CASE SCHOOL OF ENGINEERING

2015-16 ANNUAL REPORT

IMPACT

CASE SCHOOL
OF ENGINEERING

CASE WESTERN RESERVE
UNIVERSITY

CONTENTS

Our ultimate goal is to have a meaningful impact on society.

That's our charge as an academic and research institution—translating our efforts in ways that make people's lives better.

Smart, secure and connected devices are going to be pervasive in our society in the coming years, and the data created will open limitless possibilities. We've launched a new institute, created a new undergraduate degree and formed new partnerships to be at the edge of this new frontier.

We're also committed to innovation as a way to solve some of society's most pressing problems. That is why we led a university-wide innovation summit and opened the doors to the new, 50,000-square-foot home of Sears think[box], our innovation and entrepreneurship center with unprecedented scope, scale and access.

In research, we strive to meet some of humanity's greatest needs in the realm of health solutions and advances for our growing society's energy needs.

We want to make a difference. We have committed to ensuring that what we do matters. And we are here to make an impact.

Jeffrey L. Duerk
Dean, Case School of Engineering
Leonard Case Jr. Professor of Engineering

the networked revolution

The Internet of Things (IoT), big data and augmented reality are transforming our physical world. With the launch of a new IoT institute, a strategic partnership with Cleveland Clinic and Microsoft HoloLens, a new ARPA-E grant to develop software for virtual energy audits and more, Case Western Reserve University is poised to capitalize on high-tech opportunities.

> **"We're looking at a time in which you have things in homes, factories, commercial buildings, infrastructure and power delivery systems that are all going to be connected."**
>
> KENNETH LOPARO

You're probably online right now.

Even if you're reading this the old-fashioned way, you're most likely still connected. As the world's wireless devices proliferate, the internet isn't necessarily somewhere you go anymore, it's somewhere you already are.

There are nearly 6 billion networked devices out there wirelessly gathering, recording and transmitting a practically boundless amount of information. Digital TMI? Not according to industry experts, who see it as a powerful tool to tackle the world's biggest challenges in energy, manufacturing, health care, education and more.

Big data, big deal

The explosion in the sheer number of networked devices has given birth to a whole new kind of internet: the Internet of Things—something of a new frontier of constant digital connection.

"We're looking at a time in which you have things in homes, factories, commercial buildings, infrastructure and power delivery systems that are all going to be connected," says Kenneth Loparo, chair of Case Western Reserve University's Department of Electrical Engineering and Computer Science. "That's the good news. The bad news is that they're all going to be connected—the complexity of this network becomes mind-boggling."

So far, the Internet of Things has sprung up something like a city before the advent of urban planning—a bit wild and unchecked. Case Western Reserve has launched a new institute dedicated to putting infrastructure around this new frontier so that society can put this powerful connected network to work.

Led by the Case School of Engineering, the Institute for Smart, Secure and Connected Systems, or ISSACS for short, will provide a physical home for the university's virtual initiatives in data science, IoT, cybersecurity, embedded systems, data analytics and more.

"The whole idea is to look at all these connected opportunities holistically," Loparo says. "From devices to data to the algorithms and software to user interfaces and cloud infrastructure, we're looking at this as an end-to-end system."

The institute will bring all the university's IoT-related research projects and academic programs under one umbrella. That kind of big-picture thinking is what's going to drive innovation in this space, he says.

Industrial applications

Media stories about the IoT tend to focus on nifty consumer applications, but Loparo says **advances in industry will dwarf consumer IoT innovations in terms of impact**, particularly in the manufacturing and energy sectors.

Bob Herbold, former COO of Microsoft and Case Western Reserve alumnus, agrees. "If you think about the ability to outfit a power plant with sensors and measure various aspects of its performance in real time, or monitor a refinery for signs of trouble before things slide out of control, the impact of this technology is massive," he says.

Herbold has been one of Case Western Reserve's chief supporters in advancing IoT and data science initiatives. (Read more about his gifts establishing a dedicated professorship and supporting graduate scholarships on page 9).

Automation has already transformed modern factories, and the IoT promises to up the ante in terms of the control systems that manage industrial-scale equipment, helping companies get their products to market faster, lower the costs of equipment ownership, improve asset

Left, Kenneth Loparo, chair of Case Western Reserve's Department of Electrical Engineering and Computer Science, is helping launch a new institute dedicated to IOT initiatives.

Below, Case Western Reserve has joined Northeast Ohio partners in the MetroLab Network—part of the White House's Smart Cities initiative.

> **Without setting foot in a building, we can tell you how good your insulation is, how much lighting you are using, and if your heating or cooling system is sized incorrectly."**
>
> ALEXIS ABRAMSON

utilization and maximize an entire operation's efficiency, says Juergen Weinhofer, vice president of common architecture and technology at Rockwell Automation, an industrial automation and information company that's implementing its own take on the IoT through an initiative it calls the Connected Enterprise.

Basically, networking a plant gets everything talking to each other, which essentially makes the whole operation run more smoothly, Weinhofer says. With sensors monitoring equipment performance in real time, operations managers don't have to wait for machines to break down to know there's a problem. It also helps companies manage diverse operations across the globe like never before.

IoT technology also has the potential to transform the way electricity is distributed, according to Loparo, by creating a system in which energy is dynamically controlled—where smart buildings can tell the system how much energy they need and the system can distribute accordingly, adjusting nimbly to make the most efficient use of the generated energy. A smart energy system could even reroute power if a certain section of the grid gets knocked out by a storm, Loparo says.

Experts see potential to scale up—**connecting entire cities to make major improvements in everything from transportation infrastructure to health and public safety. In fact, Case Western Reserve is part of a national initiative to advance these kinds of smart civic improvements. The university has teamed with its Northeast Ohio home of Cuyahoga County to join the MetroLab Network**, which includes 34 cities, three counties and 44 universities across the country. As part of the White House's Smart Cities initiative, MetroLab partners will work together to improve public services, create jobs, drive economic development and upgrade infrastructure.

Lisa Camp, Case School of Engineering's associate dean for strategic initiatives, sits on the nine-person executive steering committee managing the national MetroLab Network, putting Case Western Reserve front-and-center on this national project.

Civic-academic teams will take on projects based on the cities' priorities matched to universities' research wheelhouses. Case Western Reserve and Cuyahoga County will focus on improving sustainability by evaluating real data on everything from CO_2 emissions to renewable energy generation costs and outputs to sewer overflows from across the county's 59 communities.

MetroLab is just one example of how Case Western Reserve is using data to solve energy problems. **With the help of a $1.4-million grant from the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E), researchers are developing a unique software platform capable of translating years of building-generated data into virtual energy audits** that could help building owners manage energy use more efficiently and reduce costs.

"What we're doing is essentially mapping the building genome," says Alexis Abramson, director of the Great Lakes Energy Institute and the Milton and Tamar Maltz Professor of Energy Innovation at Case Western Reserve. Just like mapping the human genome is uncovering characteristics in DNA that correspond to traits like hair and eye color, Abramson and her team are creating software that identifies patterns and signatures in building energy data that correspond with building characteristics and performance. "Without setting foot in a building, we can tell you how good your insulation is, how much lighting you are using, and if your heating or cooling system is sized incorrectly," Abramson explains.

Current energy audits are conducted by a cumbersome combination of multiple system tests and physical walkthroughs. Abramson and her team, including Roger French, the Kyocera Professor of Materials Science and Engineering, are looking to streamline the entire process using data already collected by smart meters installed in buildings. "With no disturbance to your operations, no extra costs in adding extra sensors, we can simply take your data and diagnose the problem," she says.

And the program can do more than just diagnose a drafty door or poor insulation. It can also incorporate weather data to predict a building's energy usage.

"For instance, we can predict the energy use patterns and total consumption in your building on a specific Monday, in January, based on the expected weather," Abramson says. "It's amazing how accurate predictions can be when they're developed from a significant amount of prior data."

That's the power of big data: gather enough information, and patterns begin to emerge.

In addition to predicting overall potential energy savings, by changing variables like the heating system, insulation or windows, building owners can also see how much energy—and money—they'll save by making certain changes and upgrades.

Abramson compares it to personalized medicine for buildings. "It's like when you go to the store to get a new appliance and you see that yellow sticker telling you how much money you'll save thanks to more efficient energy usage," she says. "That's an average—it's close, but it's not exact. What our software can provide is a more accurate snapshot of how much money you will save in your building by enacting specific changes." That kind of information will help building owners make the most informed and impactful choices when it comes to building energy upgrades.

Reality check

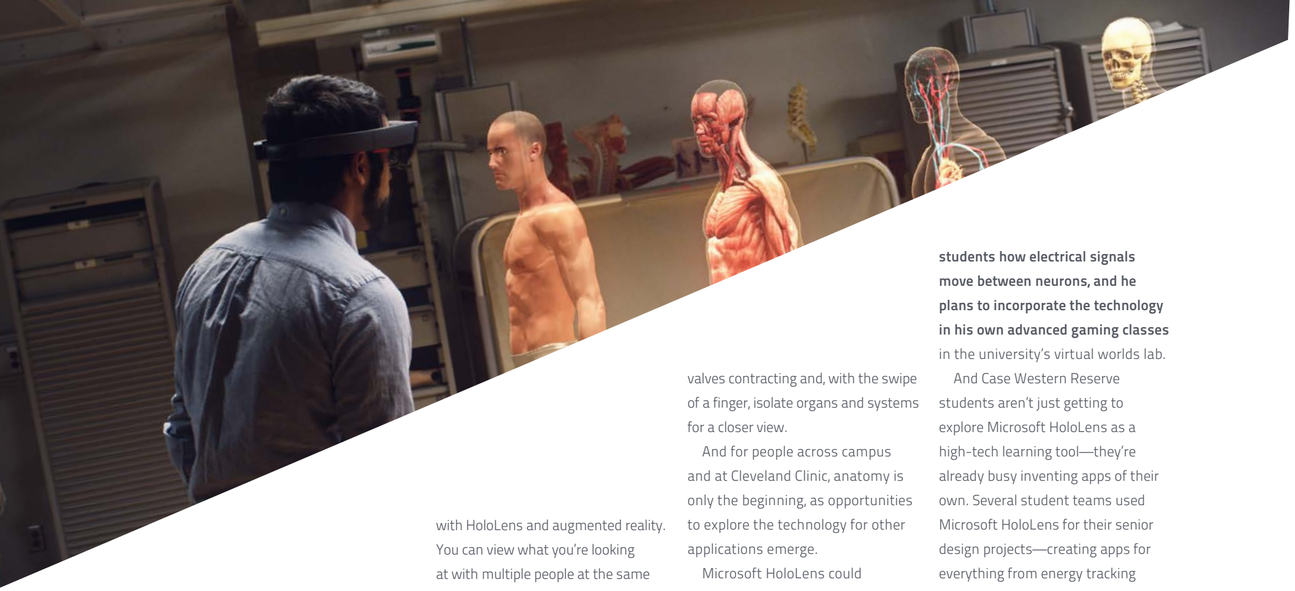
While energy researchers are using virtual information to create real changes in physical spaces, another set of scientists is introducing the university and the world to a piece of technology that's literally altering the reality you see with your own eyes.

With its sleek black headband and visor, Microsoft's HoloLens looks like a piece of virtual reality equipment. But unlike VR, when you put on a HoloLens headset, your reality stays visible. This piece of **augmented reality technology brings digital information into real space as holographic images, allowing users to see and interact with 3-D images—and other people—at the same time**.

That ability to collaborate over shared virtual information is what makes the technology so unique, according to Erin Henninger, executive director of the university's Interactive Commons. "Allowing people to visually connect with data changes their understanding of it and changes how they see the world," she says. "And when they can look at it together, it's a much more powerful interaction."

It's a different kind of experience than virtual reality, adds Mark Griswold, professor of radiology, biomedical engineering, electrical engineering and computer science, and physics, who serves as the faculty lead on the university's HoloLens initiatives. "People in virtual reality are totally immersed," he says. "That's not the way it is

Alexis Abramson, director of the Great Lakes Energy Institute and the Milton and Tamar Maltz Professor of Energy Innovation, is leading an ARPA-E project to create software that performs virtual energy audits.



Researchers at Case Western Reserve are developing Microsoft HoloLens applications for classroom use and research.

Right: Mark Griswold, professor of radiology, biomedical engineering, electrical engineering and computer science and physics, and Erin Henninger, executive director of the university's Interactive Commons, are leading university initiatives to visualize data.

with HoloLens and augmented reality. You can view what you're looking at with multiple people at the same time and totally engage together. And when you think about it from a teaching perspective, that's exactly what you want."

Microsoft forged a strategic partnership with Case Western Reserve and Cleveland Clinic last year to develop HoloLens for use in education, beginning with the teaching of anatomy to medical students. The HoloAnatomy app launched this year, giving the world its first peek at what a virtual anatomy lesson looks like: a holographic human body that students can walk around to track down a hard-to-spot pancreas, peer in to watch heart valves contracting and, with the swipe of a finger, isolate organs and systems for a closer view.

And for people across campus and at Cleveland Clinic, anatomy is only the beginning, as opportunities to explore the technology for other applications emerge.

Microsoft HoloLens could help engineering students grasp concepts that are tough to visualize when confined to a 2-D white board, says Marc Buchner, associate dean for academics and an associate professor of electrical engineering and computer science, who's using Microsoft HoloLens in his own research and lessons.

"Beyond understanding the math, students need to visualize what's happening, and we've not had the best tools to do that in the past," he says.

Buchner is working with a colleague in the biology department on a **HoloLens app that shows students how electrical signals move between neurons, and he plans to incorporate the technology in his own advanced gaming classes** in the university's virtual worlds lab.

And Case Western Reserve students aren't just getting to explore Microsoft HoloLens as a high-tech learning tool—they're already busy inventing apps of their own. Several student teams used Microsoft HoloLens for their senior design projects—creating apps for everything from energy tracking to virtual sheet music. (Read more about these apps on page 12.)

Weinhofer and his colleagues at Rockwell even see industrial applications for Microsoft HoloLens: to monitor system performance and diagnose trouble spots without necessarily having to disrupt—or even see—the physical machine.

The technology is so new, it's hard for its chief advocates and developers to articulate all the possibilities. "This is just the beginning," Griswold says. "We are at stage zero: think about how a 1985 cell phone compares to today's iPhone. That's where we're at in terms of potential for growth. This is not a small piece of cool technology—this is a completely new way of life."

That's the promise of the IoT: to continue and intensify the connectivity revolution that started in the early 1990s when the early internet changed the way the world learns, shops, does business and keeps in touch. Who knows exactly what our networked future will look like? This new world order is moving so fast, experts can't even agree on how fast it's growing: estimates for the number of networked devices in circulation by 2020 vary from 20 billion to 40 billion. But they can agree that a world in which the virtual and physical continue to grow closer is one of vast opportunities and challenges.)

> "This is just the beginning. We are at stage zero: think about how a 1985 cell phone compares to today's iPhone."
>
> MARK GRISWOLD

ALUMNUS, FORMER MICROSOFT COO SUPPORTS DATA SCIENCE STUDY

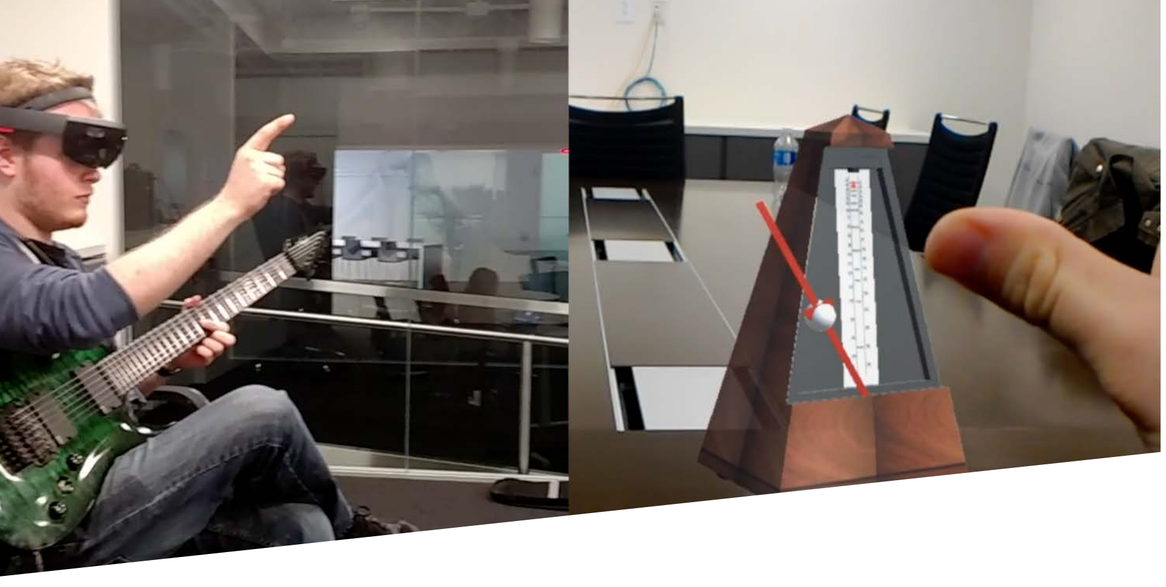
Big data is a big deal for businesses: by 2020, more than half of all business processes and systems will involve the Internet of Things, according to tech research firm Gartner. Moreover, security for IoT will comprise about 20 percent of organizations' total security costs—that's up from just 1 percent last year. This information overload translates into a pressing need for a specialized workforce equipped to handle this massive amount of data.

"This space is evolving fast, and one of the big bottlenecks is talent—skilled personnel," says Bob Herbold, former Microsoft COO and Case Western Reserve alumnus. Herbold made a $1.5-million pledge this year toward graduate student scholarships, a key component in the establishment of Case Western Reserve's Institute for Smart, Secure and Connected Systems (ISSACS) that will provide essential support for educating the exact kind of workforce a data-science-heavy future requires. "For any organization to take advantage of these IoT capabilities you need two things: the talent to actually do it, but maybe more importantly you need the leadership that acknowledges that these new capabilities exist and wants to embrace them. Both are important. From the standpoint of education, the focus I've had is enabling Case Western Reserve to be a leader in terms of qualifying these kinds of people."

The commitment builds on Herbold's 2014 gift that established an endowed professorship in data science and analytics at the university.

BEAR NECESSITIES

We all crave connection, and sometimes, those closest to us are just too far away. Student and entrepreneur Xyla Foxlin invented a way to send long-distance hugs via wirelessly connected teddy bears. A patent-pending sensor system detects when one bear is hugged and transmits those warm fuzzy feelings via haptic vibrations to its pair-bear anywhere in the world. The mechanical engineering major has been hitting the road promoting her startup, Parihug, garnering attention, top prizes and funding from CES, Disrupt NY, Her Startup Global—and bringing home the Reader's Choice Award in Tech.Co's Startup of the Year contest at South by Southwest. Her next step? Launching her crowdfunding campaign and expanding the product line beyond bears.
Learn more at engineering.case.edu/Parihug.



Augmented reality check: engineering students create virtual sheet music and more using Microsoft HoloLens

For most college seniors, graduation day can't come fast enough. But a group of engineering students at Case Western Reserve University would have preferred to slow down the clocks on their senior year to have more time to work with some seriously cutting-edge technology.

On the heels of Cleveland Clinic and Case Western Reserve University announcing their partnership with Microsoft to develop the company's augmented reality technology HoloLens into a teaching tool, **engineering students got to work directly with Microsoft HoloLens to create their senior design projects**. The results of mixing innovative young minds with radically disruptive technology: eureka-worthy apps that make it easier to play music, track energy usage and more.

One group of musically minded engineering students sought to eliminate the nuisance of constantly having to flip sheet music—they **developed a program that displays rolling virtual sheet music**, allowing the performer to follow along, hands-free, at a speed they control as they play. Another group created a **3-D rendering of campus that could capture energy-use data**—providing a real-time energy-usage snapshot to help inform sustainability initiatives. And another student is using HoloLens as a tool in cooperation with the university's psychology department to **help with cognitive behavioral therapy sessions**.

Learn more and watch the students' apps in action at engineering.case.edu/HoloLens-app-development.

Big data vs. disease: biomedical engineering researchers mine medical images for information to guide better cancer treatment

Since the moment the first X-ray gave the world a sneak-peek at the body's inner workings, medical images have become a vital tool in the clinical arsenal. Now, thanks to the advent of big data analytics, these images are becoming even more powerful in their ability to help scientists and physicians better diagnose and treat a variety of deadly diseases.

Biomedical engineering researchers at Case Western Reserve University's Center for Computational Imaging and Personalized Diagnostics (CCIPD) are developing a suite of high-tech tools and analytical techniques to mine the wealth of information contained in magnetic resonance images (MRIs) and put that data to work to make faster, more accurate diagnoses and predict the most successful treatment options.

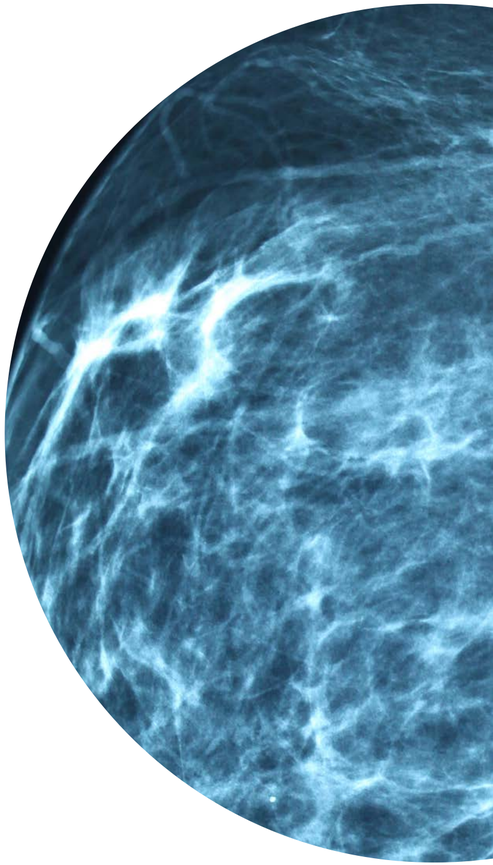
A research team led by Anant Madabhushi, center director and the F. Alex Nason Professor II of Biomedical Engineering, discovered **changes in textural patterns that turned up in the MRIs of breast cancer patients coincided with variations in gene expression that differentiated between aggressive and nonaggressive forms of the disease**. Their findings, published in *Nature Scientific Reports*, could lead to a cheaper, faster way to determine how aggressive a patient's cancer is that's just as accurate as current biopsy analyses, which could help clinicians predict which patients need chemotherapy and which could be successfully treated with hormone therapy alone.

Madabhushi also led another team that **developed a tool that aligns and fuses MRIs of the prostate before and after laser ablation treatment for cancer, allowing them to quantitatively evaluate the physical effects of the treatment**, which could better inform the risks and long-term outcomes associated with ablation, an increasingly common treatment for prostate cancer that serves as something of a middle-ground approach in low-risk cases between watchful waiting and radical actions like surgery and radiation.

And Satish Viswanath, a research assistant professor in biomedical engineering and CCIPD researcher, won a three-year **grant from the Department of Defense to develop a way to use data analytics to guide better treatment for rectal cancer**.

In addition, center researchers secured 10 U.S. patents to advance digital pathology technology.

Learn more about how big data is pushing better diagnoses at engineering.case.edu/centers/ccipd.



Case Western Reserve computer scientists and nursing researchers launched a collaborative project to develop an avatar-based, interactive software program to help families make end-of-life health care decisions.

Learn more at engineering.case.edu/avatar-software-nursing.

Introducing Gecko Hamaker

A new software tool developed by researchers at Case Western Reserve University gives the scientific community a **powerful, open-source tool capable of calculating the long-range intermolecular attractions between materials and using that data to predict how materials will assemble**.

The Gecko Hamaker program specifically evaluates a physical phenomenon called van der Waals forces, the attractive forces that pull molecules and materials together. Researchers can use the program to predict molecular organization and even evaluate whether new or not new combinations of materials will stick together—essential knowledge for chemists, physicists and materials scientists designing new nano- and meso-scale materials for use in molecular-level electronic, photonic and biological devices.

Learn more at engineering.case.edu/Gecko-Hamaker.

Data science degree launched

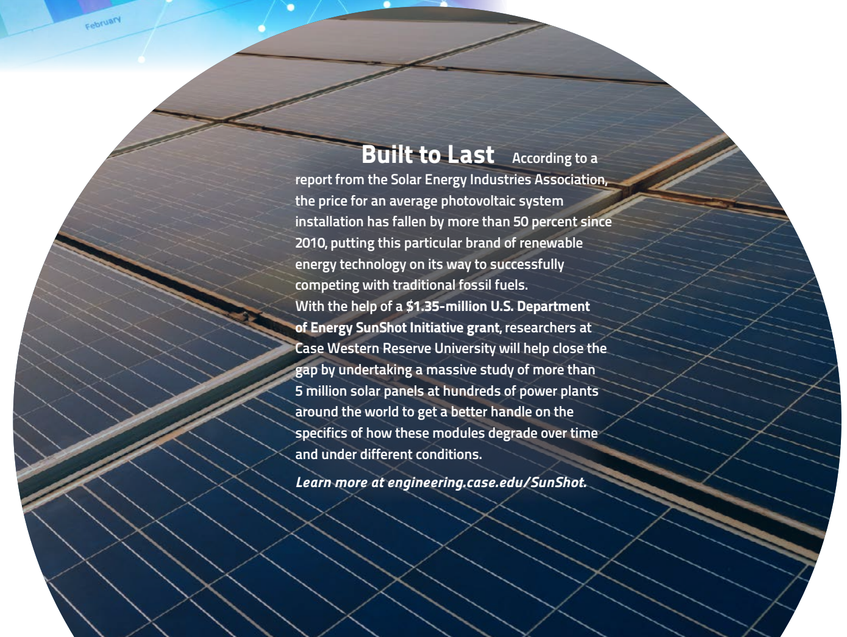
Case Western Reserve University officially launched **one of the country's few undergraduate Bachelor of Science degrees in data science and analytics** to help prepare students for careers in the new big-data-dominated world. According to reports, the United States alone will need to increase the number of its data-savvy grads by as much as 60 percent in the next five years to keep pace with industry demand for employees who can put big data to work. Housed in the engineering school, the new degree program expands on the success of the university's data science minor, which launched in 2013, and will focus on real-world applications and include a curriculum built around essential elements of this emerging field, including mathematical modeling, data analytics and visual analytics.

DIGITAL FIRM SPONSORS SUMMER TECH CAMP

Case Western Reserve University hosts a series of technology-based summer camps each year to give local third through 12th-grade students the chance to explore high-tech topics, from computer programming to robotics. This year, thanks to data company Vertical Knowledge, 20 Cleveland-area high school students were able to attend a coding-specific camp for free.

A special curriculum designed to familiarize the students with the programming language C# was developed in collaboration with Hyland Software.

In addition to the free camp sponsored by Vertical Knowledge, Case Western Reserve hosted eight other TECHie Camps in partnership with TECH CORPS for students in third through eighth grades.



Built to Last

According to a report from the Solar Energy Industries Association, the price for an average photovoltaic system installation has fallen by more than 50 percent since 2010, putting this particular brand of renewable energy technology on its way to successfully competing with traditional fossil fuels.

With the help of a **$1.35-million U.S. Department of Energy SunShot Initiative grant**, researchers at Case Western Reserve University will help close the gap by undertaking a massive study of more than 5 million solar panels at hundreds of power plants around the world to get a better handle on the specifics of how these modules degrade over time and under different conditions.

Learn more at engineering.case.edu/SunShot.

Sense4Baby capability in the new Apple Watch has roots at Case Western Reserve

Apple debuted a number of new technologies last fall, including the latest version of its Apple Watch, which includes a health monitoring capability that traces its roots to Case Western Reserve University. The device got its start in 2009 when Mehran Mehregany, the Veale Professor of Wireless Health Innovation, was on leave at the West Health Institute. Sense4Baby monitors fetal heart rate and contractions in pregnant women. The application, device development and the name were originated by Mehregany.

Learn more at engineering.case.edu/Mehregany-Sense4Baby.

fueling innovation

If innovation is to be the driver for solving modern society's complex problems, then systems are needed to teach, explore and nurture innovation and entrepreneurship. Case Western Reserve has dedicated itself to these pursuits—hosting a national summit and growing an ecosystem of innovation featuring Sears think[box] as the cornerstone.

Jeff Hoffman, co-founder of priceline.com, spoke at the university's innovation summit, encouraging innovators to think about the customer's needs first.

"We start with something cool we came across, and then we hope someone out there in the world wants it," said Jeff Hoffman, co-founder of priceline.com, describing the typical approach to innovation. "The best entrepreneurs start at the other end."

Gallup CEO Jim Clifton agreed. "If you follow innovation around, it has absolutely no value whatsoever until it has a customer standing next to it." Clifton additionally stressed the need for extreme determination and an ability to spot disruptions in order to be a successful entrepreneur.

Atari founder Nolan Bushnell went further, encouraging the use of crowdfunding as the litmus test for product profitability, and saying this ability is creating a "golden age" for innovators.

This advice came in keynote addresses during **Case Western Reserve University's inaugural Innovation Summit, which featured three days of exploring where and why innovation thrives.** The event, entitled "Models of Innovation," included a special spotlight on a new resource to support budding innovators: **the first phase of Case Western Reserve's Sears think[box]—one of the world's largest university-based innovation and entrepreneurship centers**.

Hosting an international exploration of innovation

"Our university has made a serious commitment to innovation and entrepreneurship," says Joe Jankowski, the university's chief innovation officer and co-chair of the summit. "On a local, national and international level, we want to be a resource for innovation and entrepreneurship and we want to collaborate with others on this topic."

And so, for three days in the fall of 2015, more than 500 attendees visited the Case Western Reserve campus to participate in the summit and explore the opportunities and challenges of various models of innovation at the global scale.

"We noticed that innovation was becoming too much of a buzzword," says Lisa Camp, associate dean of strategic initiatives at the Case School of Engineering and co-chair of the summit. "And that groups were trying to pigeonhole what innovation means—that there were separate flavors of innovation: energy innovation versus medical innovation versus innovations in manufacturing. We felt it was important to have a national summit to talk about innovation being a multidisciplinary, multifaceted endeavor, and one that is needs-based." And so, the idea for a summit percolated up from the engineering school, which provided strong leadership for the event.

Some of the minds behind Atari, Gallup, priceline.com, Samsung, Microsoft, *Make: Magazine*, America Makes, the Smithsonian, Goldman Sachs, the U.S. Department of Commerce and ARPA-E served as speakers and panelists guiding discussions around the processes and workflows that encourage innovation. A goal was to dissect approaches to innovation both by geographic region and by industry sector.

Those discussions helped drive at commonalities. "Collectively we realized that, at the end of the day, innovation is a way of improving and meeting the needs of a group, whether that is society as a whole or a specific population such as cancer patients," says Jankowski. An ability to iterate quickly and change direction appropriately when faced with challenges were markers of success that were noted to permeate all industries and geographies.

The summit also provided an opportunity to dive deeper into specific areas, with the second day

> **"We felt it was important to have a national summit to talk about innovation being a multidisciplinary, multifaceted endeavor, and one that is needs-based."**
>
> LISA CAMP

The innovation summit featured panels such as exploring innovation by sector opportunities, which included Marco Costa of University Hospitals, Jack Daly of Goldman Sachs, Chuck Fowler of Fairmount Santrol, Miko Charbonneau of Microsoft and Ellen Williams, director of ARPA-E.

> **We wanted a space where students from the Cleveland Institute of Art would mingle with our engineering and science students, along with law and management students, and community members, because that's a real-world team."**
>
> IAN CHARNAS

offering multiple breakout sessions on health consumer empowerment, the Internet of Things, additive manufacturing, finance models, intellectual property (IP), energy and more, allowing attendees to supplement big-picture ideas with real advice and tangibles they could readily implement.

In the realm of energy, Ellen Williams, director of ARPA-E, discussed innovations helping to move the field forward—from applying the Internet of Things to transportation, to advancing light-weight metals processing, to synchronizing pneumatic solar panels.

The summit's third day embraced the best way to ideate and iterate—by getting hands on—with opportunities such as a Shark-Tank-style "meet the market" product pitch session; a certificate-style workshop where participants developed product ideas while learning the trademarked Vertical Innovation process taught by internationally renowned industrial design and business firm Nottingham Spirk; and a tech-focused dive into new frontiers of medicine.

Concluding the event was a special Make Schools Alliance workshop that featured representation from the White House, with Office of Science Technology and Policy Director Tom Kalil video-conferencing in to kick off the session to help set national priorities to further develop the burgeoning maker movement in academic spaces.

A place to innovate: Sears think[box]

As a special spotlight during the summit, the doors were opened on the first phase of Case Western Reserve's innovation and entrepreneurship center, think[box]—unveiled as the Larry Sears and Sally Zlotnick Sears think[box] at the event in recognition of the Sears' support of the project (see "Funding Innovation" on page 21).

"Sears think[box] contains all the support systems needed to develop an idea all the way through to a startup business," says Malcolm Cooke, Sears think[box] executive director.

Sears think[box] occupies all seven floors of the Richey Mixon Building and follows the innovation process from ideation to incubation. The resource is open not just to Case Western Reserve faculty, staff and students, but also to the entire community at no cost beyond certain materials one may use.

"This is all about access," says Ian Charnas, Sears think[box] manager. In developing the space, Charnas says he and Cooke visited a number of universities that had various elements: prototyping equipment or space for ideating or legal or business support. But they were frequently not found together, and many resources were only available for certain departments or certain classes.

"We wanted a space where students from the Cleveland Institute of Art would mingle with our engineering and science students, along with law and management students, and community members, because that's a real-world team," says Charnas.

As such, the first floor will be a community space to teach innovation processes and house outreach programs. The second floor is dedicated to collaboration and idea generation. On the third floor are collections of high-end prototyping tools such as 3-D printers, laser cutters and printed circuit board routers for embedded electronics. The fourth floor provides space for larger fabricating machines for rugged prototyping using metals or very small production runs. On the fifth floor, project space is provided for student groups and senior projects, such as the Baja SAE team's off-road vehicle.

For projects that harbor commercial potential, the sixth floor will provide resources for business plan development, fundraising, intellectual property (IP) protection and other business mentorship. Set to move in are members of the law school's IP Venture Clinic, which provides professional advice on IP matters from law students under faculty supervision; CWRU LaunchNET, which helps train students in entrepreneurship; and the university's Technology Transfer Office, which helps commercialize research breakthroughs.

Finally, the seventh floor will provide incubator space for burgeoning startups to have office space, support and mentorship. Alumni keen to support students with startups will be able to keep office hours to provide advice useful to early-stage ventures.

Currently, floors two through five are open, with six and seven scheduled to open in the fall of 2017, and floor one to follow.

The seven-story innovation hub is a huge ramp-up from its more modest beginnings, which grew out of a desire to provide a space for engineering students to design and make things, initially for capstone design projects, which had previously been paper exercises only.

"We realized pretty quickly that this had a scope well beyond engineering and senior design," says Cooke. "We agreed that it should be a campus-wide resource for any student or researcher, to support their design and making activities. And we agreed that it should be freely open not only to all of campus, but to the whole community."

Alumni rallied around the idea and an initial 3,000-square-foot pilot space opened up in 2012, which quickly became one of the most-used spots on campus. It was expanded to 4,500 square feet in 2013, and then a 50,000-square-foot storage building on campus was identified as the future home for this innovator's paradise.

The idea of Sears think[box] being the center of an entire ecosystem of innovation has become a crucial differentiator for the space.

"We define innovation as solving a problem and coming up with solutions that meet a specific need," says Camp. "It's a very needs-based approach wrapped in creative processes." With that perspective, think[box] has become a university-wide resource that supports innovative thinking in relation to learning, research and

Lisa Camp, associate dean of strategic initiatives at the Case School of Engineering and co-chair of the innovation summit, developed an exploration of innovation by industry and by region.

Left, Sears think[box] offers budding innovators all the resources needed to take an idea through the commercialization process.

community engagement.

In the space of academics, Charnas cites research from the Center for Learning in Informal and Formal Environments that as much as 80 percent of learning happens outside the classroom. He notes that if students can apply, for instance, the differential equations they've just learned in an engineering class to a design project they are building with their own hands in think[box], that learning has a much greater chance of "sticking."

In the realm of research, Sears think[box] gives faculty members instant access to state-of-the-art equipment, without having to purchase or maintain it themselves.

A third goal is support for entrepreneurship. Charnas notes that more than 50 projects developed using the resources of think[box] and CWRU LaunchNet are now at some phase of commercialization. These projects have spurred dozens of jobs and patent applications, and have successfully raised more than $5 million of external funding for their startups.

Case in point: one student startup, Apollo Medical Devices—which invented a rapid blood test—applied to Sears think[box]'s Student Project Fund and received $2,500 to build a working prototype. With that in their hands to show to prospective investors instead of the more typical PowerPoint presentation, they were able to raise $900,000 of funding in nine months.

The university's role with innovation in the region

To be truly successful, a university's innovation ecosystem needs to create connections to the next stages of business development. As such, the university collaborates with entities like JumpStart and BioEnterprise, which serve as venture development organizations for the region.

Indeed, Sears think[box]'s goal for many of its startups is that they will grow too big for its walls.

"When it's time for your startup to do light manufacturing, and raise millions of dollars of investment capital to get off the ground, we're linked into the rich ecosystem of accelerators in Northeast Ohio who do a great job of supporting that," says Charnas.

JumpStart CEO Ray Leach agrees. "We're fortunate enough to be near one of the nation's finest universities and the connections we've made as a result have led directly to major success stories." One such example is CardioInsight—a Cleveland company that was acquired by medical technology giant Medtronic in a deal worth more than $90 million. The technology and team originated at the university, and JumpStart helped fund and support the startup.

"This is how it's supposed to work," says Leach. "Institutions like Case Western Reserve churn out innovative ideas and motivated entrepreneurs and entrepreneurial-support organizations like JumpStart help those entrepreneurs turn those ideas into successful businesses."

And that connection goes both ways. Companies already tapped into the Greater Cleveland business assistance channels know think[box] is a resource open to them. When Boxcast, a startup out of Akron that allows users to live broadcast their events, needed to develop its prototype, it turned to think[box] for 3-D printing and more.

Sears think[box] also serves as a resource for established companies in the region. "A lot of companies want student engagement, but not as a traditional co-op," says Cooke. "They want more flexibility and a wider interdisciplinarity."

Malcolm Cooke, Sears think[box] executive director, and Ian Charnas, think[box] manager, are helping develop an ecosystem of innovation that provides everyone with free access to all the support needed to take a concept from ideation to commercialization.

> **"We are trailblazers and many see us as the gold standard on how to set up ecosystems around innovation and entrepreneurship."**
>
> MALCOLM COOKE

To meet that need, think[box] ran a pilot in the summer of 2016, which employed eight students who were "subcontracted" out as teams to local companies based on skill sets aligning with company project needs. Six companies participated: Moen, Lincoln Electric, Lubrizol, MetroHealth Medical Center, Cuyahoga County and American Greetings. Each student worked on two or three projects primarily, but would also assist with other projects as needed.

Based on feedback from the companies and students, Cooke deemed the pilot successful and is looking to expand the program to run over the course of one or two semesters.

Replicating think[box]'s success

The Sears think[box] model has built a reputation for successfully encouraging and cultivating innovation. The State of Ohio granted think[box] $1 million, citing it as an economic driver for the region. During the Obama administration's first National Day of Making, the announcement cited three universities for their work in fostering innovation: MIT, Carnegie Mellon and Case Western Reserve. And Sears think[box]'s staff receives near-constant requests for consultation and has already worked with more than 100 institutions to develop their own innovation systems, from top-tier research universities to two-year colleges to high schools and *Fortune* 500 companies—everywhere from Nevada to Akron, India to New Zealand.

"We are trailblazers and many see us as the gold standard on how to set up ecosystems around innovation and entrepreneurship," says Cooke. "That's great feedback to know we have created something really special here." /

FUNDING INNOVATION

Think[box] got a new name in 2016: Sears think[box] or, more formally: the Larry Sears and Sally Zlotnick Sears think[box] at the Richey Mixon Building. Over the years, Larry Sears and Sally Zlotnick Sears have given $10 million to think[box], so the innovation center was fittingly renamed in their honor.

With the newest commitment, Larry, a 1969 alumnus of the engineering school, and Sally, a 1972 graduate of what was then the Flora Stone Mather College for Women (as well as a 1974 graduate of the School of Library Science) have become the largest individual donors to the Case School of Engineering in its history.

"Their visionary leadership [and] their longstanding engagement is truly extraordinary," President Barbara R. Snyder said. "They have made such a difference."

Additional important support for Sears think[box] includes:

- **The 50,000-square-foot structure, the Richey Mixon Building, which was renovated with the support of Joseph B. Richey II (CIT '62) and A. Malachi Mixon III.**
- **Floor 1, Community—the Nottingham Spirk Floor**
- **Floor 2, Collaboration—the Wyant Collaboration Floor, supported by James Wyant (CIT '65)**
- **Floor 3, Prototyping—the Prentke Romich Floor, supported by Barry Romich (CIT '67).**
- **Floor 4, Fabrication—The Lubrizol Foundation and Kent H. Smith and Kelvin Smith Fabrication Floor**
- **Floor 5, Project Space—the Eric T. Nord Project Space Floor, including the Reinberger Design Studio**
- **Floor 6, Entrepreneurship—the Cloud L. Cray Jr. and Sally Hunter Cray Center for Innovation and Entrepreneurship, including the Burton D. Morgan Suite for Entrepreneurship and the Mandato Family Innovator Office.**

#NATIONOFMAKERS

It's a fact—Adam Savage, former host of the popular TV series "Mythbusters," visited Case Western Reserve University's Larry Sears and Sally Zlotnick Sears think[box] this spring, with Cleveland serving as the first stop on a national tour of makerspaces. Organized with the White House Office of Science and Technology Policy, the visit was part of a national initiative to promote the maker movement as a driver of economic development. Participants live-tweeted throughout the day as they led Savage (seen here at right with Sears think[box] manager Ian Charnas) and other local stakeholders on a tour of Cleveland makerspaces and innovation hubs, propelling #NationofMakers to the top of the city's trending list on twitter by afternoon.

Check out highlights from the day at engineering.case.edu/Adam-Savage-visit-highlights.

High-tech detectives: Sears think[box] helps Cleveland Museum of Art match missing piece to ancient statue

A piece of 21st-century technology at Case Western Reserve University's Larry Sears and Sally Zlotnick Sears think[box] helped solve a 6th-century puzzle at the Cleveland Museum of Art.

Curators and conservators at the art museum had been trying to match a fragment to a stone statue of Krishna for decades, but the pieces never seemed to fit together correctly, leaving experts wondering if they were indeed part of the sculpture in Cleveland's collection or if they belonged to similar statues at a museum in their country of origin, Cambodia.

When additional historical documentation on the sculpture provided important clues as to how the fragment might fit on Cleveland's statue, the **museum turned to Sears think[box], which used 3-D imaging technology to scan the pieces and compare the fragments to the full sculpture in digital form, proving they did indeed match**. Full-scale prints made from the scan will aid conservators in reconstructing Krishna and reuniting the long-missing fragment: the crowning element of the sculpture.

Learn more about how 3-D scans proved a match between an ancient sculpture and its missing pieces at engineering.case.edu/thinkbox-CMA.

Case Western Reserve ranked among nation's top universities with a lasting impact on science

Case Western Reserve has built a proud reputation as a new-knowledge powerhouse, and statisticians agree, ranking the university among the country's top institutions with a lasting impact on science.

Researchers at Michigan State University and Duke University ranked their top 25 institutions in *Quartz*, an online business publication affiliated with *The Atlantic* magazine. They based their list on lasting contributions to society using a unique system that accounts for undergraduate alumni who have won the most prestigious academic awards—including Nobel Prizes, Fields Medals and Turing Awards—and those who have gained membership in the National Academies.

Case Western Reserve counts three Nobel laureates among its undergraduate alumni—Donald A. Glaser (CIT '41), Polykarp Kusch (CIT '31) and Paul C. Lauterbur (CIT '51, HON '00)—and a **Turing Prize winner** in Donald Knuth (CIT '60). **Twenty-eight undergraduate alumni have earned admission to the National Academies**.

An additional 13 graduate/professional school alumni and faculty have earned Nobel Prizes, and many others have been inducted to the National Academies.

The new industrial revolution: researchers tackle advanced manufacturing projects in lightweight and orthopedic materials and digital production

Advanced manufacturing has the potential to revolutionize the way products are made in the United States, and historical industrial powerhouses like Northeast Ohio are poised to lead in advancing new techniques and technologies. Case Western Reserve University researchers are collaborating on a number of projects across the nation to advance research in manufacturing innovation.

Within Lightweight Innovations for Tomorrow (LIFT)—part of the Obama administration's National Network for Manufacturing Innovation program, recently renamed Manufacturing USA—**university researchers are carrying out multiple validation experiments to ensure the reliability of aluminum-lithium alloys in critical applications, as well as methods to maintain the performance of aluminum silicon carbide composites while reducing costs**. Both projects have important ramifications for next-generation aerospace and automotive applications.

Materials researchers at the engineering school won more funding from America Makes, the National Additive Manufacturing Innovation Institute, to use additive manufacturing and experiment with powder reuse to find a more economical way to make orthopedic materials.

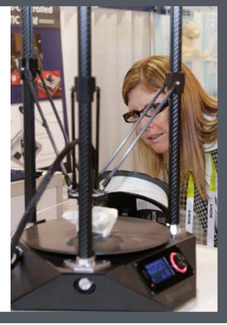
Case School of Engineering researchers continue to hold leadership positions within LIFT and America Makes, as well as a new representative on the Technical Advisory Committee within the Digital Manufacturing and Design Innovation Institute.

Clean water and commercialization NASA

Glenn Research Center scientists are teaming with students from the university's Fusion program to study a novel water-purification technology and how to commercialize it. Fusion is an interdisciplinary academic approach that groups law, management, science and engineering students into collaborative teams to learn about technology commercialization. ***Learn more at engineering.case.edu/NASA-Fusion.***

Showcasing innovation

More than 30 Case Western Reserve University students, staff and alumni shared their great ideas on one of the world's biggest stages in tech: CES, the Consumer Electronics Show, held annually in Las Vegas. This January marked the university's third consecutive trip to the show and boasted its biggest presence yet, packing 10 booths on the show floor with innovations like high-tech teddy bears that deliver digital hugs, rapid blood-testing technology and high-performance 3-D printers. Case School of Engineering **Dean Jeffrey L. Duerk also addressed show attendees**, discussing the impact of university-based makerspaces. ***Learn more at engineering.case.edu/CES-2016-announcement.***



A startup worth seeing

LYGENT, a startup company founded by Nicholas VanDillen as a Case Western Reserve biomedical engineering graduate student, is developing a new vision test for eye misalignment—and has won a grant from VentureWell to help move its product forward. ***Learn more at engineering.case.edu/LYGENT-VentureWell.***

Thomson Reuters named Case Western Reserve one of the world's top 100 most innovative schools.

Neurostimulation advancement

With the support of a $3-million Ohio Third Frontier Innovation Platform Program grant, Synapse Biomedical and the Institute for Functional Restoration at Case Western Reserve University are collaborating to commercialize the third generation of neurostimulation technology pioneered by biomedical engineering professor Hunter Peckham and his team at Case Western Reserve. **The fully implantable system uses neurostimulation to restore muscle function in patients with paralysis**.

LAUNCHING LAUNCHNET

The university's services to help students and alumni launch new companies received a new name in 2016.

NEOLaunchNET, a regional entrepreneurship education network powered by the Burton D. Morgan Foundation, includes four Northeast Ohio institutions of higher education—including Case Western Reserve University LaunchNET.

Since its 2012 launch, the student innovator support system—originally named Blackstone LaunchPad—has helped dozens of students with their entrepreneurial dreams.

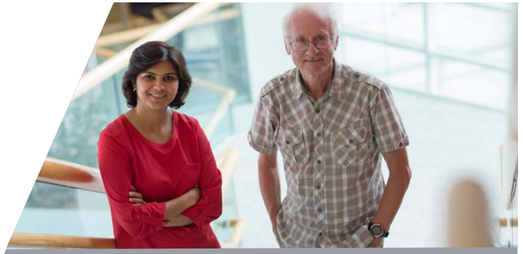
"It was CWRU LaunchNET who encouraged me to turn my research idea into a company, which made all the difference in moving my project forward," says student innovator-turned-CEO Felipe Gomez del Campo (see page 26). "I've used their resources extensively, they've provided me with office space on campus and introduced me to the Northeast Ohio entrepreneurial community."

For fellow student startup founder Xyla Foxlin (read more about her company on page 10), CWRU LaunchNET was equally valuable in her entrepreneurial journey. "LaunchNET makes it possible for students to dream big and deliver big. They helped my company get its big break at CES and they've provided so many ideas and connections."

Student innovator in *Forbes*

During his senior year, mechanical and aerospace student Felipe Gomez del Campo, who is also the CEO of his own startup, made national headlines: the innovator behind a plasma-injection device that promises to save on jet-fuel consumption was featured in the *Chicago Tribune* and made *Forbes* magazine's 30 Under 30 list celebrating the country's brightest young minds. Gomez del Campo spent the summer completing a successful test of the technology in collaboration with NASA Glenn Research Center, and began working toward his master's in aerospace engineering at Case Western Reserve.

Student startup Apollo Medical Devices won two first-place awards at innovation competitions Techweek Chicago and Jumpstart's "StartUp—ScaleUp," earning an additional $70,000 for the development of its blood testing system.



Biomedical translation

Two biomedical engineering faculty members secured funding from the state to help move their technologies from campus to the marketplace. Grants from both the Ohio Third Frontier Technology Validation and Start-Up Fund and the state Department of Education's I-Corps Ohio program will help with both testing and prototyping, as well as hands-on training in the commercialization process. Assistant professor **Pallavi Tiwari is leading the development of NeuroRadVision, imaging software that uses routine MRI scans to distinguish between a recurrent brain tumor and benign effects of radiation**, which is currently challenging to do. Associate professor **Miklos Gratzl is developing a low-cost, hand-held device to diagnose cystic fibrosis.**

Learn more at engineering.case.edu/BME-translational-funding.

Everykey starts shipping

Everykey, a startup launched by Case Western Reserve University alumnus Chris Wentz during his senior year, started shipping its signature product: a small Bluetooth device that stores and secures complex passwords to wirelessly access a whole host of digital devices, from phones to computers to online accounts. ***Learn more at engineering.case.edu/meet-our-innovators/everykey.***

As part of the second national Week of Making, the White House announced Case Western Reserve University's Sears think[box]'s commitment to launching a MOOC, or free massive open online course, entitled "Making, Manufacturing & Innovation: A New Economic Narrative" in 2017.

Startup boost

The **Ohio Third Frontier Commission awarded $50,000 each to four early-stage tech companies developed at the university**. Led by mechanical and aerospace engineering's Umut Gurkan, HemeChip is a device that provides rapid diagnosis of sickle cell disease and other hemoglobin disorders in newborns. Biomedical engineering's Niloy Bhadra is developing a removable device that uses electrical currents for pain control. SynthoPlate, artificial blood platelets that can reduce bleeding in instances of traumatic injury, is being developed by biomedical engineering's Anirban Sen Gupta. Electrical engineering's Philip Feng has developed self-powering wireless sensors that could turn conventional buildings into energy efficient "smart" buildings.

Learn more at engineering.case.edu/Ohio-Third-Frontier-2015-awards.

the brain frontier

Whether hyperactive or interrupted, brain activity is a bundle of secrets. Untangling the mysteries of the brain requires tapping deeper into our body's most complex organ.

> **"It's the whole body, and the interaction between the brain and the body."**
>
> ROBERTO FERNÁNDEZ GALÁN

Memories, thoughts, movements, feelings—they all originate in our brain. The multi-faceted headquarters of our body has remained one of science's most challenging frontiers to understand. With new recording and stimulating technologies, researchers at Case Western Reserve are tackling some of our most pressing questions about the brain, from how seizures affect the body as a whole to how brain waves propagate and how to rewire a brain that has been rendered silent by injury.

Roberto Fernández Galán, assistant professor of electrical engineering and computer science at Case Western Reserve, has found a surprising connection between epilepsy and the autonomic nervous system.

Epilepsy, the brain and the heart

Epilepsy's devastating effects on the brain have been well documented clinically. Seizures come recurrently, unprovoked, and can lead to severe cognitive dysfunction. SUDEP (Sudden Unexpected Death in Epilepsy) is the No. 1 cause of death in epilepsy patients. Now, **research is uncovering how epilepsy affects more than the brain; how, even in the absence of seizures, it impacts the autonomic nervous system—including critical heart activity**.

Roberto Fernández Galán, assistant professor of electrical engineering and computer science at Case Western Reserve University, has been exploring epilepsy's connection to the heart and how a more complete picture of the disease's toll on the brain and body as a whole might lead to the prevention of SUDEP.

Galán analyzed hospital records of pediatric patients under observation for epilepsy, which included recording brain activity and cardiac function. What he found was a surprising correlation: more than 60 percent of children with epilepsy had abnormally strong sinus arrhythmia—the process of the heart rate accelerating during inhalation and slowing down during exhalation, as well as a significantly lower heart rate during sleep and a longer diastole—the time during which the heart fills with blood. These three observed cardiac functions are controlled by the parasympathetic nervous system, the "rest-and digest" portion of the autonomic nervous system.

Especially surprising was Galán's finding that some children under evaluation had an overly pronounced parasympathetic tone in the absence of seizures; yet they developed seizures and received an epilepsy diagnosis in the future—**suggesting that changes in parasympathetic tone may be an early indicator of epilepsy**, even before the condition has caused any notable brain abnormalities.

"It's not just the brain," says Galán. "It's the whole body, and the interaction between the brain and the body."

Understanding the link between enhanced parasympathetic tone and epilepsy could be a key to better understanding—and preventing—SUDEP. After the exhaustion of a seizure, an epileptic patient's heart rate tends to go down. So if the patient already has a low baseline heart rate due to an overly active parasympathetic nervous system, their heart is at risk of slipping down to a rate that can't support the body.

"If your baseline heart rate is too low, you'll be at a much higher risk for SUDEP," says Galán. "We may be pointing to the mechanisms for SUDEP," the cause of which is not currently known.

Sitting at the stem of the brain is the vagus nerve, which controls the entire autonomic nervous system—including parasympathetic tone. The more active the vagus nerve, the lower your heart rate, the stronger your sinus arrhythmia and the longer your diastole. So a hyperactive vagus nerve, Galán suspects, could be a precursor to epileptic seizures.

Galán is looking at ways to monitor this part of the brain to document any connection between a hyperactive vagus nerve, increased parasympathetic tone and epilepsy, which could open a pathway to new treatments for epilepsy.

Dominique Durand, the Elmer Lincoln Lindseth Professor in Biomedical Engineering at Case Western Reserve, has discovered a new way brain waves propagate and an electrically silent source of interictal spikes in epilepsy.

Interestingly, one therapeutic approach sometimes employed in the treatment of epilepsy has been to stimulate the vagus nerve in order to perform a cerebral "system reset" in an attempt to diminish seizures. But this could also encourage the vagus nerve to push parasympathetic tone to dangerously low levels—putting patients at risk of SUDEP.

Galán wants to review drugs currently available to manipulate the autonomic nervous system as a way to prevent SUDEP and even prevent seizures. He's also working to **develop a wearable device to non-invasively monitor the heart rates of epileptic children in order to signal when heart rate sinks too low**.

Brain wave propagation

If epilepsy does begin with hyperactivity in the vagus nerve, how does the condition also create seizures in other parts of the brain? To understand this, other mysteries of the brain need to be unraveled, including how electrical signals in epilepsy propagate.

One of the hallmarks of epilepsy are interictal spikes—single electrical spikes observed in the brain in between seizures. Dominique Durand, the Elmer Lincoln Lindseth Professor in Biomedical Engineering at Case Western Reserve, looked to monitor those spikes to understand how they move across the brain, how fast they move and where they originate.

With funding from the National Institute of Neurological Disorders and using a microelectrode array developed in conjunction with NASA, Durand was able to clock the electrical spikes at speeds of about 0.1 meters per second, which is quite fast, but not as fast as the speed of synaptic transmission—one of the most common forms of brain circuit communication. Nor could they be using diffusion, another way brain waves travel, which moves at speeds 100 to 1,000 times slower. To confirm, Durand blocked these methods in the lab, along with the final known way brain waves propagate—gap junction—and found the interictal spikes still propagating.

In ruling out all three known methods of propagation, **Durand realized he had discovered a new way that brain waves spread**—raising the question of what the unknown method was.

Electrical fields are known to exist in the brain and to affect neighboring cells, but they'd never been shown to transport information. Durand took a closer look at these fields to see if they could in fact be a channel of transmission.

Through computer simulations, he modeled large numbers of brain cells and eliminated all known possible connections between them, only allowing communication through electrical fields. He found that neurons could indeed transmit a message to their neighboring cells via the electrical field, and also recruit their neighbors to continue disseminating the message through a process called volume conduction. The model confirmed that the signals would propagate at the speed Durand had observed in vivo. Adjustments for space between neurons and field size confirmed that the **brain spikes were indeed propagating via electric fields**.

"This is an important finding," says Durand. "We've discovered a new way that neural signals can propagate. And it's quite exciting because it means there is a mechanism by which parts of the brain can be synchronized without any other mechanism than being next to another area of the brain."

Durand next turned to investigating how the spikes begin in the first place. Using isochrome maps that recorded the time of arrival of the spikes at certain sites, **he was able to track back to the likely source in the brain—yet that location didn't have any recordable electrical activity. It looked silent—and it also looked like the source itself was moving**, albeit at speeds slower than the faster-moving spikes it was generating.

> **"This is an important finding. We've discovered a new way that neural signals can propagate. And it's quite exciting because it means there is a mechanism by which parts of the brain can be synchronized without any other mechanism than being next to another area of the brain."**
>
> DOMINIQUE DURAND

This was surprising because the focus of epileptic seizures had been thought to be fixed.

"Imagine a car putting out flashes of light as it drives," says Durand. This is what the interictal spike source seems to be doing across the brain. Using Doppler effect equations, Durand gathered more evidence that the source itself is moving—and moving silently.

The moving, electrically "silent" source raises as many new questions as it answers about epilepsy and the brain.

"We don't really know much of anything about the brain," Durand muses. "I've been working on a small, two-by-three millimeter portion of the hippocampus for the last 30 years and I'm still making discoveries. We're just beginning to map what's going on, and not yet fully understand it."

From observation to action: rewiring the brain to restore movement

Recording the brain to decode disease is just one application of advancements in brain monitoring and electrical arrays. In instances of healthy brains that have been silenced by injury to or disease in the spinal cord, brain recordings can translate into a powerful therapy.

Pairing a brain recording system with electrical implants for muscle stimulation, a **team at Case Western Reserve has bridged over a paralyzed patient's injured spinal cord to reconnect his brain to his muscles, allowing him to move his hand and arm once again**.

The medical first is an important milestone on a journey that began decades earlier in two areas: functional electrical stimulation (FES) and brain-computer interface (BCI).

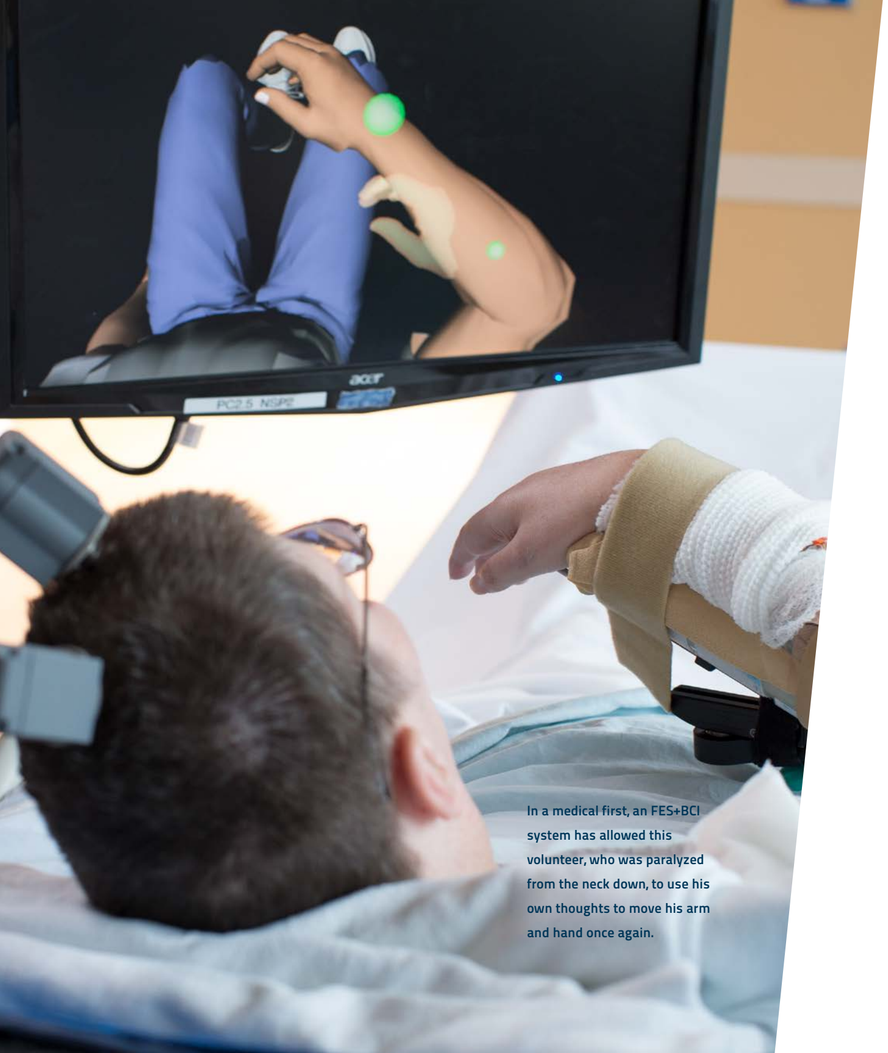
FES technology was pioneered at Case Western Reserve by biomedical engineering professors Thomas Mortimer, and furthered by Hunter Peckham in the 1990s. In instances of spinal injury, devices are implanted in muscles to apply small electrical currents, which cause contractions and allow limbs to move once again.

Intracortical BCI technology was first demonstrated in non-human models in the late 1960s, showcasing that recorded brain signals could be used to control movement. In 1998, the first human-implanted BCI was used by a paralyzed man to play a computer game and, in 2012, a BCI allowed a paralyzed woman to move a robotic arm using just her thoughts.

Bringing these two proven technologies, FES and BCI, together to restore natural arm and hand function is the core focus of the Case Western Reserve site for BrainGate2, an interdisciplinary research group composed of colleagues at Brown, Massachusetts General Hospital, Stanford and the Department of Veterans Affairs, with an overarching goal of developing technologies to restore the communication, mobility and independence of people with neurologic disease or injury.

Before the most recent trials, patients with spinal cord injury receiving FES devices would need to recreate movement cues using artificial signals, such as shrugging a shoulder to open and close one's hand. BrainGate2 seeks to use BCIs to link up the interrupted brain signals with implanted FES devices in the muscle to return movement simply by thinking so.

A first patient was found at the Louis Stokes Cleveland VA Medical Center. In 2006, the Ohio man was participating in a 150-mile bicycle



In a medical first, an FES+BCI system has allowed this volunteer, who was paralyzed from the neck down, to use his own thoughts to move his arm and hand once again.

Right, Robert Kirsch, chair of the Department of Biomedical Engineering at the university and director of the Cleveland FES Center, and A. Bolu Ajiboye, assistant professor of biomedical engineering, are combining FES and BCI technology to restore movement to paralyzed individuals.

> **"We are currently where the computer was in 1980. Look how far computing has come since then. Our understanding of the brain in the next 20, 30, 40 years will be astronomical."**
>
> A. BOLU AJIBOYE

ride for charity when he collided with a truck. Injuring his cervical spine, he could no longer move his body below the neck. Keen to participate in the new research, he volunteered to be the first to undergo the joint BCI+FES system.

"It was exciting to be the first to try this," says the patient. "Someone has to go first, otherwise research would never get done."

In December of 2014, he underwent surgery to receive two recording silicon electrodes, each just 4 by 4 millimeters, placed in his primary motor cortex. The multichannel arrays penetrate a millimeter into his brain, just below the skull, and record from hundreds of neurons. The arrays' wires emerge from his skull and link to a port, which can be plugged into a computer to record and interpret the signals.

Over the next six months, a team from Case Western Reserve, led by Robert Kirsch, chair of the Department of Biomedical Engineering at the university and director of the Cleveland FES Center, worked with the volunteer, recording his brain signals and teaching him to control a virtual arm on a computer screen. Then, in April 2015, 16 FES electrodes were implanted percutaneously in the patient's right shoulder, arm and hand muscles. The next week, for the first time in eight years, he moved his hand and elbow.

Since then, the volunteer has worked with the research team to improve his control. He's now able to command simple movements of his wrist, elbow and shoulder in multiple directions, grasp with his hand, and combine these to perform functional and meaningful activities, such as taking a drink from a cup.

"It's just amazing," says the patient volunteer. "Every time I move my arm, I'm still so amazed that I can." At first, he says he had to think about each individual movement specifically—breaking down a fluid motion into a dozen individual components. With time, he's been able to think about solely the end goal, though he admits it's not the simple process it was prior to his injury.

"It's our first pass, so the degrees of freedom are limited," says A. Bolu Ajiboye, assistant professor of biomedical engineering and a member of the Case Western Reserve BrainGate team. "He can make multiple movements at the same time. He won't be able to play the piano, though that's not our goal. It's to restore functional activity, so he can pick up a cup and drink from a straw, grasp items and the like."

The current fine-wire intramuscular implant of the FES system, while minimizing risk of infection, has limitations in muscle selectivity and in the proportion of a muscle that is activated compared to more fully implanted versions—but it serves as a fully reversible proof-of-concept of the FES+BCI system. In future iterations, the research team hopes to utilize a more sensitive and effective FES system.

Another next step is to make the technology wireless, so patients won't have to plug in to record brain signals. Ajiboye is working on a multi-institutional NIH grant led by Brown University to develop a 24/7 wireless recording system. There are hurdles to overcome, such as maintaining the quality of the signal within the reduced bandwidth of wireless technology.

Challenges aside, the life-changing advances of this technology are incredible. "We're definitely in a golden era of neural engineering now," says Kirsch. "We better understand the fundamentals, and now it's a matter of applying them appropriately to these disorders. There's so much untapped potential with recording and stimulating the brain."

Ajiboye likens the next decade or two in brain research to the rise of the computer. "We are currently where the computer was in 1980. Look how far computing has come since then. Our understanding of the brain in the next 20, 30, 40 years will be astronomical." +

THE POWER OF TOUCH

When Igor Spetic lost his right hand in an industrial accident six years ago, he also lost part of his ability to interact with the world around him. With the help of $15.9 million in funding from DARPA, researchers at Case Western Reserve and the Louis Stokes Cleveland Veterans Administration Hospital have developed an advanced prosthetics system that actually restores some of that lost sense of touch, allowing him to distinguish between some 19 different sensations via a collection of pressure sensors tapped into the residual nerves in his upper arm. *MIT Technology Review* heralded the project, led by Kent H. Smith II Professor of Biomedical Engineering Dustin Tyler, as one of the best biomedical stories of 2015, and the work made national headlines with features in *TIME* and the *New Yorker*.

Breathing easier: Case Western Reserve researchers team up with NASA and fire departments to protect firefighters

Fire consumes everything in its path, and it kicks up dangerous chemicals and particulates as it burns, releasing them into the air and putting firefighters at risk even after the flames have been extinguished.

Researchers from Case Western Reserve University have teamed up with scientists at NASA Glenn Research Center and fire departments across the country to **design and test special sensors aimed at protecting firefighters from these airborne toxic substances**.

A self-contained breathing apparatus and a carbon monoxide detector come standard in modern firefighting equipment. Once carbon monoxide readings are clear, firefighters often remove the gear during the cleanup phase that follows a fire knockdown. But since carbon monoxide isn't the only danger in the air, they could be exposing themselves to a variety of particulates that could lead to respiratory problems.

Fumiaki Takahashi, professor of mechanical and aerospace engineering, is leading a team of researchers designing sensors that will detect other substances like formaldehyde and acrolein that can be released during structural and forest fires. They will build on sensor technology NASA uses to detect fires aboard the International Space Station with the help of a $1.5-million Assistance to Firefighters/Fire Prevention and Safety Grant from the Department of Homeland Security.

Learn more about how high-tech sensors can help protect firefighters at engineering.case.edu/firefighter-sensors.

Battling sickle cells: researchers win NIH grant to study cellular adhesion

Healthy blood vessels run like a well-maintained highway—blood cells zip along throughout the body unimpeded, delivering vital oxygen and nutrients to our tissues. But in sickle cell disease, an abnormal type of hemoglobin causes usually disc-shaped red blood cells to change shape into sickles, which become sticky and block the flow of blood vessel traffic, creating dangerous complications in the body. The disease impacts some 3 million people around the world and has no cure.

Researchers at Case Western Reserve University have received a **$2 million R01 grant from the National Institutes of Health to take a closer look at how those misshapen cells stick together in blood vessels to see if adhesion properties might indicate effectiveness of treatment**.

Umut Gurkan, assistant professor of mechanical and aerospace engineering, is serving as the project's principal investigator, along with Jane Little, an associate professor of medicine at the Case Western Reserve School of Medicine.

The research team hopes to gain a better understanding of the abnormal adhesion events that take place in sickle cell disease and aims to use adhesion levels as a means to measure the progress of treatment.

Early detection tool: Biomedical engineering researchers develop MRI contrast agent that detects tumors at the smallest level

Ninety-nine percent. That's the five-year survival rate for breast cancer patients if the cancer is caught before the tumor spreads. Once cancer cells metastasize, however, that number drops rapidly, which means early detection saves lives.

Biomedical engineering researchers at Case Western Reserve University have **created a new contrast agent that lets clinicians use MRI to spot tumors with metastatic potential at unprecedentedly small sizes**—as tiny as just a few hundred cells—allowing for faster detection, diagnosis and treatment.

The small peptide gadolinium-based MRI contrast agent developed by Zheng-Rong Lu, the M. Frank Rudy and Margaret Domiter Rudy Professor of Biomedical Engineering, and his team binds to molecular markers that are expressed in aggressive tumors, particularly the ones on the verge of metastasizing. Once adhered to the contrast agent, these markers then pop up on the MRI, allowing clinicians to detect the burgeoning tumor itself and gauge its aggressiveness.

Lu and his team hope to begin clinical trials within three years and are also refining the agent to make it more tumor-specific, tweaking the technology to detect prostate cancer as well.

Learn more about how a new contrast agent could help detect tumors at the earliest stages at engineering.case.edu/Lu-contrast-agent.

Plant viruses vs. cancer

In the typical health care story, viruses usually play the villain. But a biomedical engineering researcher at Case Western Reserve University is flipping the script and turning plant viruses into powerful weapons in the fight against human cancers.

Nicole Steinmetz, associate professor of biomedical engineering, has made a career out of manipulating plant virus nanoparticles and pitting them against human diseases. This year, she won more than $3 million in federal and foundation funding to advance two specific projects. In the first, funded by the NIH's National Institute of Biomedical Imaging and Bioengineering and National Cancer Institute, Steinmetz and her team are **using tobacco mosaic virus to deliver a contrast agent—also developed by her lab—designed to track two particular biomarkers that distinguish between aggressive and slow-growing prostate cancer**. In a second, American Cancer Society-funded project, Steinmetz is **using a potato virus to deliver chemotherapy drugs to combat triple-negative breast cancer**.

Working in collaboration with researchers at Dartmouth University, Steinmetz also discovered that cowpea-virus-based nanoparticles trigger the body's immune system to fight off cancer cells when injected into tumors. The work was published in *Nature Nanotechnology*.

Learn more at engineering.case.edu/Steinmetz-research-cancer.

Zooming in on charge distribution

Researchers at Yeshiva University and Case Western Reserve University are taking a nanoscopic look at charge distribution on the surface of nanoparticles. With the help of a grant from the **National Science Foundation, they are developing the first instrument capable of measuring these tiny charges under water**. Nanocharge distribution is the primary driving force in a wide range of self-assembling systems, from cancer-targeted nanotherapeutics to the construction of natural extracellular matrices. Better understanding of these forces will lead to advances in biology, materials science and engineering, and improved medical treatment.

INTERNATIONAL SUPPORT FOR BIOMEDICAL ENGINEERING

Alumnus and international health care technology entrepreneur Qiang "Al" Zhang (GRS '00, biomedical engineering) made an inaugural gift to his alma mater this year, offering crucial support to the next generation of biomedical engineering innovators.

Zhang, who earned his PhD in biomedical engineering from Case Western Reserve in 2000, is co-president of United Imaging Healthcare, a Shanghai-based company that provides innovative medical solutions, including diagnostic imaging devices, radiation therapy equipment, training and medical IT solutions.

In addition to providing valuable financial support to the department with his commitment this year, Zhang is also leading the expanding global alumni network in Shanghai and serves as an ambassador for the Case School of Engineering for new graduates as well as current and prospective students.

Biomedical engineering professor Eben Alsberg received two new NIH R01 grants totaling $4M to use stem cells, biomaterials and bioactive factor delivery to bioengineer better replacement cartilage.

Tech-assisted athletes head to Cybathlon

A paralyzed athlete using assistive technology developed by researchers at Case Western Reserve University and the Louis Stokes Cleveland VA Medical Center—with additional sponsorship support from University Hospitals Cleveland Medical Center and MetroHealth Medical Center—competed in the first-ever Cybathlon in Switzerland—and won a gold medal! *Learn more at engineering.case.edu/Cybathlon.*

Detecting unsafe meds

Researchers at Case Western Reserve are developing a **low-cost, portable device that can root out tainted medication and dietary supplements.** Soumyajit Mandal, an assistant professor of electrical engineering and computer science, and his team, including colleagues at the University of Florida, were inspired to take on the project after the United Nations Human Rights Council adopted a resolution to improve access to safe, effective and high-quality medications.

According to the researchers, the product could be used by consumers at home to check the contents of their medication or by security officers at customs checkpoints and post offices. The work is being supported by a four-year, $1M grant from the NSF.

Learn more at engineering.case.edu/medication-safety-analysis.

Researchers have won a $2.8M NIH grant to build a stealthy drug-delivery system that essentially smuggles the medication across the blood-brain barrier to attack tumors directly.
Learn more at engineering.case.edu/stealth-brain-tumor-treatment.

Super-sensitive cancer detector

A team of engineers and physicists from Case Western Reserve University has developed an **optical biosensor that's 1 million times more sensitive** than currently available technology that can detect a single molecule of an enzyme produced by cancer cells. *Learn more at engineering.case.edu/sensitive-biosensor.*

Biomedical engineering researchers at Case Western Reserve have developed a non-viral, nanoparticle-based gene delivery system to treat inherited retinal diseases by replacing faulty genes with healthy ones.

New diagnostic technologies

Funding from NIH's National Center for Accelerated Innovation can help speed the diagnoses of two serious diseases. Miklos Gratzl, associate professor of biomedical engineering, is developing a **test to diagnose cystic fibrosis in infants** as early as two weeks of age. Umut Gurkan, assistant professor of mechanical and aerospace engineering, is testing his HemeChip technology, a **mobile device that can rapidly—and at a low cost—detect a number of blood disorders**, including sickle cell disease.

Researchers root out BPA

Drink up! An international team of researchers, including scientists at Case Western Reserve University, has developed a **molecular-level test for minute amounts of Bisphenol A**—or BPA—a nearly ubiquitous industrial chemical used in many plastics and resins that's been linked to some alarming health consequences. The team hopes their technique could be used as a basis for developing sensor devices to monitor BPA levels in water.

Creating clot-busters

The body's ability to heal hinges on blood clotting, but a rogue clot in the wrong place can trigger a deadly event like a heart attack or stroke. Anirban Sen Gupta, associate professor of biomedical engineering, and his team won a **$1.9-million NIH grant to turn artificial platelets originally designed to form clots into clot-busting drug delivery tools** that can lock onto and destroy dangerous clots. The work builds on Sen Gupta's ongoing efforts to refine his synthetic platelet technology called SynthoPlate. Sen Gupta was awarded two patents this year for his synthetic platelet technology, as well as additional funding from NIH-NCAI, the Ohio Third Frontier Commission and the Case-Coulter Translational Research Partnership in support of the work. *Learn more at engineering.case.edu/platelet-clot-busters.*

the energy puzzle

Advances are happening all over the energy map—from building wind farms, to improving the reliability and affordability of solar energy, to developing sun-powered cars, and to making the grid smarter. Researchers at Case Western Reserve are taking a system-wide approach to advance these critical components and explore how to best fit them together in the bigger energy picture.

Marija Prica, assistant professor of electrical engineering and computer science, is working on a DOE project to make photovoltaic technology more affordable and reliable.

Any chef knows you need two things to make an excellent meal: high-quality ingredients and a solid recipe. Concentrate solely on one or the other and you'll miss a chance to make the best meal.

Revolutionizing our approach to energy requires a similar strategy, according to Alexis Abramson, director of Case Western Reserve's Great Lakes Energy Institute and the Milton and Tamar Maltz Professor of Energy Innovation. The world needs better renewable technology and advances in storage and distribution, but just finding all the pieces won't solve the puzzle. "We need to look at the whole picture together to optimize the system: the hardware, the software, renewables, controls. It's a whole new paradigm in terms of energy," she says.

So Abramson and other energy researchers at Case Western Reserve are waging a two-front campaign on energy challenges: teaming up to improve components while simultaneously exploring how to fit those pieces together to create a more optimized whole.

Shine on

Thinking about the system as a whole has revealed that it's not as simple as just plugging a wind turbine or solar panel into the grid for instant-renewable energy. When it comes to power generation, these natural sources like solar and wind are introducing an unprecedented level of variability into the system. Unlike traditional power plants, these nature-based generators are intermittent, which has presented challenges when trying to incorporate them into the existing main power grid. For instance, the sun is probably the most powerful energy source we'll ever find, at least in our corner of the universe. According to the Department of Energy, the amount of sunlight that strikes the Earth's surface in an hour and a half is enough to handle the whole world's energy consumption for an entire year. But the sun doesn't shine everywhere all the time at the same intensity.

"Solar may be renewable, but it's intermittent," says Marija Prica, assistant professor of electrical engineering and computer science at Case Western Reserve. "You have to have something else with solar to keep generation controllable and dispatchable."

Prica, along with a research team made up of scientists, corporate partners and utility companies, is working on that "something else" as **part of a $6.3-million Department of Energy (DOE) project aimed to make photovoltaic—or PV—technology more affordable and reliable**.

Led by a consortium of utilities called the Electric Power Research Institute (EPRI) and part of the DOE's Sustainable and Holistic Integration of Energy Storage and Solar PV—or SHINES—program, the project will take a deep dive into energy storage and the integration of solar photovoltaics into the grid.

The missing piece Prica and her partners hope to provide is a **high-tech control system that can mitigate some of the wild variability of PV-generated power without pushing costs** higher than 14 cents

> **"You have to have something else with solar to keep generation controllable and dispatchable."**
>
> MARIJA PRICA

per kilowatt hour so it remains cost-competitive with traditionally generated power.

Prica says people tend to underestimate just how variable solar PV generation can be—a passing cloud or cast shadow can lead to drastic shifts in power generated from minute to minute, making it nearly impossible to create an affordable energy system that relies on solar PV alone. "In any power system, you can achieve whatever you want, but the problem is cost: how much will it cost you to do that," Prica says. "Think of it like a non-standard fixture in your home. Anything non-standard is usually more expensive—variability adds costs."

But for solar power, variability is part of the package. "You can't control PV—you get what the sun is giving you," Prica says. But what researchers can do is add energy storage capabilities that PV can feed into, which can collect, hold and distribute solar-generated power as needed to smooth out spikes in generation.

Prica and her team—which includes Kenneth Loparo, chair of the university's Department of Electrical Engineering and Computer Science and Nord Professor of Engineering, Richard Kolacinski and Mingguo Hong, associate professors of electrical engineering and computer science—are developing the actual software and algorithms that will make up two separate controllers: a local control that communicates directly between the PV cells and storage units and a master control that monitors and orchestrates the entire system.

And they're doing more than designing the software—working with Cleveland's electricity company FirstEnergy and a collection of private energy companies including MCCo, Eaton, GE's Grid Solutions and LG Chem, they'll be using Case Western Reserve's campus as a testing ground for what they've built.

The team will add solar panels and energy storage into the building that houses the university's social work academic program, the Jack, Joseph and Morton Mandel School of Applied Social Sciences—50 kilowatts of PV generation paired with 50 kilowatts/200 kilowatt-hours of storage—which they will use to test their control system in a real environment.

A smarter charge

Harnessing the sun's rays can make a big impact not just on the power delivered to our homes and businesses; it can also radically change how we drive.

Consumers depend on vehicles to go hundreds of miles without stopping to refuel. The call of the open road is part of car culture, and it's part of why many consumers shy away from electric vehicles (EVs)—which, depending on driving speed, make and model, might only be able to travel 40 or 50 miles between charges.

But what if you didn't need to stop to recharge? A researcher at Case Western Reserve is **testing a new type of solar cell coupled with a lithium-ion battery that could pave the way for solar-powered EVs that charge up on the road, no pit stops required**.

There's no shortage of barriers to the mass adoption of electric vehicles, says Liming Dai, the Kent Hale Smith Professor of macromolecular science and engineering. "First, the energy density isn't high enough, so even on a full charge, you can't drive as far," he says. Second, he adds, our whole system is set up to support gas-powered vehicles. "Even if you had batteries with a high enough energy density for auto applications, you've got a system of gas stations, not electrical charging stations," he says. "So a continuous charge could help solve these issues."

To provide that non-stop energy source, Dai is looking for the right balance between energy density and power density—a Goldilocks-style system with enough oomph to drive up a hill in a Midwestern winter and enough endurance to drive distances competitive with traditional-fuel vehicles. And all for a cost that's affordable for everyday drivers.

Liming Dai, the Kent Hale Smith Professor of macromolecular science and engineering, is using perovskite solar cells to better charge electric vehicle batteries.

He and his research team built a system of solar cells hooked to a battery—but not just any solar cell and not just any battery. They used perovskite cells—a newer type of PV technology that meets somewhere in the middle between the superior efficiency of silicon cells and the lower-cost benefits of polymer cells. **By wiring the perovskite cells in a series of four to pump up the voltage, the researchers were able to directly charge a lithium-ion battery with a level of efficiency that outperformed other reported attempts** at photo-charging an energy storage device, from lithium-ion batteries to flow batteries to super-capacitors.

It's a promising first step that could eventually lead to a system of on-board solar panels that pull power on sunny days matched with a battery to store and distribute that energy even when the sun isn't shining.

Looking offshore

An optimized energy system would be able to incorporate multiple sources of intermittent power generation to maximize the potential of all the world's renewables. Wind energy is another important piece of the power puzzle, and—**in a little more than two years, there will be a six-turbine pilot wind farm operation up and running off the shores of Lake Erie, thanks to the efforts of a local wind technology company and researchers at Case Western Reserve**.

Project Icebreaker has spent four years in the making since LEEDCo—the Lake Erie Energy Development Corporation—and Case Western Reserve first won a $4-million grant from the Department of Energy to design

> **"Even if you had batteries with a high enough energy density for auto applications, you've got a system of gas stations, not electrical charging stations. So a continuous charge could help solve these issues."**
>
> LIMING DAI

an offshore freshwater wind farm. Lake Erie holds tremendous potential for the project, according to David Zeng, chair of the Department of Civil Engineering at Case Western Reserve, who has been working with LEEDCo on the project since the beginning.

Lake Erie strikes a balance between a workable water depth and adequate availability of wind, according to Zeng. "Anyone who's been out on the lake knows: you get out a mile or two and the wind's always blowing," he says. Other great lakes might boast even stronger winds off their shores, but they're too deep to make a wind farm practical, he adds.

As favorable as the wind and geography of Lake Erie may be, Zeng says there are any number of challenges with freshwater wind turbines. Chief among them off the shores of Cleveland and its often punishing winters: ice.

"The potential for damage and accelerated wear-and-tear is a significant concern," Zeng says. Bridges in winter climates are subject to this type of ice loading, so there are civil engineering precedents for dealing with it. But there just aren't that many of these structures around yet—there are some offshore wind farms off the coasts of Nordic countries in Northern Europe, but they are built in saltwater seas, which reduces the amount of ice to deal with. The challenge, Zeng says, is adapting structural techniques used on other domestic structures to wind turbine foundations.

Zeng's team was involved in the original foundation design of the hypothetical system that won additional funding from the DOE to move the project forward. This summer, he and his fellow civil engineering researchers began **analyzing core samples drilled from the bed of Lake Erie to see what kind of foundation would work best**.

LEEDCo won a $40-million grant from the DOE to get the six-turbine pilot project installed and up-and-running by the end of 2018. Zeng's team will continue to be involved even after the turbines are built—adding sensors to the foundation to monitor performance, wear-and-tear and make plans for improvement over the course of the project.

Testing the system

Renewables are shaking up the current energy system. For much of its history, electric power has been pretty much a one-way street: generated at a power plant that was fed by hydroelectricity, nuclear energy or old-fashioned fossil fuels and delivered from that central node to your switch at home. But that's changing. The advent of renewables, the rise of the Internet of Things and rapid advances in sensor technology are all pushing us toward a major energy transformation, which will require a radically different kind of system: one that's smart, nimble and thrives on variability—and that is affordable for consumers.

To introduce a new, smart system, we need to change the one-way energy street from power-plant to end user into a two-way system where our homes and businesses talk back.

There's a lot of talk about renewables creating variability on the generation side, but there's always been variability on the demand side as well, according to Prica. "Every time you turn a switch on or off, you change demand," she says. But demand was always governed by averages—patterns that emerge when hundreds and thousands of users are turning their switches off and on over time. The system we're moving toward now, thanks to the constant connectivity of the Internet of Things (read more about advances in IoT on page 4) and sensor technology, is one where end users can talk back to the power plant and tell it exactly how much energy they need and when.

Essentially—a smart grid that can handle a variable load.

According to Prica and others, a more dynamic system is ultimately more efficient and will save more energy by not doling out more than what's needed. But research to optimize such a complicated system is hard to conduct—not very many cities are willing to let scientists experiment with a live grid. To that end, Case Western Reserve is turning its campus into a living lab—a place to hone the technologies that will help refine a smarter grid. **With the help of a DOE grant and in partnership with Pacific Northwest Laboratories, energy researchers will link multiple campus buildings with very different energy profiles, the on-campus wind turbine and PV systems together to develop strategies for optimized operation and demonstrate this kind of multi-asset integration in a real-world setting.**

"The technology is changing," says Prica. "And to be able to incorporate new technologies and operate them, we need some type of real experience, a living lab, that will help us to understand technology capabilities and how it interacts with the existing system and devices."

Innovation doesn't happen in a vacuum and the solutions we need to create a better energy system won't happen in silos, according to Prica and her team of scientists, who hope the living lab project will serve as a crucial proving ground to finally see how all the pieces of tomorrow's optimized energy puzzle fit together best. **>**

> **"Anyone who's been out on the lake knows: you get out a mile or two and the wind's always blowing."**
>
> DAVID ZENG

David Zeng, chair of the Department of Civil Engineering at Case Western Reserve, is working with LEEDCo to design an offshore freshwater wind farm on Lake Erie.

TRUE GRID

How do you experiment on the power grid without risking sweeping blackouts and aggravating disruptions? By taking the grid down to size. This table-top system was built by energy researchers at Case Western Reserve with support from the Department of Energy and Rockwell Automation to drive development of smart grid sensing and control technologies. Its low voltage AC (18 V RMS) electrical network mimics a full-sized power system, including nodes representing traditional power generators like fossil-fueled power plants, a mix of renewables and energy storage devices, and three categories of power consumers: residential, commercial and industrial. The distributed sensor network provides real-time data to a control system, and each distributed energy resource includes a custom-designed inverter to dynamically control power to manage system voltage, power quality and service quality.

Portable power: Polymer researchers develop flexible microsupercapacitors that could be woven into fabrics

Wearables are everywhere—from nifty consumer gadgets like fitness trackers to life-saving biosensors. And while these devices are designed to go wherever their users go, they can only travel so far before they need to recharge. A research team led by Liming Dai, the Kent Hale Smith Professor in the Department of Macromolecular Science and Engineering at Case Western Reserve University, has developed a power source for these electronics that's just as portable as they are.

Their microsupercapacitor is small enough and flexible enough to actually be sewn into fabrics, which could lead to clothing that's just as functional as it is fashionable—a closet full of seamlessly wearable power sources that can tailor their charges to match the load demands of different devices.

Made from titanium wires wrapped with carbon nanotubes, this new supercapacitor can be bent up to 180 degrees hundreds of times with no loss of performance. Researchers say they are also adjustable—by connecting several microsupercapacitors in a series or in parallel, they can scale up the voltage or current.

Learn more about new microsupercapacitors that could lead to charge-carrying clothing at engineering.case.edu/wearable-power-source.

Team energy: Case Western Reserve University joins Tri-State University Energy Alliance

Case Western Reserve University has agreed to join forces with three other research powerhouses to put energy innovations on the fast-track to commercialization as part of the Tri-State University Energy Alliance.

The research consortium includes Case Western Reserve, Carnegie Mellon University, the University of Pittsburgh and West Virginia University.

Each member brings its own specific area of energy expertise to the group: Case Western Reserve, through its Great Lakes Energy Institute, has a particular flair for electrochemistry research, materials in applied energy storage and a growing reputation for strength in big data analytics used to explore the lifetime reliability of energy technologies. The other members bring strong work in electric power delivery, smart grid development, carbon management, energy policy and more.

Moreover, all four players have overlapping initiatives in key research areas like grid modernization, energy storage and oil and gas—which means by pooling their resources and collaborating, they could produce results, faster technology commercialization, increased industry partnerships and more.

Learn more about how the Tri-State Energy Alliance will help move energy innovations to market quicker at engineering.case.edu/Energy-Alliance.

Solar-powered plane

Around the world fuel-free: Solar Impulse 2—an experimental solar-powered aircraft—completed its round-the-world journey this summer. In the midst of its record-breaking trip, Case Western Reserve University Professor of Macromolecular Science and Engineering Rigoberto Advincula was tapped by the American Chemical Society to offer insights on the advanced materials that made the flight possible, offering his expertise during a National Press Club briefing in May.

Undergraduate computer engineering major Jean Castillo spent the fall working on an emissions-free controlled flight project at the National University of Singapore.

Student entrepreneurs shine

Student startup CrystalE pitched its self-powered building monitoring sensor technology on the national stage at two major competitions: the final round of the Clean Energy Trust Challenge and the Rice Business Plan Competition.

Learn more at engineering.case.edu/CrystalE-competitions.

Better batteries

Energy researchers at Case Western Reserve University won a $1.65M State of Ohio Federal Research Network grant to develop better batteries for defense and aerospace industries.

The funding will create a new research consortium: the Partnership for Research in Energy Storage and Integration for Defense and Space Exploration (PRESIDES) Center of Excellence within the university's Great Lakes Energy Institute. Initial projects include developing a high-energy-density lithium-ion battery; exploring a new approach to developing a lithium-sulfur battery; and investigating the potential impact of embedded batteries on energy storage.

Learn more at engineering.case.edu/PRESIDES.

Best seat on the quad

The Case Western Reserve University community now has a new place to take a seat and recharge—literally.

This spring, Elizabeth Stricker (Freund) and Jason Pickering, along with other members of the university's new ThinkEnergy Fellowship Program, **built a picnic table outfitted with two 90-watt solar panels and a battery pack to serve as an outdoor charging station**.

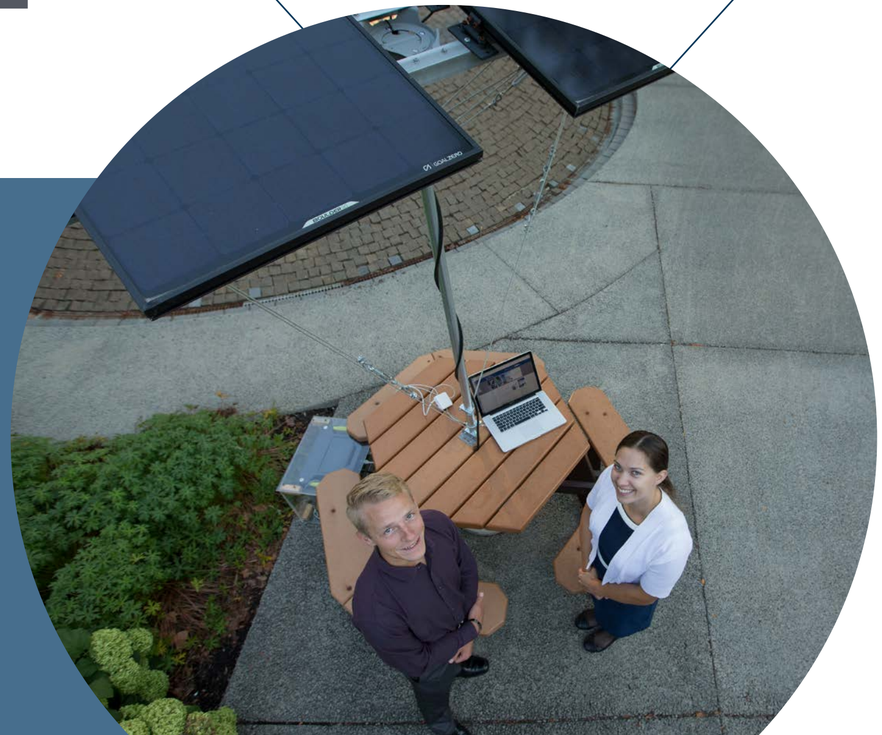
The battery contains multiple USB ports and AC plugs, and it packs enough power to allow multiple users to charge their devices simultaneously.

The project was the pilot for the ThinkEnergy Fellows program—a new initiative spearheaded by the Great Lakes Energy Institute designed to connect Case Western Reserve's top students with faculty, companies and communities around energy topics to bring energy literacy to campus.

Learn more at engineering.case.edu/solar-powered-charging-table.

A new carbon nanomaterial developed by polymer researchers at Case Western Reserve holds its conductivity in three dimensions, which could lead to advances in battery storage capability, more efficient energy conversion in solar cells, lightweight thermal coatings and more.

Learn more at engineering.case.edu/nanomaterial-3D-conductivity.



Engineering students install solar panels in Namibia

Only 34 percent of Namibia's population has access to electricity, which creates a whole host of power-related problems for residents and farmers—particularly in rural areas.

A trio of Case Western Reserve University students—two engineering and a business major—**traveled to the small African nation in January and installed solar panels on several homes in a rural village**, bringing reliable—and renewable—electric power to people's homes for the first time. The trip was organized by Daniel Lacks, chair of the Department of Chemical and Biomolecular Engineering, and Michael Goldberg, assistant professor of design and innovation at the Weatherhead School of Management.

Learn more and watch highlights from the trip at engineering.case.edu/Namibia-solar-panels.

Burning to learn: CWRU teams up with NASA to perform the largest-ever fire safety experiment in space

Space is an unforgiving environment, and a fire on board a spacecraft is one of the most dangerous situations astronauts can face. So why on Earth—let alone off it—would researchers light one in space on purpose? Because a **better understanding of how flames behave in microgravity could help keep astronauts safer**.

Two aerospace engineering researchers at Case Western Reserve—professor James T'ien and assistant professor Ya-Ting Liao—teamed up with NASA Glenn Research Center along with scientists around the world to perform the **largest fire safety experiment ever conducted in space** when the unmanned Cygnus cargo module disembarked from the International Space Station earlier this summer.

The experiment, called Saffire-I, was the first in a series of six to be conducted over the next five years that will give scientists valuable data on how large-scale fires grow and spread in space, which will help improve fire safety protocols and guide the development of new materials for the ISS and future manned missions to Mars.

Learn more at engineering.case.edu/Saffire.

Polymer science goes global: CWRU launches dual-PhD program in Brazil

Case Western Reserve University boasts a track record of firsts when it comes to polymer science, including launching the country's first accredited undergraduate polymer degree program more than 50 years ago. Now, thanks to a new international partnership, polymer science students in Brazil can take advantage of that academic and research pedigree through a new dual PhD degree program.

Funded by the Coordenação de Aperfeicoamento de Pessoal de Nível Superior, or CAPES, the Brazilian equivalent of the National Science Foundation, the program will eventually reach a steady state of **supporting 40 PhD students in polymer science**. **Students will start the program at their home institution in Brazil, conduct their second and third years in residence at Case Western Reserve, and complete the program in a fourth year back at home**.

The first 12 students started the program this spring and another seven joined this fall. The partner institutions expect to expand the program to biomedical engineering students as well.

Cyborg sea slug: Researchers develop biohybrid robot using organic tissue and 3-D printed parts

If the phrase "partially organic robot" makes you think of Terminator-driven future wars, don't panic—this isn't that kind of robot. While technically a cyborg, the living machine developed by researchers at Case Western Reserve University is designed for search and rescue, not seek and destroy.

Victoria Webster, a PhD student in the Department of Mechanical and Aerospace Engineering, led the team that created this unique piece of technology: a **2-inch-long biohybrid robot constructed from a combination of living sea slug tissue and 3-D printed parts**.

Why put organic tissue in the mix? Because in the case of Webster's robot, sea slug tissue is designed by nature to function underwater. Electronics? Not so much.

The robot is built around a single muscle from a sea slug's mouth, which provides the movement—the robot can crawl when stimulated by an external electrical field. But the researchers hope to control future iterations by incorporating living neurons into the robot as well.

The team envisions swarms of these hybrid 'bots scouring the ocean floor in search of a black box recorder, for example, or rooting out the source of a toxic leak in a pond.

Webster worked with Roger Quinn, the Arthur P. Armington Professor of Engineering and director of Case Western Reserve's Biologically Inspired Robotics Laboratory; biology professor Hillel Chiel; Ozan Akkus, the Leonard Case Jr. Professor in the Department of Mechanical and Aerospace Engineering; Umut Gurkan, assistant professor of mechanical and aerospace engineering, undergraduate researchers Emma L. Hawley and Jill M. Patel; and recent master's graduate Katherine J. Chapin.

Learn more at engineering.case.edu/biohybrid-robot.

SUPPORTING DEAN'S INITIATIVES

The Case School of Engineering gained valuable support for special projects thanks to gifts from two generous alumni: Bill Kerler (CIT '51) and Charles Phipps (CIT '49).

Phipps and Kerler made commitments this year to the dean's strategic initiatives fund, providing valuable unrestricted support that gives the school's leadership the ability to fund special projects when needed. These gifts support a host of strategic priorities—from providing bridge funding to faculty, creating new collaboration funds and supporting the school's faculty investment program.

"As the widespread use of digital intelligence occurs in the next decade, the impact on engineering curricula will be as great, if not greater, than that for prior generations of digital technology. The dean will need early access to resources to initiate projects that may lead to new fields of study, which may allow the school to gain a leadership role for a few select areas. This gift is an attempt to address a few of these challenges," says Phipps, who earned his bachelor's degree from the Case Institute of Technology in 1949 before launching a successful career that includes positions at General Electric, Motorola and Texas Instruments.

Kerler earned his bachelor's degree in chemical engineering in 1951, after which he built a successful career at Jacobs Engineering, retiring as the company's COO in 2000. In addition to his valuable financial support, Kerler has been instrumental in creating an alumni network in his hometown of Charlottesville, Va.

New biomedical, chemical textbook

Professors Gerald Saidel and Harihara Baskaran co-authored a new textbook titled *Biomedical Mass Transport and Chemical Reaction: Physicochemical Principles and Mathematical Modeling*, which teaches the fundamentals of mass transport with a unique approach emphasizing engineering principles and analysis with biomedical applications. The textbook is intended for undergraduate and graduate students in biomedical and chemical engineering, and includes material Saidel has taught during his 49-year career.

Professor of Mechanical Engineering Vikas Prakash is studying the remains of ancient earthquake epicenters to better understand modern seismic events.

Non-woven nanofiber processing

A new approach to the production of non-woven materials has been developed by researchers in the Department of Macromolecular Science and Engineering at Case Western Reserve—one that is entirely free of the organic solvents required in traditional electrospinning nanofiber production. **Formed through a continuous, multi-layering co-extrusion process, the polymer nanofibers**, which have a diameter as small as 10 nanometers—10,000 times thinner than a human hair—feature an **unusual rectangular cross section that provides a high surface area-to-volume ratio and strong mechanical properties**. Potential applications for these nanofibers include air filters, fuel filters, water filters, lithium-ion battery separators and drug delivery substrates. The manufacturing process is highly flexible, making it easily scalable to produce large amounts of nonwoven material.

The research team—which includes faculty members Eric Baer, LaShanda Korley and Gary Wnek, and graduate student Jia Wang—has recently **received a patent for this novel process**.

A faster chemical imager

Ozan Akkus, the Leonard Case Jr. Professor of mechanical and aerospace engineering, received funding from the **National Science Foundation and the Ohio Board of Regents to turn a Raman microscope into FastRAM**—a chemical imager that can provide images of materials in seconds to minutes instead of hours to days. Akkus' goal is supported by 11 fellow professors from various disciplines, as well as an art conservation group at the Cleveland Museum of Art—all of whom signed on to express their interest in using the new device.
Learn more at engineering.case.edu/FastRAM.

Knotty polymers

Celtic art. Boy Scout knots. Mobius strip ring. M.C. Escher's art. They fascinate viewers and challenge their ability to trace the origin of connectivity. Mathematicians, too, are intrigued by these structures and have long described the topology of rings and cyclic overlapping structures with their programmable qualities into the so-called Knot Theory. In biology, too, the topology of DNA can result in knotted structures. In polymer science, **understanding chain entanglement and compatibilization in surfaces can result in new materials with interesting physical and chemical properties** that can extend the applications of plastics, coatings, rubber and composites. But chemical companies have not yet been able to use them for commercial applications. Rigoberto Advincula, professor of macromolecular science and engineering, has received a **National Science Foundation grant to explore the design and synthesis of catenated polymer and block copolymer compositions, and utilize Knot Theory** to produce various knotted macromolecules that could bring these structures closer to commercial use.
Learn more at engineering.case.edu/knotty-polymers.

A greener way to fire-proofing

Imagine if materials from your kitchen could help keep unwanted fires at bay. A research team led by David Schiraldi, the Peter A. Asseff Professor and chair of the Department of Macromolecular Science and Engineering, is **using bioavailable materials as alternatives to the potentially toxic compounds traditionally used to make plastics flame retardant**. Mixing materials like tannins (that stuff that makes your red wine heart-healthy) and gelatin (think Jell-O), the team added the combo to polyethylene—one of the most flammable materials known. The result? A material that will not stay lit. The team has filed a patent and is working on broadening the range of polymers that can be made fire safe.

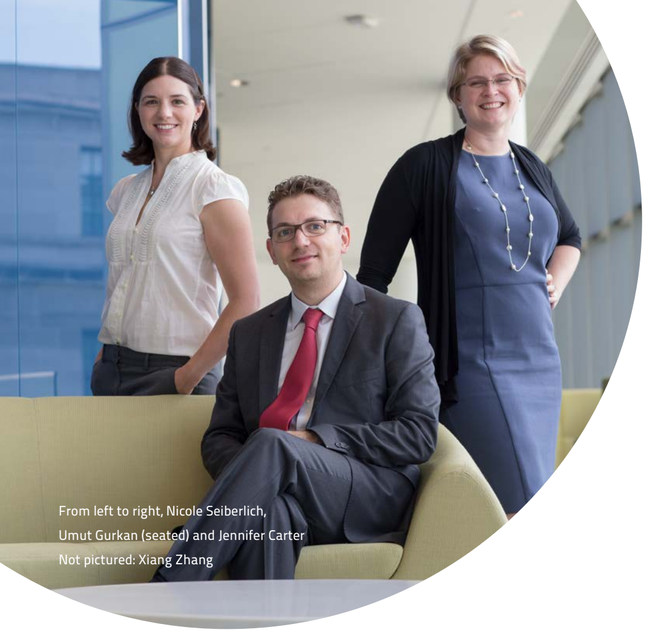
Learning for chocoholics

What goes better with studying than chocolate? How about learning with it? The unlikely subject matter is actually a great way to introduce students to concepts in macromolecular science (as well as some history and sociology) as the delicious material can have six different crystal structures—making it much like a modern polymer system. The new class, "The Chemistry, Physics and Engineering of Chocolate," is available to all first-year university undergraduate students and, yes—it involves taste tests.

GLOBAL SUPPORT

International initiatives at Case Western Reserve are primed for broader impacts, thanks to a generous gift from alumnus Joel Schwartz (CIT '64, '66), the former senior vice president and general manager at EMC Corporation and a member of the school's Boston Think Tank.

As a leader of the university's International Affairs Visiting Committee, Schwartz understands the importance of sharing global perspectives in the classroom and through on-site training. His financial support is allowing the engineering school to enhance its international programs, which seek to increase the school's global footprint by utilizing the international alumni network to recruit more international students, develop new global industry partnerships and create international academic programs.



From left to right, Nicole Seiberlich,
Umut Gurkan (seated) and Jennifer Carter
Not pictured: Xiang Zhang

Four Case School of Engineering junior faculty members won **National Science Foundation CAREER grants**: **Nicole Seiberlich**, associate professor of biomedical engineering; **Umut Gurkan**, assistant professor of mechanical and aerospace engineering; **Jennifer Carter**, assistant professor of materials science and engineering; and **Xiang Zhang**, assistant professor of electrical engineering and computer science. The funding will support research exploring advanced materials and energy, changing tissue properties in disease, new medical imaging techniques, and improving the efficiency of large network analysis.

Three biomedical engineering professors—Eben Alsberg, Horst von Recum, and Cameron McIntyre—were elected to the College of Fellows of the American Institute for Medical and Biological Engineering (AIMBE), an elite group of scholars that is comprised of the top 2 percent of the country's medical and biological engineers.

The Indian government named Assistant Professor of Biomedical Engineering **Pallavi Tiwari one of the top "100 Women Achievers in India**."

Alp Sehirlioglu, the Warren E. Rupp Assistant Professor of Materials Science and Engineering, was named a **senior member of the Institute of Electrical and Electronics Engineers** (IEEE).

James T'ien, the Leonard Case Jr. Professor of Engineering in the Department of Mechanical and Aerospace Engineering, won the **2015 Space Processing Award from the American Institute of Aeronautics and Astronautics**.

Liming Dai, the Kent Hale Smith Professor in the Department of Macromolecular Science and Engineering, was named a **Highly Cited Researcher by Thomson Reuters** for his research contributions in the fields of chemistry and materials science and engineering.

Associate Professor of Biomedical Engineering **Nicole Seiberlich** was elected to the **Board of Trustees of the International Society for Magnetic Resonance in Medicine and named associate editor of *IEEE Transactions on Medical Imaging***.

Umut Gurkan, assistant professor of mechanical and aerospace engineering, received the **Rising Star award** at the 2016 Biomedical Engineering Society-Cellular and Molecular Bioengineering and Advanced Biomanufacturing Joint Conference held in January.

Dominique Durand, the Elmer Lincoln Lindseth Professor of Biomedical Engineering, was named a **fellow of the American Association for the Advancement of Science** and elected to serve on the **administrative committee of the IEEE Engineering in Medicine and Biology Society**, the world's largest international society of biomedical engineers.

STUDENT AWARDS

Two Case Western Reserve University students won Baxter Young Investigator Awards: mechanical and aerospace engineering doctoral candidate Mustafa Unal for his research entitled "Assessment of Bone Quality by Novel Spectroscopic Biomarkers," and biomedical engineering graduate student Anna Dikina for her research entitled "Engineering Cartilaginous Tracheal Replacements: Vascular Tissue Incorporation and Epithelialization." Unal also received the **Osteoarthritis Young Investigator Award** from the Orthopaedic Research Society.

Macromolecular science and engineering PhD student **Symone Alexander received a National Science Foundation Graduate Research Fellowship** for her research into polymer composites that respond to heat, light and other stimuli.

Three engineering students won **Department of Defense Science, Mathematics and Research for Transformation (SMART) Scholarships**: mechanical and aerospace engineering undergraduate **Diana Illingsworth**, chemical engineering undergraduate **Lauren Anderson** and macromolecular science and engineering PhD candidate **Michelle Leslie**.

Mechanical and aerospace PhD student **Peng Wang** won the **Best Student Paper Award** at the IEEE International Conference on Automation Science and Engineering.

Materials science PhD candidate **Janet Gbur was awarded an ASTM International Graduate Scholarship** and was selected as one of the **2016 Henry DeWitt Smith Scholars** by the Minerals, Metals and Materials Society.

Mechanical and aerospace engineering graduate student **Yunus Alapan** and his team won first place in the **2015 Student Technology Prize for Primary Healthcare**, a national competition seeking innovations in health care delivery organized by the Center for Integration of Medicine and Innovative Technology, for their sickle-cell disease diagnostic device.

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Professor

*School of Medicine campus

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Fumiaki Takahashi
Professor

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Gregory S. Lee
Assistant Professor, Electrical Engineering and Computer Science

The Case School of Engineering has a proud 125-year history as one of America's top engineering schools. We are innovators and educators—tackling the world's most challenging engineering problems through groundbreaking research while balancing a rigorous academic curriculum with ample experiential learning opportunities that bring those lessons to life for tomorrow's engineers. More than 100 full-time faculty represent the best minds in their fields, and our students are among the brightest and most ambitious in the nation.

*Learn more at **engineering.case.edu**.*

Departments

Biomedical Engineering
Chemical and Biomolecular Engineering
Civil Engineering
Electrical Engineering and Computer Science
Macromolecular Science and Engineering
Materials Science and Engineering
Mechanical and Aerospace Engineering

Centers and Institutes

Advanced Manufacturing and Mechanical Reliability Center (AMMRC)
Advanced Platform Technology Center
Case Metal Casting Laboratory
Center for Advanced Polymer Processing
Center for Advanced Science and Engineering for Carbon
Center for Biomaterials
Center for Computational Imaging and Personalized Diagnostics
Center for the Evaluation of Implant Performance
Cleveland Functional Electrical Stimulation Center
Control and Energy Systems Center
Electro-Ceramics for Sustainable Energy Solutions
Electronics Design Center
Great Lakes Energy Institute
Institute for Advanced Materials
Magnetic Materials Characterization Laboratory
Materials for Opto/Electronics Research and Education (MORE) Center
Microfabrication Laboratory
Neural Engineering Center
Nitinol Commercialization Accelerator
NSF Center for Layered Polymeric Systems (CLiPS)
Rapid Solidification Laboratory
Sears think[box]
Solar-Durability and Lifetime Extension Center
Swagelok Center for Surface Analysis of Materials
The Institute for Management and Engineering
Wind Energy Research and Commercialization Center
Yeager Center for Electrochemical Sciences

Degrees and Majors

Bachelor of Science in Engineering (BSE)

Available majors:

Aerospace Engineering
Biomedical Engineering
Chemical Engineering
Civil Engineering
Computer Engineering
Electrical Engineering
Engineering Physics
Materials Science and Engineering
Mechanical Engineering
Polymer Science and Engineering
Systems and Control Engineering
Bachelor of Science in Engineering without designation

Bachelor of Science (BS)

Available majors:

Computer Science
Data Science and Analytics

Master of Science (MS)

Available majors:

Aerospace Engineering
Biomedical Engineering, with optional specialization in Translational Health Technology or Wireless Health
Chemical Engineering
Civil Engineering
Computer Engineering
Computing and Information Science
Electrical Engineering, with optional specialization in Wearable Computing or Wireless Health
Macromolecular Science and Engineering, with optional specialization in Fire Science and Engineering
Materials Science and Engineering
Mechanical Engineering, with optional specialization in Fire Science and Engineering
Systems and Control Engineering
Undesignated

Master of Engineering (ME)

Master of Engineering and Management (MEM)

Doctor of Medicine/Master of Science in Biomedical Engineering (MD/MS)

Doctor of Philosophy (PhD)

Available majors:

Aerospace Engineering
Biomedical Engineering
Chemical Engineering
Civil Engineering
Computer Engineering
Computing and Information Sciences
Electrical Engineering
Macromolecular Science
Materials Science and Engineering
Mechanical Engineering
Systems and Control Engineering

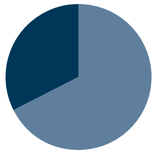
Doctor of Medicine/Doctor of Philosophy (MD/PhD)

Available majors:

Biomedical Engineering
Mechanical Engineering

Student Enrollment Fall 2016

2,290 Total*



743 Graduate and professional-degree students

1,547 Declared undergraduate engineering students

*In addition, 719 undergraduate students expressed interest in engineering majors but are not expected to declare majors until the end of their sophomore year.

FY 2016 Full-time faculty

124

Total revenue

$99 million

Research, training and grant revenue

$44.3 million

Fundraising FY 2016

Total: $33.4 million

In FY2016, the Case Alumni Foundation/Association provided $3.9 million from annual and endowed gifts to the Case School of Engineering.

Technology Transfer

In FY2016 Case School of Engineering faculty contributed to:

- 81 invention disclosures—4.39 times the national per-dollar proficiency average*
- 139 patent applications—8.28 times the national per-dollar proficiency average*
- 17 deals with industry—3.22 times the national per-dollar proficiency average*
- 2 startup companies —2.54 times the national per-dollar proficiency average*

*AUTM U.S. Licensing Activity Survey, FY14 (latest data available)

U.S. News & World Report rankings

46th
for engineering graduate schools*

37st
for undergraduate engineering programs**

17th
for graduate biomedical engineering programs*

13th
for undergraduate biomedical engineering programs**

*published spring 2016

**published fall 2016

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Every effort has been made to ensure the accuracy of this report. If you have any questions or concerns, please contact Christine Coolick, director of marketing and communications, Case School of Engineering, Case Western Reserve University, 10900 Euclid Ave., Cleveland, Ohio 44106-7220; 216.368.8694; cmc174@case.edu.

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