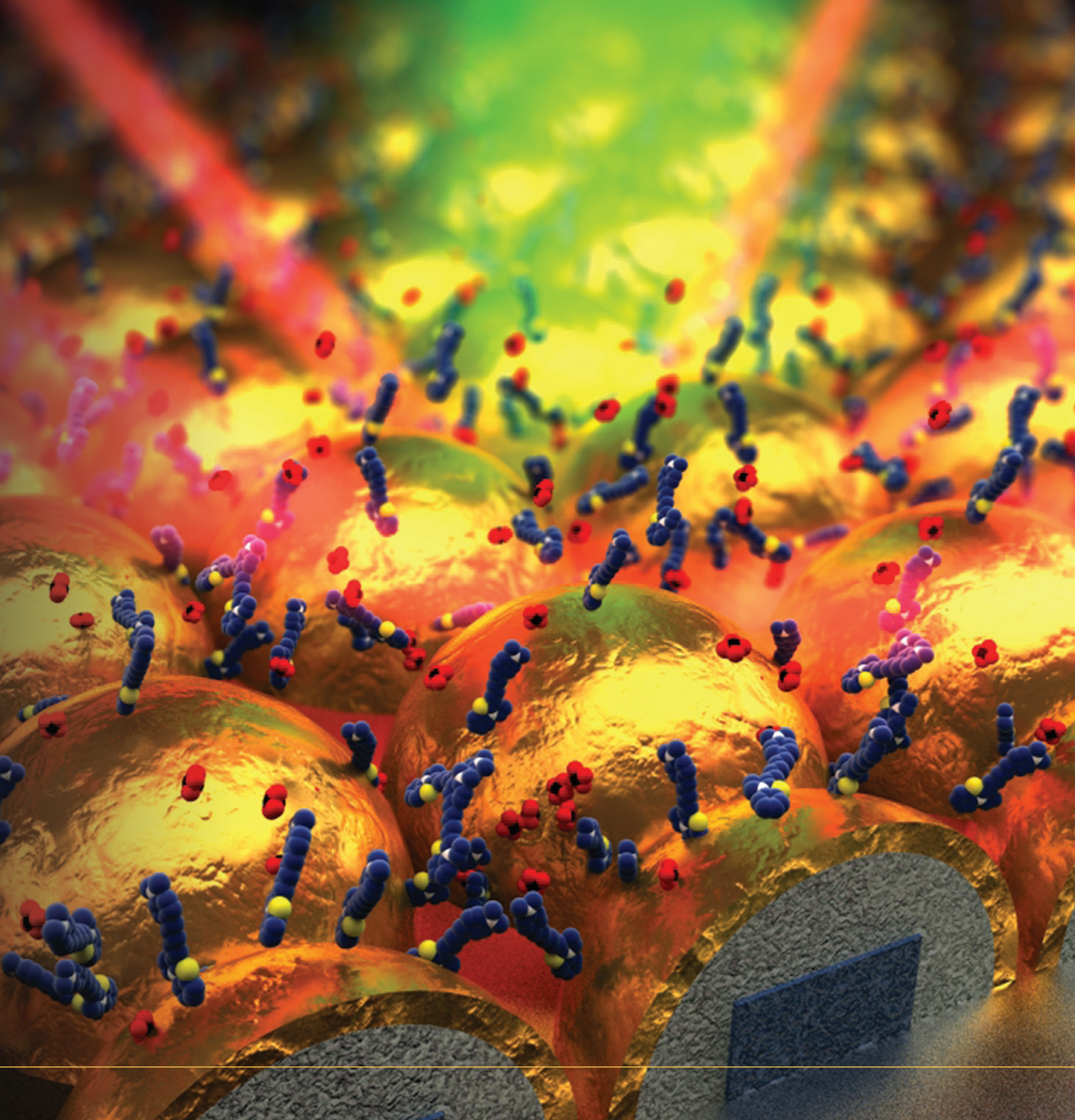



*ABOVE: Instrumentation that measures optical signals from paper-based sensors. Meng Lu's research goal is to miniaturize the system to a hand-held device. RIGHT: A nanostructured sensor surface that can be used to detect chemicals, including disease biomarkers, at very low levels of concentration.*

biomarker molecules, so the texture of the paper will change when it comes in contact with even very small quantities of the biomarker," says Lu. "We can then measure changes in how the light interacts with the paper to see if the biomarker is present."

What's more, since Lu's sensors are paper-based, they will be low-cost and disposable.

"Optofluidic paper sensors fill a significant need in areas with limited medical facilities, such as rural communities, developing countries and military deployments," says Lu. "This technology will bring inexpensive and reliable testing right to patients' bedsides."



*Meng Lu, assistant professor of electrical and computer engineering and mechanical engineering*

# NEWS BITES

### REMADE INSTITUTE TO IMPROVE MANUFACTURING ENERGY EFFICIENCY

Iowa State University engineers are partners in the Department of Energy's Reducing Embodied-energy and Decreasing Emissions Institute, or REMADE, a new $140 million national manufacturing institute dedicated to recycling and remanufacturing materials as well as reducing material consumption in manufacturing in ways that can improve the energy efficiency of American manufacturing by up to 50 percent.

REMADE will focus on lowering the cost of technologies that U.S. manufacturers need to reuse, recycle and remanufacture metals, fibers, polymers, electronic wastes and other materials.

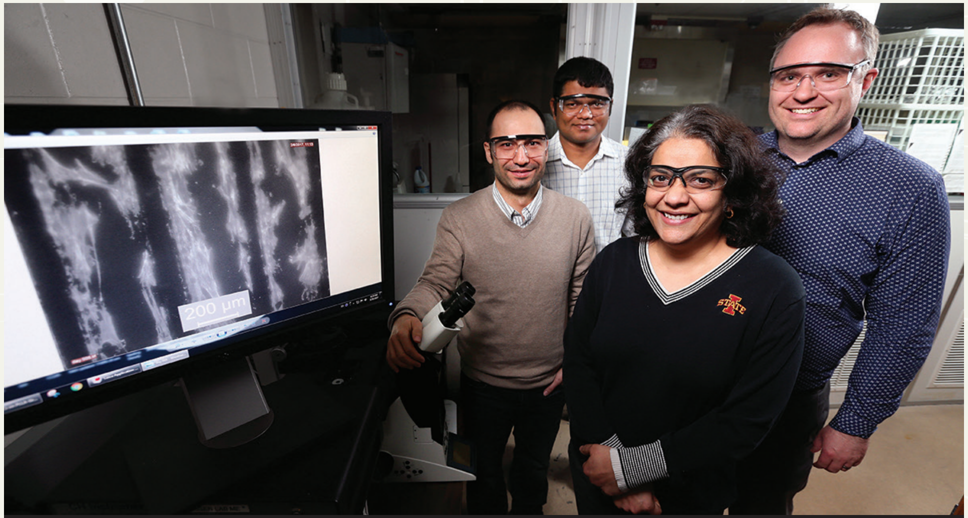
**Gül Kremer**, the C.G. "Turk" & Joyce A. Therkildsen Department Chair in Industrial and Manufacturing Systems Engineering, said Iowa State's REMADE-affiliated researchers will work directly with Iowa companies to speed up the transfer of discoveries to manufacturing processes that will reuse materials and save energy.

### NEW NANOTECH TRANSFORMS STEM CELLS FOR NERVE REGROWTH

**Surya Mallapragada**, Anson Marston Distinguished Professor and Carol Vohs Johnson Chair in Chemical and Biological Engineering, and **Jonathan Claussen**, assistant professor of mechanical engineering, are leading a team that's developing a better way to transform stem cells into Schwann-like cells that promote nerve regrowth.

They've created a nanotechnology that uses inkjet printers to print multi-layer graphene circuits and also uses lasers to treat and improve the surface structure and conductivity of those circuits. It turns out stem cells adhere and grow well on the treated circuits raised, rough and 3-D nanostructures. Add small doses of electricity – 100 millivolts for 10 minutes per day over 15 days – and the stem cells become Schwann-like cells.

The process is very effective, differentiating 85 percent of the stem cells into Schwann-like cells, compared to the 75 percent by the standard chemical processes. The differentiated cells also produce more nerve growth factor compared to other techniques. These gains open the door to new possibilities for treating nerve injuries, like dissolvable or absorbable nerve regeneration materials that could be surgically placed in the body.




*Iowa State researchers, left to right, Metin Uz, Suprem Das, Surya Mallapragada and Jonathan Claussen are developing technologies to promote nerve regrowth. The monitor shows mesenchymal stem cells (the white) aligned along graphene circuits (the black.)*

## SUSTAINABLE SOLUTIONS FOR WASTEWATER TREATMENT

Graduate student **Sahar Da'Er** (pictured) is seeking solutions to a water crisis in her home in Sana'a, Yemen. Working with **Kaoru Ikuma**, assistant professor of civil, construction, and environmental engineering, Da'Er is studying algae as a cost-effective and sustainable wastewater treatment strategy to help provide communities all over the world with safe, clean water.

"We are using a biofilm system based on algae for sustainable wastewater treatment," Ikuma says. "The idea would be to use algae – to allow them to photosynthesize and release oxygen. Then the other bacterial cells in the wastewater would do the rest of the treatment."

Da'Er, who is co-majoring in environmental science and civil engineering, is the recipient of an Iowa State interdisciplinary research fellowship that will bring together researchers from across campus to develop new water processing techniques.

## HIGH MARKS: HEXCRETE WIND TOWERS PASS TESTS

**Sri Sritharan**, Wilkinson Chair in Iowa State's College of Engineering and professor of civil, construction and environmental engineering, has created new concrete technology that will take wind towers – and wind energy production – to new heights.

In an 18-month study, Sritharan pushed and pulled an assembled test section with 100,000 pounds of force for more than 2 million cycles. The test section passed that fatigue test. The researchers have also tested a full-scale cross-section of a tower cell for operational loads and extreme loads for a 2.3 megawatt Siemens turbine. Again, Hexcrete passed the tests.

"The testing was very successful," Sritharan says. "The testing did show the system will work as we expected. There are no concerns about the cable connections or the concrete panels and columns."

The technology also looked good in economic studies.

"Our study shows the Hexcrete option at heights of 120 to 140 meters (about 394 to 459 feet) will be cost competitive," he says.

Next up is building a prototype tower, perhaps in a part of the U.S. that isn't known right now as a wind-energy powerhouse. Sritharan plans to show that tall towers will add capacity for renewable energy in all states across the nation.

## 70 YEARS OF RESEARCH COLLABORATION AND INNOVATION

The collaboration between Iowa State University and the U.S. Department of Energy's Ames Laboratory celebrated its 70th anniversary this year. Since Ames Laboratory's founding in 1947, the close university-laboratory relationship has helped both Iowa State and Ames Laboratory recruit researchers, educate students, build research teams and make scientific discoveries possible.

"Ames Laboratory is the only Department of Energy national laboratory located right on a university campus, and this unique 'co-laboratory' has created close, highly-productive research collaborations among Iowa State faculty and Ames Laboratory scientists. Both Ames Laboratory and Iowa State benefit from leveraging each other's strengths and facilities, as evidenced by the many groundbreaking discoveries and technologies that have resulted from our partnership," says **Sarah Nusser**, Iowa State's vice president for research.

AMES LABORATORY
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**POWERFUL PARTNERSHIPS**

Cyclone engineers have a mission to create, share and apply knowledge to make the world a better place. Iowa State students and faculty partner with developing communities in service-learning projects or in Engineers Without Borders missions to use engineering to address critical health, water, energy and agricultural challenges.