

# Solutions

VANDERBILT  
SCHOOL OF  
ENGINEERING  
Nashville, Tennessee

2018-2019

Google data mining  
from Android devices  
comes amid growing  
digital privacy concerns

Stronger, sustainable  
concrete with seawater

Steerable robotic needles  
for lung biopsies







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VANDERBILT  
SCHOOL OF  
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INSIGHT • INNOVATION • IMPACT

2018-2019

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Cover: Pamela Saxon, Saxon Creative

Inside cover photo: Researchers work in the commercial-grade cleanroom that is part of the Vanderbilt Institute for Nanoscale Science and Engineering.

# Opportunities in the age of disruption

By Philippe M. Fauchet  
Bruce and Bridgitt Evans Dean

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Each August I welcome our new first-year students with a brief history of revolutions that advancements in engineering made possible. With quick nods to the wheel and Roman aqueducts, I leave ancient history behind and focus on more recent marvels.

To 21st century students, the first commercially viable steam engine (1700) and the first practical telephone (1870s) don't seem revolutionary and may not even be recognizable. These relics, however, transformed business, travel and communication.

Revolution here refers to an activity or new technology that fundamentally changes how society works and thinks. There is a clear "before" and an equally clear "after."

Consider the first affordable automobile (1908), mass electrification (1935), the first working transistor (1947) and the Internet (1982). Each example has its own before and after, as does the advent of commercial air travel and, more recently, additive manufacturing with 3D printing.

None of these revolutions happen overnight. No one flipped the switch and brought electric power to all corners of the country. But mass electrification and reliably powered air conditioning made development of the southwestern U.S. possible. As more and more people could afford to buy a car, private automobile ownership fundamentally changed the landscape. The U.S. interstate network connected major cities from east to west and north to south while decimating longstanding neighborhoods, albeit by vastly improving automobile travel and safety. Urban centers, now in a sort of

Renaissance, suffered as easy mobility paved the way for the growth of suburbs and exurbs.

Every revolution causes disruption and discomfort.

We are in the midst of one now. It began with the release of the first smartphone in 1994 and continues, profoundly changing how we conduct our lives.

We are in the age of everything, everywhere, all the time. No matter where I travel, my phone knows where I am. At home or in my office on a desktop or laptop, when I read Belgian newspapers online in French, I am served up ads in English for products and services in Nashville.

The articles in this publication document important technological advancements and foretell inevitable

biopsies will benefit patients and clinicians but will require investment and specialized training.

Advanced diagnostic techniques, such as those Rizia Bardhan and colleagues are developing, may better identify cancer patients who would benefit from immunotherapy but will need to be incorporated into a standard workflow alongside traditional histology. Likewise, gold nanoparticles can flag defects in 3D printed parts, and our team has shown how it can be done quickly with minimal disruption to the manufacturing process.

Each year, I also challenge our new undergraduates to go beyond their technical training. A Vanderbilt undergraduate engineering education is set apart by an unyielding emphasis

## Each revolution invites us to define who we are and what is important to us.

disruptions that will follow. Professor Douglas Schmidt's study on Google data collection practices is the most obvious example. The Internet of Things and our 24/7 connectivity raise delicate questions about digital privacy and may, in fact, redefine how we think about our personal information.

Traffic routing apps, as Professor Janos Sztipanovits points out, create winners and losers. In other examples the calculus is more subtle. Flexible robotic tools for less invasive lung

on responsibility, sustainability, consequences of what we create, and an awareness of a much bigger picture.

Even non-political revolutions can be messy. Discontinuity accompanies each of them, but these turning points create opportunities – not only to improve medical care, manufacturing, and communication, but also leadership, entrepreneurship, and civic engagement. Each revolution also invites us to define who we are and what is important to us.

# Defending the value of higher education



There is no such thing as a typical day for a federal relations officer of the nation's largest public university system.

There is a rhythm. It is the federal budget cycle – in four phases – and the final phase is the execution of the budget by government agencies,

hopefully by the beginning of the fiscal year on Oct. 1. There are meetings. Lots of meetings. The one constant daily rhythm is the tracking of every issue the federal relations office monitors.

“And we have a huge number of issues,” said Deborah Hammond Altenburg, BE'96, assistant vice chancellor for federal relations for The State University of New York. “Officially, the work day is 8:30 to 6,” said Altenburg, a biomedical engineering graduate and higher education lobbyist. “Even that's not typical,” she said and laughed. On a recent Friday, word reached the Washington, D.C. office that SUNY Chancellor Kristina Johnson, also an engineer, would be stopping by. Work shifted to prepare for her visit.

## A heady experience - working on the Hill

Always “science and math focused,” Altenburg took a senior year Advances in Medicine class about how medical advances can change society and impact public policy. That class tipped her interest toward the interplay of science, society and policy.

“I decided I wanted experience on the policy side,” she said. Altenburg headed to the Capitol shortly after leaving Vanderbilt.

After graduation and at home in New Hartford, N.Y., she learned her hometown representative Sherwood Boehlert was looking for interns. He represented a large swath of central New York in the U.S. House of Representatives from 1993 until 2006, serving on the Science Committee for his entire congressional career and as its chairman from 2001 to 2006.

“I was an intern for one month, then quickly hired!” She worked for Boehlert from 1997 to 2003 and rose to Legislative Director in January 2001. “It was a wonderful opportunity. Rep. Boehlert analyzed every issue and consulted experts before taking a view. He was strong on environmental policy and he's

**With 64 college and university campuses located within 30 miles of every home, school, and business in the state, SUNY serves more than 1.4 million students annually and employs more than 90,000 faculty and staff.**

In addition to tracking the federal budget, the higher education appropriations process, research regulations and other traditional higher ed topics, top concerns for large public universities include tax revenue due to the recent overhaul of federal taxes and growing pressure in Congress to reauthorize the main federal law governing higher education. These unleash complex and serious questions about the value of higher education.

Altenburg was appointed to her SUNY role in January 2018 but she has spent more than 20 years working inside the Beltway. She is ably prepared to guide the tenth largest university network in the world by enrollment.

had a lasting impact on homeland security and cybersecurity.”

“Working on the Hill is a heady experience, especially in the House of Representatives with elections every two years. But it is challenging for a family,” said Altenburg, whose husband is a government consultant on national security. They have a daughter in the seventh grade and a son in the fourth grade. Colleagues urged her to consider university federal relations to avoid the ‘all-nighters’ they were used to in the House. “They were partially right,” Altenburg said.





(L to R) Deborah Altenburg, then with RPI; William Colona (Pace University); Rep. Nita Lowey, New York; Alex Krigstein (SUNY); Vanessa Herman (Pace) and Steve Heuer (NYU) meet in Lowey's office in 2016. (Photo courtesy of SUNY)

The Pew survey found that attitudes about the effect of colleges and universities have changed dramatically over a relatively short period of time. Positive views, partisan or not, are declining by significant percentage points. A Gallup survey last year also revealed meaningful public doubts about cost of college and the value of degrees.

### An engineering evangelist for a long time

Altenburg left Boehlert's office but stayed in D.C. to establish a federal relations office in Washington for Rensselaer Polytechnic Institute, a private research university in Troy, N.Y. with emphasis on science and technology. RPI is recognized for its engineering and computing programs, in particular. She served as director of RPI's federal relations office for 14 years.

Engineering is an excellent preparation for a federal relations position, Altenburg believes. "Engineers like to get to the heart of a matter. We learn how to solve problems. We analyze complex issues, summarize, offer solutions, and drive to consensus. I've been an engineering evangelist for a long time."

Many administrators in federal relations are former legislative staffers or lawyers or have graduate degrees in public policy or political science. It takes research and data to make the case; it takes patience and diplomacy to work with constituents inside and outside the university and the federal government. "I think we could use a few more engineers," she said. "We use data and research for all the arguments we make. Experience and the ability to relate to people certainly help."

A university is a complex place and the business model for delivering education is changing. "Across the higher education community we're trying blended learning, flipped classrooms, online classes and online degrees," Altenburg said. "There are issues about free speech and campus safety. What does federal financial aid look like in the future?"

### An existential threat to higher education

"University lobbyists have many similar goals. Research universities support America's technological innovation and the promise of opportunity for the next generation. I would like to think university lobbyists wear white hats," Altenburg said. "We are representing institutions that serve a public good." According to the American Academy of Arts & Sciences, public research universities represent only 3 percent of the total number of institutions in the U.S. higher education system

but the impact is profound through contributions to research, infrastructure, our knowledge base and the economy.

Altenburg thinks these important contributions are being subverted by a troublesome shift in public opinion. Two recent surveys show sharply declining public support for colleges and universities.

"There is an existential threat to higher education. Six in 10 Americans say higher education is going in the wrong direction, according to a 2018 Pew Research Center survey," she said. Democrats and Republicans share that opinion but for different reasons. "According to the survey, Democrats think tuition is too high. Republicans think professors are bringing their political and social views into the classroom."

Public opinion data that show a growing enmity for higher education can't be ignored. "Those attitudes influence politicians. Those attitudes drive funding," Altenburg said.

"How we show our value is so important. We have to have the public behind us."



# ENGINEERING NEIGHBORHOODS

In a global world where Skyping with a colleague half a world away or reviewing medical test data via email from remote areas of Africa is commonplace, the term “neighborhood” is redefined and revitalized. At Vanderbilt University School of Engineering, neighborhood is how we describe our distinctive culture of trans-institutionality, collaboration and cross-pollination both within and beyond the traditional walls of departments, schools, institutions and disciplines.

Vanderbilt Engineering has a long and successful tradition of collaboration with colleagues at other universities and at Vanderbilt University Medical Center, the College of Arts and Science and the other colleges and schools that comprise one of the nation’s top research universities.

In developing its own bottom-up strategic plan, the School of Engineering identified major areas of emphasis—nine neighborhoods drawing faculty, staff, students and outside researchers together in the search for solutions. A Vanderbilt engineer’s research routinely spans more than one neighborhood.

## Biomedical Imaging and Biophotonics

uses physical phenomena such as magnetic fields, radiation and light to aid diagnoses and treatments of disease and dysfunction.

## Big Data Science and Engineering

develops tools and processes to harvest and leverage knowledge from data sets too large and complex for traditional software to handle, often involving predictive or user behavior analytics.

## Surgery and Engineering

concentrates on the collaborative efforts of engineers and surgical experts to create, develop, implement and evaluate technology, methods and tools that improve patients’ outcomes and experiences.



## Energy and Natural Resources

targets transformative research that will enable sustainable resource and energy conservation, production and recovery.

## Cyber-Physical Systems

technology develops processes, protocols, networking and technology needed for the seamless and secure integration of cyber (software) and physical (hardware, networks and users) systems.

## Nanoscience and Nanoengineering

concerns the discovery and application of how materials and processes behave on the nanoscale in diverse areas of engineering, science and health care.

## Regenerative Medicine

involves tissue engineering, drug delivery, drug efficacy and molecular biology and works to replace and heal damaged cells, tissues and organs.

## Risk, Reliability and Resilience

advances risk quantification; improves predictability; increases reliability of systems, infrastructure and materials; and creates technology and materials with more resilience.

## Rehabilitation Engineering

develops mechanical devices and robotics to help restore lost physical and cognitive functions.

# Leveraging machine learning to advance brain imaging techniques and hardware

## The human brain does not give up its secrets easily.

A brain contains billions of neurons, a number so large each cubic millimeter is estimated to hold about one million neurons. They communicate through networks of electrical activity that change and adapt, much like a processor that learns and updates itself.

It is fitting, then, that computers with enormous processing capacity, combined with machine learning algorithms, power today's advancements in brain imaging. Vanderbilt engineers are at the forefront of this new age of neuroimaging, developing new hardware and combining imaging modalities to better understand brains that are healthy and those that are not.

Associate Professor of Biomedical Engineering William Grissom earlier this year received a \$2.6 million basic research grant from the National Institutes of Health to develop a novel approach that combines new pulse and coil design for improved, finer resolution. The ambitious project aims to achieve higher quality imaging as small as 600 microns, or 6/10 of a millimeter.

He and Vanderbilt Institute of Imaging Science colleague Xinquiang Yan, a staff research engineer, recently succeeded in creating a novel, self-decoupled radiofrequency coil design. The project, foundational work for the larger grant, marks a significant breakthrough in better RF coil design for parallel and high-field imaging. Their findings were published online in *Nature Communication* in August 2018.

The self-decoupled coils will allow flexible and size-adjustable arrays, which enable higher quality images during fMRI scanning because coil proximity to the skull is one factor in image resolution.

In a separate effort, Brett Byram, assistant professor of biomedical engineering, received a \$550,000 National Science Foundation Faculty Early Career Development grant to develop an ultrasound helmet that would enable a brain-machine interface and live images.

Byram will use machine learning that gradually accounts for distortion and delivers workable images. He

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also wants to integrate electroencephalogram technology to show not only brain perfusion—how blood flow correlates to changes in thought—but also areas of stimulation related to movement and emotion.

Because basic ultrasound beams bounce around inside the skull, no useful imagery makes it out, and next-generation brain imaging has eluded medical doctors and scientists for decades.

Only now have the technologies aligned to make it possible, said Byram, whose lab is affiliated with the Vanderbilt Institute for Surgery and Engineering.

“The goal is to create a brain-machine interface using an ultrasound helmet and EEG,” he said. “A lot of the technology we’re using now wasn’t available when people were working on this 20 or 30 years ago. Deep neural networks and machine learning have become popular, and our group is the first to show how you can use those for ultrasound beam-forming.”

The applications, he said, are endless. At the basic level, it could allow for images at least as clear as those doctors are accustomed to seeing of the heart or uterus. Ultrasound technology for the brain could produce real-time images during surgery, identify where certain feelings or actions stimulate brain activity, and even create the ability to control software and robotics by thought.

“We expect the portable ultrasound helmet prototypes will resolve ultrasound image quality problems, and the new integrated algorithms will lead to new techniques for both understanding brain activity and using it to interact with computers,” Byram said.

Computational power also plays a significant role in Grissom’s NIH project. Until recently, the science has outpaced the ability of traditional tools and techniques to capture brain activity at a finer scale.

Ultra-high field MRI now can detect brain activity in areas as small as 1 to 2 millimeters. But at such levels background “noise” from magnetic pulses compromises image clarity and accuracy.

Using parallel coil arrays, the new RF coil design and improved algorithms will extract higher quality data that translates into higher resolution images, as small as 6/10 of a millimeter.

The difference is significant. Functional MRI uses changes associated with blood flow to measure brain activity because cerebral blood flow and neuron activation are linked. Recent neuroscience research has shown what unfolds in the brain – in space as well as in time – takes place at a much smaller scale than previously thought.

“We have not been able to perform MRI at fine enough scales to take advantage of these new insights,” Grissom said. ▽

(Left) With a prestigious NSF Early Career Development Award, Brett Byram, assistant professor of biomedical engineering, is integrating machine learning, ultrasound and electroencephalogram technology for improved brain imaging.

(Center) Brett Byram captures brain images for preliminary work toward building an ultrasound helmet and brain-machine interface.

(Right) Xinquiang Yan, left, a staff engineer with the Vanderbilt University Institute of Imaging Science, and William Grissom, right, associate professor of biomedical engineering, develop self-decoupling radio frequency coils, a significant advancement in high-field MRI brain imaging.



# New hyperlens can view a tiny virus on a living cell

A fundamental advance in the quality of an optical material used in hyperlensing can potentially boost current imaging capability by a factor of ten.

A team of researchers led by Joshua Caldwell, associate professor of mechanical engineering, used hexagonal boron nitride, a natural crystal with hyperlensing properties. The best previously reported resolution using hBN was an object about 36 times smaller than the infrared wavelength used to provide simultaneous spectroscopic information – about the size of the smallest bacteria.

The research, published in November 2017 in *Nature Materials*, describes improvements in the quality of the crystal that enhance its potential imaging capability by about a factor of ten. The team made its crystals using isotopically purified boron.

The high quality crystals showed a dramatic reduction in optical losses compared to natural crystals, which allows them to travel triple the distance and significantly enhances image resolution.

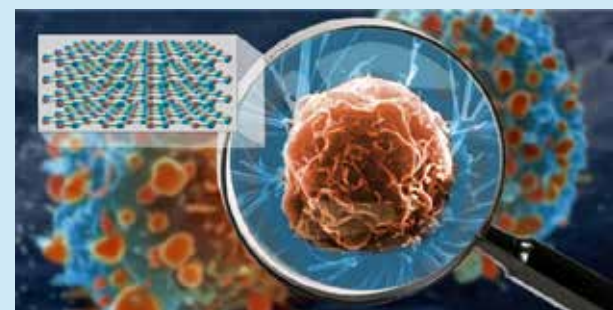
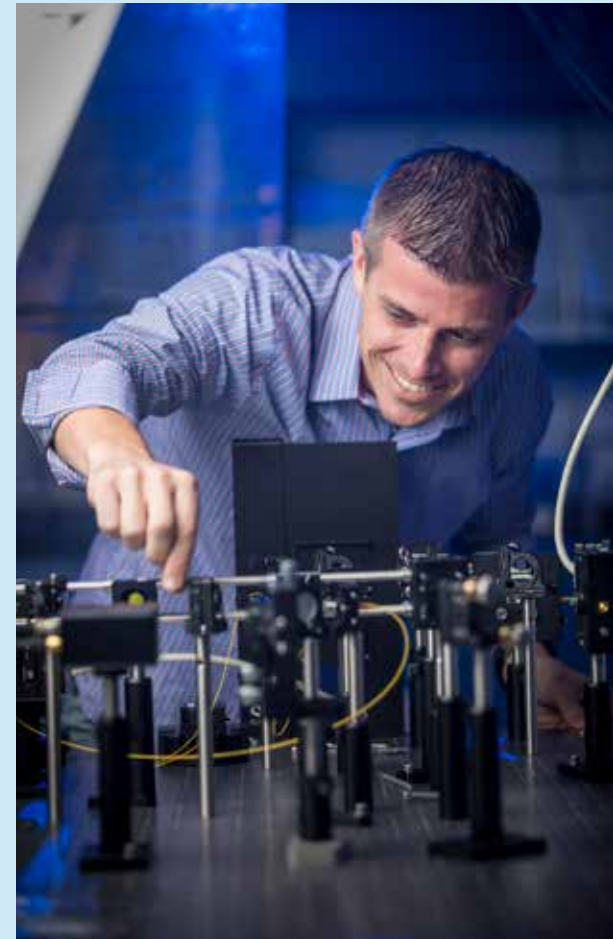
**A human red blood cell is about 9,000 nanometers and viruses range from 20 to 400 nanometers.**

“Currently, we have been testing very small flakes of purified hBN,” said Caldwell. “We think that we will see even further improvements with larger crystals.”

The researchers calculate that a lens made from their purified crystal can, in principle, capture images of objects as small as 30 nanometers in size. An inch is 25 million nanometers and a human hair is about 100,000 nanometers in diameter. A human red blood cell is about 9,000 nanometers and viruses range from 20 to 400 nanometers.

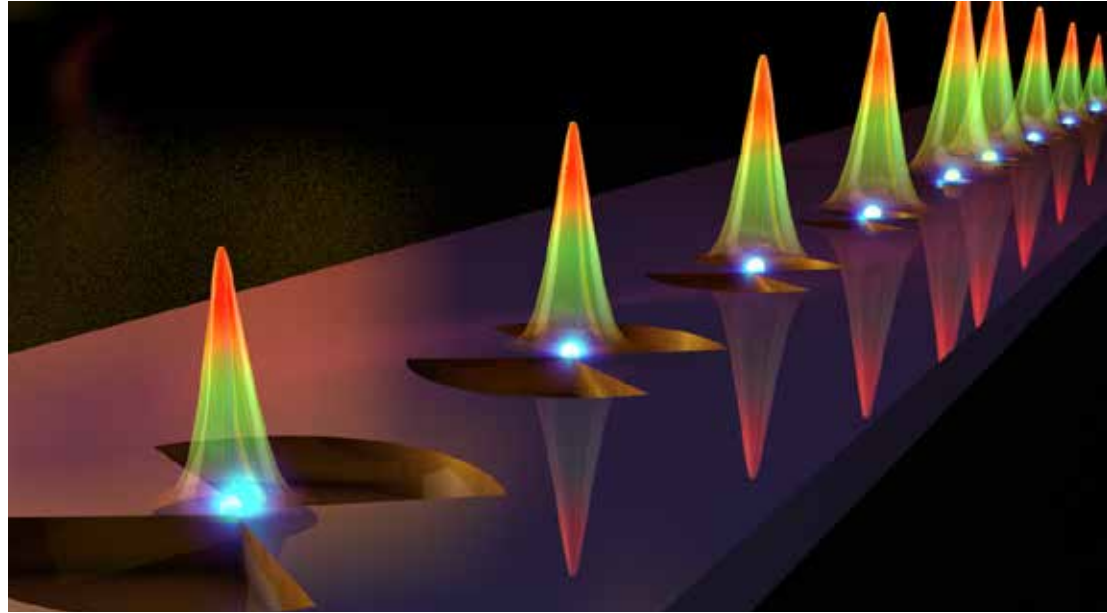
Hyperlenses can provide highly detailed images of living cells in their natural environments using low-energy light that does not harm them. Such capability has significant implications for biological and medical science as well as potential applications in communications and nanoscale optical components.

Various components and participants of this work were funded either in whole or part by the Office of Naval Research, the Army Research Office, the Air Force Office of Scientific Research, the National Science Foundation and the U.S. Department of Energy. Researchers from the University of California, San Diego, Kansas State University, Oak Ridge National Laboratory and Columbia University also contributed to the study.



Joshua Caldwell, associate professor of mechanical engineering, has developed a new hyperlens crystal that can resolve details as small as a virus on the surface of living cells. The atomic structure of the crystal, hexagonal boron nitride, is shown in the cutout. (Illustration by Keith Wood/Vanderbilt)





The team led by Cornelius Vanderbilt Professor of Engineering Sharon Weiss (left) develops a structure that's part bowtie, part funnel and conducts light powerfully and indefinitely, as measured by a scanning near field optical microscope (right). (Ella Maru Studio)

## Bowtie-funnel combination optimal for conducting light

James Clerk Maxwell would be beaming.

The renowned 19th Century Scottish mathematician and physicist's set of equations became the foundation of classical electromagnetism, classical optics and electric circuits. Every college physics textbook contains his work.

So when a Vanderbilt team used Maxwell's formulas

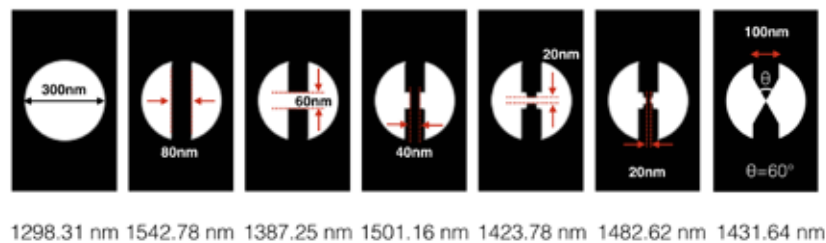
to concentrate light powerfully and nearly indefinitely – allowing computers to run on virtually invisible beams of light rather than microelectronics – reviewers found the solution tough to believe.

Simple and elegant, it applied boundary conditions that account for materials used to Maxwell's long-known equations. And it worked.

The team led by Cornelius Vanderbilt Endowed Chair and Professor of Electrical Engineering Sharon Weiss developed a structure that's part bowtie, part funnel. It concentrates light so intensely that a minute amount of light is highly amplified in a small region.

Only 12 nanometers connect the points of the bowtie. The diameter of a human hair is 100,000 nanometers.

Weiss, her doctoral student, Shuren Hu, and collaborators at the IBM T. J. Watson Research Center and University of Technology in Troyes, France, published the proof in an August 2018 edition of *Science Advances*, a peer-reviewed, open-access journal from AAAS.



doesn't have the same heating issues as the copper wires currently carrying the information in computers," Weiss said. "What is really special about our new research is that the use of the bowtie shape concentrates the light so that a small amount of input light becomes highly amplified in a small region. We can potentially use that for low-power manipulation of information on computer chips."

The team published its work as a theory two years ago in *ACS Photonics*, then partnered with Will Green's silicon photonics team at IBM to fabricate a device that could prove it.

"Light travels faster than electricity and

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Running computers on virtually invisible beams of light rather than microelectronics would make them faster, lighter and more energy efficient. A version of that technology exists in fiber optic cables, but they're much too large to be practical inside a computer.

To find a solution, the team began with Maxwell's equations, which describe how light propagates in space and time. Using two principles from those equations and adding the material-related boundary conditions, they combined a nanoscale air slot surrounded by silicon with a nanoscale silicon bar surrounded by air to make the bowtie shape.

"To increase optical energy density, there are generally two ways: focus light down to a small tiny space and trap light

in that space as long as possible," Hu said. "The challenge is not only to squeeze a comparatively elephant-size photon into refrigerator-size space, but also to keep the elephant voluntarily in the refrigerator for a long time. It has been a prevailing belief in photonics that you have to compromise between trapping time and trapping space: the harder you squeeze photons, the more eager they are to escape."

As measured by a scanning near field optical microscope, the device concentrated the light nearly indefinitely. The team will continue to improve the device and explore its application in future computer platforms. The work was funded by National Science Foundation GOALI grant ECCS1407777.



## FELLOWSHIP EXTENDS NDUKAIFE'S LAB-ON-CHIP WORK TO NIGERIA

An engineering researcher who has developed a new kind of nanotweezers spent several weeks this past summer working with graduate students at the University of Nigeria, Nsukka, on trapping and manipulating biological particles.

Assistant Professor of Electrical Engineering Justus Ndukaife was selected for the Carnegie African Diaspora Fellowship Program, part of

a larger initiative that pairs scholars with one of 43 higher education institutions and collaborators in Ghana, Kenya, Nigeria, South Africa, Tanzania and Uganda.

Nearly three dozen graduate students in electrical engineering, biochemistry, microbiology and physics and astronomy received hands-on exposure to developing and testing a lab-on-a-chip device for isolation and concentration of e-coli bacteria.

The Nigerian students took part in experimental design, packing and assembling nanotweezer chips, culturing benign bacteria samples and imaging bacterial capture. Ndukaife's nanotweezers require less laser power, have more potential to trap and stabilize molecules and allow for higher resolution than previous versions used for lab-on-a-chip applications.

Ndukaife, who won the 2017 Chorafas Foundation Prize in Physics for his nanotweezers work, said the project was very well received by the students.

The Carnegie fellowships, administered by the Institute of International Education, also help build relationships between African and U.S. institutions. Plans here include co-mentoring of graduate students, creating a pipeline to recruit University of Nigeria students to Vanderbilt, and exploring collaborative research grants and student exchanges.

Ndukaife and collaborators have used plasmonics to develop nanotweezers that can rapidly trap and detect molecules, viruses and DNA. They poked holes in gold film smaller than the wavelength of light, a process enabled by surface plasmon resonance, which causes molecules to be trapped near the film and makes them available for study under powerful microscopes.



Assistant Professor of Electrical Engineering Justus Ndukaife (above) works with graduate students at the University of Nigeria, Nsukka, on lab-on-a-chip devices and manipulation. (Submitted photo)

# Gold nanoparticles put shine on defects in 3D printed parts

Gold is eye-catching but the precious metal now has a more practical use. An interdisciplinary team of Vanderbilt engineering researchers has developed a technique for using tiny gold particles to solve a big problem in advanced manufacturing.

The embedded nanoparticles can highlight defects in 3D printed parts.

"This is one of the first applications using gold for defect detection. We are able to inspect and detect defects that aren't visible to the naked eye, using the optical properties of embedded gold nanoparticles," said Cole Brubaker, civil engineering graduate student, and lead author of a published study. "That's a very critical step – being able to say 'We have a defect. It's right here.'"

"3D printed materials are becoming increasingly common in our day-to-day life, from consumer goods and products to even demonstrations of 3D-printed automobiles and homes," said Kane Jennings, chair and professor of chemical and biomolecular engineering, and study co-author. "But there can be problems in the processing. Small defects or missing print layers can occur. These defects can compromise and weaken the structural integrity of 3D printed products, causing failure."

The innovative process mixes the gold nanoparticles, which show up as a deep red color, with a dissolved plastic polymer. Once dried and hardened, the gold-infused material is extruded into polymer filaments for use in standard 3D printers.

The embedded gold nanoparticles, which are about 100,000 times thinner than a human hair, have unique optical properties that don't degrade over time but do flag defects when inspected by a specialized spectrophotometer.

"You just scan light across the surface of the sample and see where the absorbance decreases inside, signaling a defect in that material," Brubaker said. "A defect can be found with one single nondestructive measurement. It's very quick. It takes just a matter of seconds."

The research was funded by the U.S. Office of Naval Research. Patents are pending on the technology and the research findings have been published in the American Chemical Society *Applied Nano Materials Journal*.

"What really gets me excited is the broad range of applications we can use this technology for," he said.



Cole Brubaker, a civil engineering Ph.D. student, creates an innovative process using gold nanoparticles for defect detection in 3D printed parts. Brubaker (left) is collaborating with Kane Jennings, chair and professor of chemical and biomolecular engineering (right).



# Koutsoukos heads \$14 million NSA Lablet to enhance national post-hack resiliency

Cyber-physical systems analyze Fitbit data on a smartphone. They tell a house to bump up the thermostat before evening rush hour and to bump it down when everyone is away for the day. They run traffic lights. Mass transit. Electrical grids.

Whether these systems connecting humans and technology are hackable isn't the question. The challenge is keeping them running after inevitable hacks occur.

The National Security Agency selected a Vanderbilt University team to lead a \$14 million, five-year, multi-university effort to figure out how. The grant funds a Science of Security Lablet—mini-labs aimed at increasing knowledge and collaboration in the field.

"It comes as no surprise that basic systems in America are not as secure as we would like them to be," said Xenofon Koutsoukos, the new Lablet's principal investigator and a professor of computer science, computer engineering and electrical engineering.

"The main motivation is to stop being reactive and start being proactive by designing resilient systems," he said. "We need to understand the foundational principles of cyber-physical systems, develop methodologies to keep them going when they're compromised, and then build these solutions in on the front end."


Most of the Vanderbilt team is affiliated with the Institute for Software Integrated Systems, whose founding director, Janos Sztipanovits, the E. Bronson Ingram Professor of Engineering, is a renowned researcher in the field of cyber-physical systems. He and six other Vanderbilt School of Engineering professors are on the grant, along with Jennifer Trueblood, assistant professor of psychology.

University of California–Berkeley, Massachusetts Institute of Technology and University of Texas at Dallas also are involved in the massive project. An MIT political scientist, for example, is developing analytics for cyber-physical systems cybersecurity policy.

"We have a critical mass of talent at Vanderbilt," Koutsoukos said. "That only gets stronger when you add in our partners. We wanted a strong, interdisciplinary team."

Understanding and accounting for human behavior is one of the five "hard problems" identified by the NSA's Science of Security program, along with scalability and composability, policy-governed secure collaboration, security metrics and resilient architectures.

"End users are a critical link in the cyber-security chain," said Trueblood, who uses computational modeling to predict human behavior. "Users often make poor decisions, for example, clicking on suspicious links. Through computational modeling and experimentation, we can uncover how users think about cyber-physical systems, ultimately leading to the development of tools for improving cyber-security behavior."



“It comes as no surprise that basic systems in America are not as secure as we would like them to be.”

**Xenofon Koutsoukos**

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## BUILDING SOCIAL VALUES INTO THE IoT

An ambitious new international, interdisciplinary project will develop and test the concept of incorporating social norms, policies and values into the basic architecture of smart devices.

“The fusion between people, computing and the physical environment is becoming so deep that it is getting harder and harder to tell them apart,” said Janos Sztipanovits, E. Bronson Ingram Professor of Engineering and one of four principal investigators on the five-year project.

The \$4 million project is funded through NSF’s PIRE program.

“Science of Design for Societal-Scale Cyber-Physical Systems” will develop prototype policy-aware systems in three domains: connected vehicles, including self-driving cars, smart grid energy systems, and unmanned aerial vehicles.

“It is not surprising that societal tensions are developing,” Sztipanovits said.

The evolution of the Internet of Things creates winners and losers. Take route-planning apps. Individual drivers win with reduced commute times. Society, as a whole, wins because the system helps balance overall traffic flows. But those who live on neighborhood

streets that now experience increased traffic lose.

“How do we resolve conflicts like this?”

Social norms vary greatly. In the U.S., for example, people are much more suspicious of government than big business. In Europe, the reverse is true. People generally view big companies as evil and government as benign, Sztipanovits said.

“Unless we adopt a new approach, these different social norms will be hardwired into the evolving systems,” he said.

## SMART GRID PLATFORM JOINS LINUX FOUNDATION ENERGY PROJECT

Vanderbilt School of Engineering will contribute both deep expertise and a platform for smart grid applications to a new effort by The Linux Foundation to advance open source innovation in the energy and electricity sectors.

Through LF Energy, The Linux Foundation will host the platform and related projects, providing a hub for multi-vendor collaboration to help seed an open source ecosystem.

Vanderbilt was the initiative's first academic partner. LF Energy also has support from Europe's largest transmission power systems provider, a network that represents 43

transmission system operators from 36 countries, and the Electric Power Research Institute, whose membership represents 90 percent of annual electric utility revenue in the U.S.

"The power industry is increasingly realizing it has to rely on software and putting together the kind of software apps they need is not easy," said Gabor Karsai, associate director of the Vanderbilt Institute for Software Integrated Systems. "Having this software infrastructure and having it open sourced enables faster implementation yet delivers the kind of functionality existing systems cannot."

Karsai, a professor of computer engineering, computer science and electrical engineering, also is principal investigator on The Resilient Information Architecture Platform for Smart Grid, or RIAPS, which provides core services for building effective, secure and powerful distributed software applications. RIAPS enables smart grid control software to run reliably, just as smartphone apps run on platforms like Android and Apple iOS that have become industry standards.

## EXPERTISE IN AUTONOMOUS VEHICLES LANDS NEW PROFESSOR IN FAST LANE

In less than a year since joining the School of Engineering faculty, Dan Work cemented his reputation as an authority on one of technology's hottest topics.

Work studies self-driving vehicles and traffic control. The associate professor of civil and environmental engineering has been tapped as an "expert voice" by tech publisher Axios. He partnered with a major U.S. auto manufacturer on a closed-track test that showed adding one autonomous car to a group of 20 with humans in control ended a typical stop-and-go wave, or "phantom" traffic jam, and reduced fuel consumption by 40 percent.

Though the experiment didn't include the lane changes, merges or wide variations in vehicles that drivers experience on regular roads, future research will, Work said.

When he joined Vanderbilt in December 2017, Work brought his expertise on cyber-physical systems in transportation to a fast-growing city where traffic and transit are top issues. During his transition from the University of Illinois at Urbana-Champaign, he was named a Gilbreth Lecturer for the February 2018 National Academy of Engineering

meeting. *Connected World* put Work on its list 2018 Pioneers, selecting him one of 10 Innovators of IoT (Internet of Things) under age 40.

And he's been invited to give a talk on the future of transportation at The Royal Swedish Academy of Engineering Sciences in June 2019. The international conference will mark the Academy's 100th anniversary.

He is already part of the Vanderbilt Engineering Center for Transportation and Operational Resiliency and collaborating with the Vanderbilt Institute for Software Integrated Systems, a global leader in CPS technologies.

"I'm deeply impressed by what Vanderbilt is accomplishing in this field and by the collaborative nature of the work that happens here," he said. "Nashville is a rich landscape that is going to provide many opportunities to research and develop the latest transportation technologies."





## Research internship reaffirms undergraduate's passion for rehab engineering

by Adrianna Johnson

When I came to Vanderbilt School of Engineering I knew I wanted to learn how to use my interests and talents to better the world by helping others. At a young age I discovered a knack for things mechanical and a love of physical problem solving. Finding a way to combine the two and improve the lives of as many people as possible became my dream.

Over the summer I worked with graduate students and post-doctoral scholars in the Center for Rehabilitation Engineering and Assistive Technology as a researcher in the lab of Assistant Professor of Mechanical Engineering Karl Zelik. I worked mainly with graduate student Matthew Yandell, whose focus is assistive exoskeleton technology, but I also helped others on human gait-related projects. I became IRB certified. With that important credential I could assist researchers with experimental protocols involving human subjects and data collection. During some preliminary trials, I even participated as a subject.

Testing and data collection are important components of this type of research. Processing and analyzing the data is critical, too, and I worked with researchers to turn testing outcomes into meaningful results for use in scholarly papers as well as to support and direct subsequent testing.

And I did get out of the lab, which is so vital for studying human motion. Visiting with a prosthetist, I saw the complexities involved in fitting prosthetic limbs and learned best practices for fitting research devices to subjects.

Those graduate students and postdocs, working in labs that have made great advancements in

the fields of human gait research and exoskeleton devices, are living my dream. Witnessing the amazing findings and innovations that arise from interaction between the human body and creative mechanical devices reaffirmed my desire to help those with mobility impairments and my passion for engineering.

As a rising sophomore, this research experience was an incredible opportunity, which the Clark Scholars Program made possible for me. My summer was exciting, educational and challenging in the best ways possible. I know it will be a key stepping stone in my engineering career and an experience I will never forget.



Adrianna Johnson, a sophomore mechanical engineering major, works on rehabilitative engineering projects during her summer internship funded by the Clark Scholars Program.

**Clark Scholars** A \$15 million gift in 2017 from the A. James and Alice B. Clark Charitable Foundation established the A. James Clark Scholars Program at the School of Engineering. Each year a cohort of 10 students is chosen from the incoming first-year class, and sophomore Adrianna Johnson was in the inaugural group. The program, part of Opportunity Vanderbilt, provides scholarship support to exceptional students with financial need and from underrepresented backgrounds. It emphasizes engineering excellence, business acumen, service learning and leadership—characteristics that the late A. James Clark embodied and wished to cultivate in others. Clark was the president and CEO of Clark Construction.

Engineering undergraduates learn about wind turbines and testing of a new resin for turbine blades from Doug Adams, Daniel F. Flowers Professor and Distinguished Professor of Civil and Environmental Engineering. Adams is also department chair.

## Testing a self-setting resin to improve sustainability of wind turbine blades

In the U.S. alone, wind power avoids the carbon pollution of more than 28 million cars. The “carbon cost” of a typical commercial wind project repays itself in six months, displacing fossil fuels and producing no carbon emissions for decades.



“This composite materials technology is exciting because it closes the loop on sustainability in wind energy.”

**Doug Adams**

But wind power has its costs. The resin that makes 150-foot fiberglass turbine blades strong and durable needs a great deal of time and energy to cure. When the blades reach the end of their lifespan of 20 or 25 years, very little of the material can be recycled.

That problem has a solution in sight, and Vanderbilt engineers are playing a key role. The Laboratory for Systems Integrity and Reliability has tested a new recyclable resin that cures at room temperature and allows the fiberglass blade itself to be recycled.

This new resin by Arkema, called Elium, creates its own heat and cures without creating flaws in the fiberglass. Resins that have been in use destined turbine blades for the landfill.

“This composite materials technology is exciting because it closes the loop on sustainability in wind energy,” said Doug Adams, Daniel F. Flowers Professor and Distinguished Professor of Civil and Environmental Engineering.

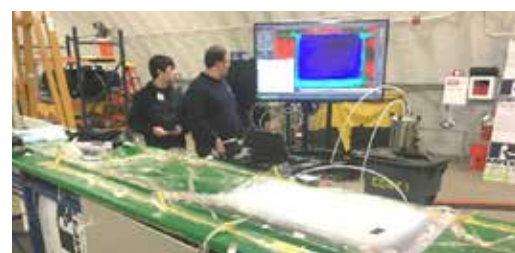
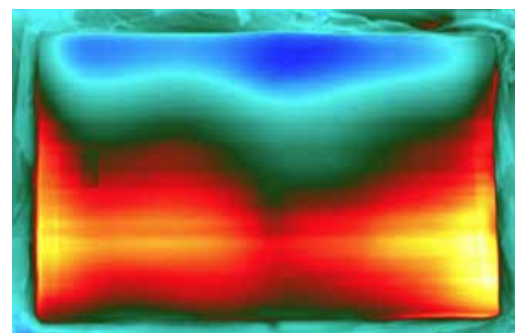
“What better application to look at than wind power, where energy and sustainability are foremost in our minds?” he said. “It’s a grand challenge in composites manufacturing.”

Adams is director of LASIR and chair of the Vanderbilt’s Department of Civil and Environmental Engineering. The challenge, he said, made an ideal project for the Institute for Advanced Composites Manufacturing Innovation, a consortium of industry, government and academic institutions aimed at improving composite materials manufactured for use in turbines, cars, compressed gas storage tanks, airplanes and even sporting goods.

At LASIR, Adams, staff engineers and mechanical engineering graduate student Christopher Nash tested the resin’s self-setting properties using infrared imaging on a nine-meter demonstration blade. They also produced an algorithm for use in setting up the process on the commercial production lines.

Arkema showcased the Elium blade at JEC World in March 2018. Elium is a liquid thermoplastic resin that can be processed with the same manufacturing methods as a thermoset liquid resin. Thermoplastic resins may reduce manufacturing costs and time as well as increase sustainability. Thermoset resins take energy and time to cure but cannot be reheated, which renders components that use them non-recyclable.

As the wind industry grows and wind turbines age, using more sustainable materials increases in importance. The U.S. has more than 54,000 active industrial-scale turbines, each with three blades, and thousands more on the way. The IACMI has a five-year goal of 80 percent recyclability for the composite structures of wind turbine blades.



Testing Elium, a self-curing resin developed by Arkema, takes place at the National Renewable Energy Lab in Boulder, Colorado, and at Vanderbilt’s LASIR facility. The middle image shows a real-time infrared display as the material cures. (Photos courtesy of the Institute of Advanced Composite Manufacturing Innovation, the project sponsor, and NREL)



## FINDING AND FIXING FAILURE POINTS ON THE ROAD TO SAFE SOLID-STATE BATTERIES

Researchers in the race to produce safe, powerful and affordable solid-state batteries have two routes – develop new materials or reengineer existing materials. Assistant Professor of Mechanical Engineering Kelsey Hatzell and her group are tackling the latter by uncoupling physical and chemical transformations within batteries to identify failure points.

And then fixing them.

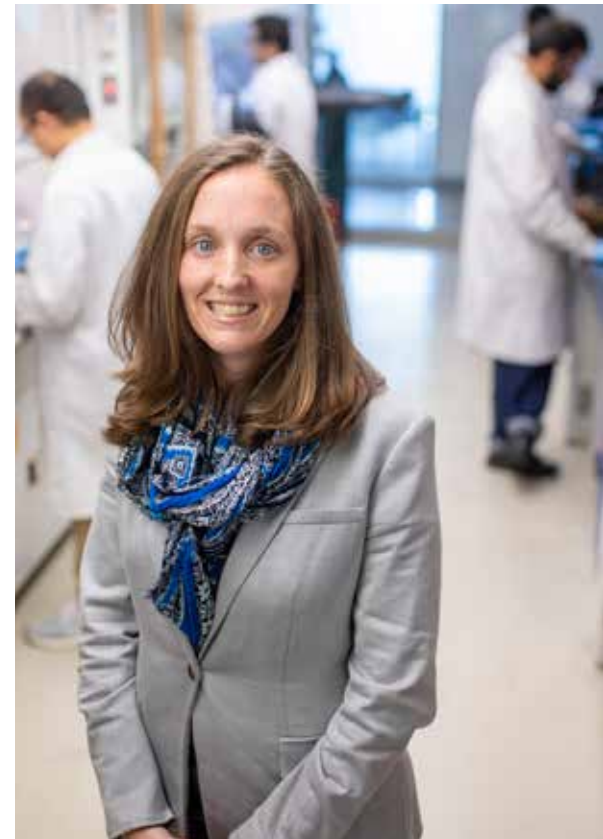
Hatzell's team tested Lithium lanthanum Zirconium Oxide or LLZO. The garnet-type material shows great promise for solid-state batteries due to its high Li-ion conductivity and compatibility with Li metal.

"This is a paradigm shift in energy storage," she said. "These results can potentially inform materials design for the next generation of all solid-state battery systems. The results concluded that the presence of voids or connected pores led to a higher failure rate."

Solid-state batteries are desirable for all-electric vehicles and other applications where energy storage and safety are paramount. Lithium-ion batteries typically contain a liquid organic electrolyte that can catch fire, but the fire risk is eliminated with a non-flammable electrolyte such as LLZO. Replacing liquid electrolytes with a solid organic like garnet also potentially lowers the cost by increasing battery life.

Hatzell's novel research tracked structural changes in LLZO after realistic charging and discharging events using synchrotron X-ray tomography at Argonne National Lab.

The American Chemical Society's *Energy Letters* published Hatzell's findings, "The Effect of Pore Connectivity on Li Dendrite Propagation Within LLZO Electrolytes Observed with Synchrotron X-ray Tomography," online in March 2018. It was among the most read ACS Letters articles that month.



Safe solid-state battery technology drives one aspect of research by Assistant Professor of Mechanical Engineering Kelsey Hatzell and her group.

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### Application deadlines:

**Nov. 15** (for spring '19);

**June 15** (for fall '19)

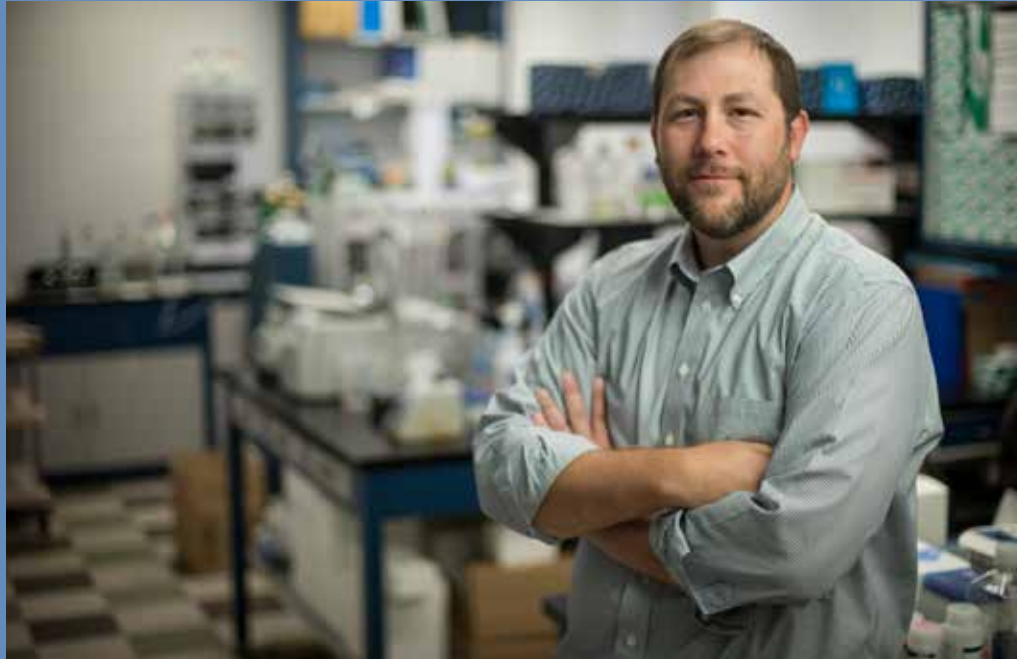
Contact Dr. Joanne Wang at

[joanne.wang@vanderbilt.edu](mailto:joanne.wang@vanderbilt.edu)

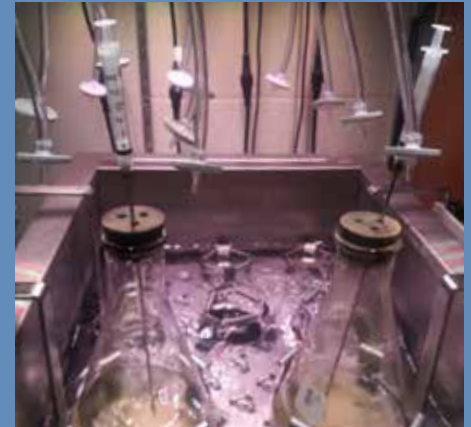
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School of Engineering



Associate Professor of Chemical and Biomolecular Engineering Jamey Young explores diatom metabolism as part of a \$10.7 million DOE project to engineer the microscopic sea algae for biofuel production. He cultures the diatoms in his lab (below) for study. (Young lab photo)



## YOUNG LAB TAKES DEEP DIVE INTO DIATOM METABOLISM

A microscopic, single-celled algae with outsized potential is the focus of a \$10.7 million Department of Energy study into next-generation biofuels.

*Phaeodactylum tricornutum* is a leading contender to improve sustainable production of biodiesel and other products using seawater and carbon dioxide as raw materials. The diatom captures and stores energy from light, grows quickly and contains a high proportion of lipids, which provide essential oils to much of the marine food chain.

Yet how these diatoms do what they do is not well understood. Associate Professor of Chemical and Biomolecular Engineering Jamey Young and his lab have set out to change that. Young is part of a team led by the J. Craig Venter Institute that received the five-year, DOE grant to optimize metabolic networks in photosynthetic microalgae.

Engineered microalgae could play a huge role in creating sustainable energy. Oil-rich photosynthetic algae could produce about 200 barrels of biofuel per hectare of land, according to JCVI, a non-profit genomic research organization based in La Jolla, California. That's 100 times the amount of biodiesel the U.S. now produces from soybeans.

"Diatom photosynthesis is estimated to account for between 25 percent and 40 percent of the nearly 50 billion tons of organic

carbon fixed annually in the sea," Young said, "yet the true potential for light-driven metabolism remains poorly understood."

The goal is to leverage significant recent advances in diatom genome engineering and metabolic modeling to dramatically improve the ability to understand and redirect metabolism in these microbes. *Phaeodactylum tricornutum* is one of only four diatom species for which a complete genome sequence has been generated.

### ENGINEERING MICROBE METABOLISM

A separate project to accelerate metabolic engineering of cyanobacteria, led by Jamey Young, has been recommended for \$1.5 million in funding as part of a \$40 million push by the U.S. Department of Energy. DOE in June 2018 announced plans to accelerate research into transforming microbes as platforms to produce biofuels and other bioproducts from renewable resources. The three-year grant also includes Vanderbilt University faculty from the biology and chemistry departments. Cyanobacteria, an ancient group of photosynthetic microbes, are found in most inland waters and also produce oxygen.



# Google's vast data collection from Android, Chrome at times surprising, study says

*Report accompanies increased scrutiny and worries over digital privacy*

Google may not know whether you've been bad or good but it knows when you're sleeping and when you're awake. If you use an Android device with the Chrome browser running, the tech giant knows whether you are traveling by foot or car, where you shop, how often you use your Starbucks app and when you've made a doctor's appointment.

Cornelius Vanderbilt Professor of Engineering Douglas Schmidt studied Google's data collection practices under a "day in the life" scenario of an Android phone user. The 55-page study, commissioned by Digital Content Next, a trade group representing digital publishers, also detailed data mining over a 24-hour period from an idle Android phone with Chrome running in the background.

The stationary smartphone running Google's Android operating system and Chrome sent data to the company's servers an average of 14 times an hour, 24 hours a day.

"These products are able to collect user data through a variety of techniques that may not be easily graspable by a general user," Schmidt concluded in the paper, released in August 2018. "A major part of Google's data collection occurs while a user is not directly engaged with any of its products."

## Mounting privacy concerns

The study comes amid growing scrutiny of how Google collects data, including lawsuits by consumers who claim the company misled them over its practices when they used their devices in "incognito" mode and attempted to turn off their location history settings.

Also escalating is a larger debate about digital privacy and consideration in Washington D.C. of stricter privacy regulation, a step the European Union took in May 2018. Facebook, too, is under pressure for a range of practices, including how it gathers data even when people aren't using the social media network—through third-party websites that have Facebook "like" and "share" buttons.

"The national conversation about personal data collection by various companies is intensifying, with Americans beginning to understand who's invested in knowing their online behaviors," Schmidt said. "As more information becomes available about which companies are monitoring our online behavior and for what purpose, laws and regulations will need to keep up."

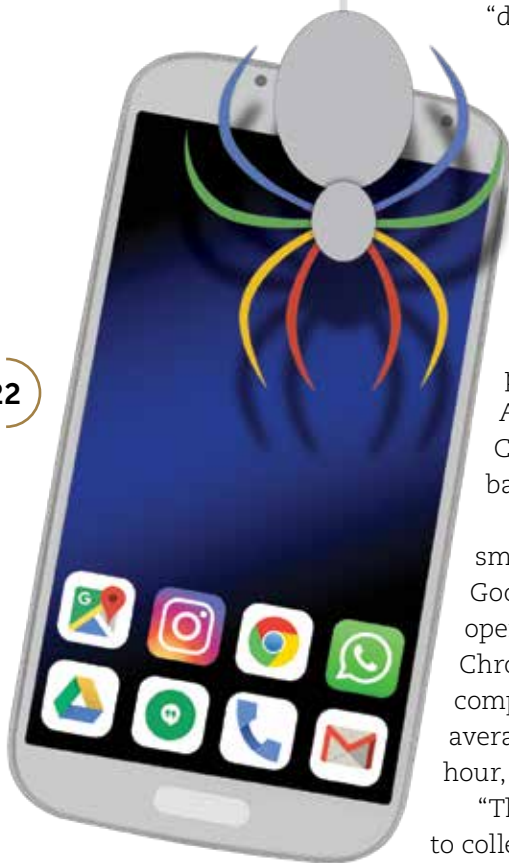
After the study's release, Google questioned its credibility.

"This report is commissioned by a professional lobbyist group, and written by a witness for Oracle in their ongoing copyright litigation with Google. So, it's no surprise that it contains wildly misleading information," the company said in a statement.

"In May of 2016 I was a witness for the Oracle vs. Google 'Fair Use Copyright' trial, which had nothing to do with Google's data collection practices, but have not been involved with this case since then," Schmidt replied. "Moreover, Google has not been able to identify any specific aspects of my report's methods or conclusions as erroneous."

## Phoning home – often

Schmidt studied data gathering from all Google platforms and products, such as Android mobile devices, the Chrome browser, YouTube and Google Photos, plus the company's publishing and advertising services, such as DoubleClick and AdWords.





In the study's scenario, a researcher created a new Google account as "Jane" and carried a factory-reset Android mobile phone with a new SIM card throughout a normal day. While riding the subway to work, she searched for cold medicine and later scheduled a doctor's appointment. From the appointment confirmation email, Google created a calendar event.


She searched for a new lunch spot, took Uber home from work, used Google Play and Google Home for music and watched videos on YouTube.

In all those instances Jane was actively engaged with Google products. The study distinguishes "active data collection" and "passive data collection," which occurs when the user is not using Google products directly.

Surprisingly, Schmidt wrote, "Google collected or inferred over two-thirds of the information through passive means. At the end of the day, Google identified user interests with remarkable accuracy."

What qualifies as passive data? With Chrome running and location enabled, an Android phone is "pinged"

(continued on next page)

 The gray pings represent "passive data" collection via cell towers, Bluetooth beacons and wireless networks throughout the day. (Infographic by Pamela Saxon, Saxon Creative.)



(continued from previous page)

throughout the day by other wireless networks, hot spots, cell towers and Bluetooth beacons. During a short 15-minute walk around a residential neighborhood, for example, Jane's phone sent nine location requests to Google. The requests collected 100 unique basic service set identifiers from public and private Wi-Fi access points.

"Android phones can also use information from the Bluetooth beacons registered with Google's Proximity Beacon feature," Schmidt said. "These beacons not only provide user's geolocation coordinates but also could pinpoint exact floor levels in buildings."

Even when a consumer does not use Google Maps, Google Search, Gmail or YouTube, the company's publisher and ad products collect data as she visits web pages, uses apps and clicks ads. The number of passive data collection events was twice that of active ones.

### Comparing iPhone data

The study also compared data collection from an idle Android phone running Chrome with an idle iPhone running Apple's operating system and the Safari browser. Google did not collect user location information during the 24-hour timeframe. The Android phone communicated with Google twice as often as the iPhone did.

"I found that an idle Android phone running the Chrome browser sends back to Google nearly 50 times as many data requests per hour as an idle iOS phone running Safari," Schmidt said. "I also found that idle Android devices communicate with Google nearly 10 times more frequently as Apple devices communicate with Apple servers. These results highlight the fact that Android and Chrome platforms are critical vehicles for Google's passive data collection."

Schmidt found Google has the ability to identify specific users by combining "user-anonymous" advertiser data with its own collected data. The study could not determine whether the company takes such steps to link de-anonymized data when a user logs into Gmail or other Google services. In its statement, Google said it does not connect the data sources or identify users.

Not using Google's devices or services does limit data collection, but the company's dominant advertising network and tight integration of the Android platform, Chrome browser and other products makes it nearly impossible to block Google from collecting some data, the study said.

"Overall, I found that a major part of Google's data collection occurs while a user is not directly engaged with any of its products," said Schmidt. "The magnitude of Google's data collection is significant, especially on Android mobile devices, arguably the most popular personal accessory now carried 24/7 by more than 2 billion people."

ACTIVE  
DATA SHARING

## PASSIVE DATA SHARING

### Sources used in the study

- Google's My Activity and Takeout tools, which describe information collected during use of Google's user-facing products
- Data intercepted as it is sent to Google server domains while Google or third-party products are used
- Google's privacy policies, both general and product-specific
- Other third-party research that has examined Google's data collection efforts

## DATA SCIENCE INSTITUTE BRIDGES DISCIPLINES AND SCHOOLS AS RESEARCH, TRAINING HUB

Data science is revolutionizing academic fields and emerging as a discipline that provides critical training for students at all levels and interests to create a competitive advantage in their future careers.

Vanderbilt's new Data Science Institute will promote data-driven research in all schools and departments and add courses in data science for undergraduate and graduate students. An initial goal is to design and launch a professional master's-level degree program in data science.

The institute also will support university-wide coalitions since data is becoming the core for research and insight for a broad set of academic disciplines. That support extends to resources for faculty, students and researchers to help spark dramatic advances in academic discovery.

"In research, there's often a problem of recognition," said Padma Raghavan, vice provost for research and professor of computer science and computer engineering. "Data science can filter out the distracting information and reveal the essential. Over the next decade, data science is estimated to have a significant impact across all sectors of the economy, from transportation, manufacturing and construction to health care, urban living and more."

The institute is co-directed by Douglas Schmidt, associate provost for research development and technologies and Cornelius Vanderbilt Professor of Engineering, and Associate Professor of Physics and Astronomy Andreas Berlind.

"We are building a foundation to meet current and near-term needs of data-driven efforts that span research, education and other application domains at the university and beyond, and evolve data science as a trans-institutional discipline that can meet the future needs of data-driven scenarios," Schmidt said.

"And, prepare data-savvy students to shape our future."



### About the study and the author

Digital Content Next, a trade group, commissioned Cornelius Vanderbilt Professor of Engineering Douglas Schmidt to conduct the research. Schmidt is a professor of computer science and computer engineering, associate provost for research development and technologies, and co-director of the Vanderbilt Data Science Institute.

The study, "Google's Data Collection," was made available to the public at Schmidt's request. Visit <https://digitalcontentnext.org/blog/2018/08/21/google-data-collection-research/> to download the report.



# A little nudge goes a long way in activating killer T cells

**Vanderbilt engineers have made a significant leap toward developing killer T cells to attack cancer tumors with far less evidence of disease than long believed – using a nudge so small it can't be seen without advanced microscopy.**

“We can, for the first time, pick the closer on the baseball team who can reliably pitch fastballs,” Lang said. “Which T cell do you pick? Which one do you put back into the patient to fight their disease? Maybe you get lucky and pick the right one. With these new tests, we can measure the interaction under the native, energized state. The good news is these cells are extremely sensitive. We’ve been able to trigger them with as little as two molecules.”

The work by Vanderbilt University Professor of Chemical and Biomolecular Engineering Matt Lang, Yinnian Feng, Ph.D. '18, and their Harvard University collaborators changes what researchers look for in activating T cells for immunotherapy. Now, the task is finding T cells that

demonstrate strong binding potential when they’re flung ever so gently at damaged cells.

Scientists studying the body’s cancer-fighting T cells have faced a serious hurdle: Cultured in the lab, T cells sit at equilibrium, waiting to bump into cancerous cells. Once inside the body, however, they become motorized little bloodhounds and seek out infected cells.

Feng and Lang performed their experiments using optical tweezers – highly focused laser beams – to pick up microscopic spheres and coat them with the same peptides found on diseased cells. They then placed the spheres onto T cells.

With no force, the T cells were thought to go about lackadaisically sniffing out one peptide, then another, then another in a process requiring hundreds or even thousands of binding events before the immune response was activated.

The team applied 10 piconewtons of force to the T cell, equivalent to the gravitational force exerted by dropping 1/1,000th of an eyelash. A special dye applied to the T cell immediately revealed an increase of intracellular calcium, which signals activation. Removing a peptide at a time and testing again, the researchers concluded the T cell can

do its job when this tiny amount of force prompts contact with as few as two peptides.

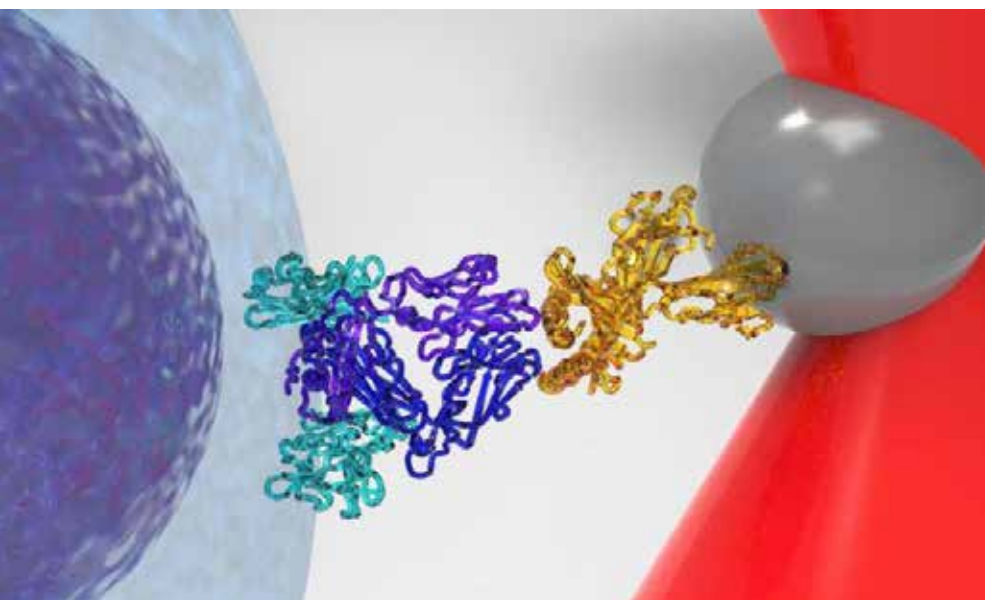
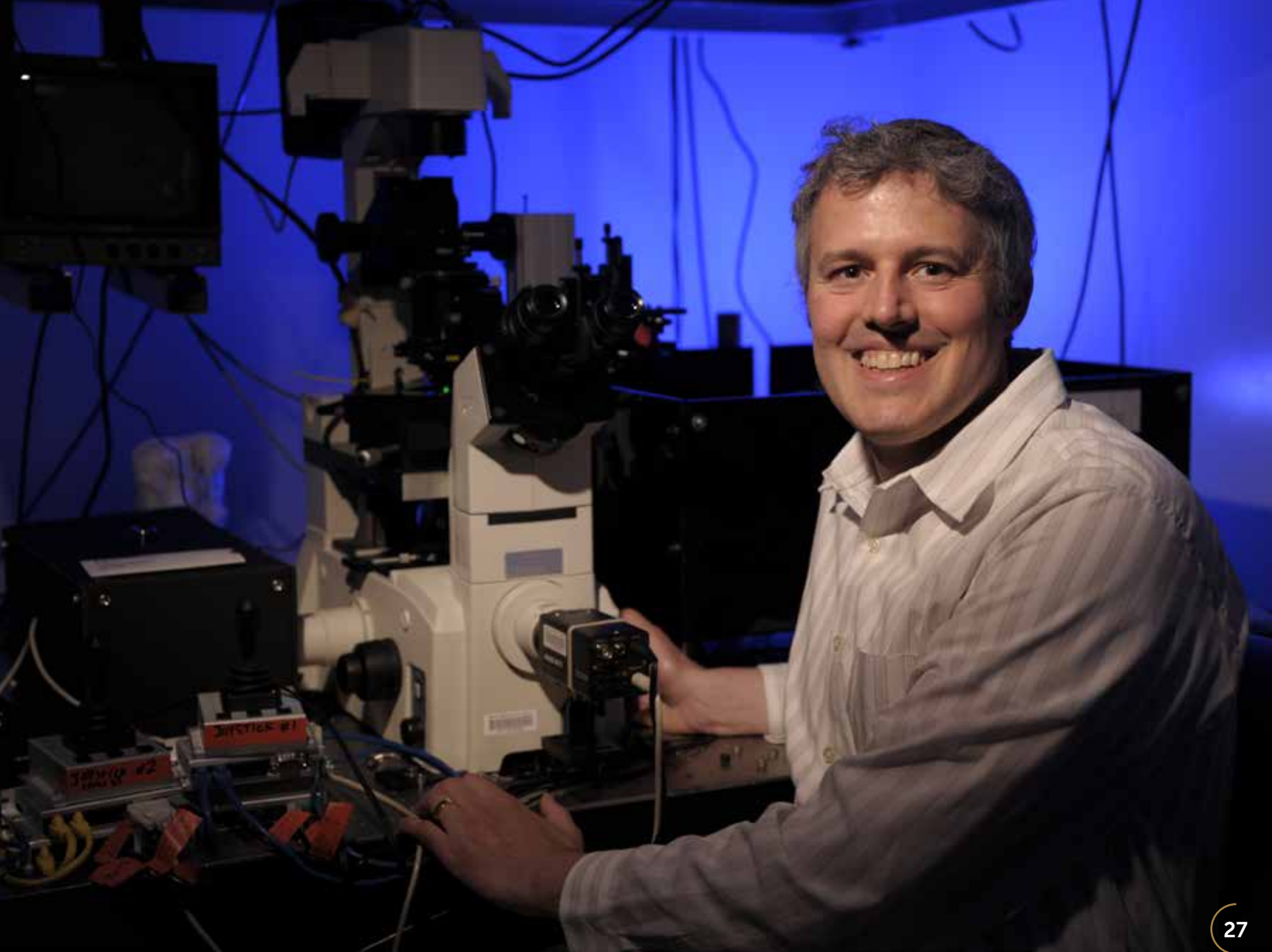
The study involved more than 1,000 individual experiments aimed at triggering T cells given this humanly undetectable push.

“With the very precise microscopes we have, we saw a single binding event,” Lang said. “This project is telling us about the mechanism, about how the system actually works. It’s basically saying that we’re dealing with a mechanosensor that requires force to be activated.”

The work could inform design strategies for T cell therapies, said Dr. Christian S. Hinrichs, an investigator with the National Cancer Institute.

“In the emerging and very promising field of T cell therapy, these findings help us understand at a very basic level how therapeutic T cells are triggered to attack their targets,” he said.

The work, “Mechanosensing drives acuity of  $\alpha\beta$  T cell recognition,” was published in the Proceedings of the National Academy of Sciences, in late 2017. It was supported by NIH Grants R01AI100643 and SU2C-AACR-DT1314.



A wee nudge activates cancer-fighting T cells, based on research by Matt Lang, professor of chemical and biomolecular engineering, and lead author Yinnian Feng, Ph.D. '18. Feng received the School of Engineering's award for best research paper for 2017-18 for the work. A trapped bead (left) decorated with a pMHC ligand is placed on a T cell and pulled to facilitate recognition by the T cell receptor complex. (illustration, Lang laboratory)

# Novel, multiplexed diagnosis could better select patients for immunotherapy

For some cancer patients, immunotherapy performs its mission – enhancing the body’s existing defenses to attack malignant cells. For many, many others it does not work at all, though the failure follows toxic side effects, extra expense and additional invasive biopsies.

A Vanderbilt engineering researcher has made a significant step toward predicting which patients would benefit from immunotherapy before the receiving the treatment.

Rizia Bardhan, assistant professor of chemical and biomolecular engineering, has shown that a novel combination of an enhanced vibrational spectroscopy technique and tagged gold nanostructures can detect important tumor immunomarkers.

The study involved breast tumors but the work has broader relevance. Overexpression of one of the biomarkers, PD-L1, is also seen in melanoma, renal, colon, and non-small cell cancer, among others. The study also successfully and simultaneously diagnosed a second biomarker, epidermal growth factor receptor (EGFR), in triple-negative breast cancer, a highly aggressive disease.

Retrieving PD-L1 biomarker from preserved tumor tissue is very difficult and can result in misdiagnosis. Plus, traditional histology of biopsy samples typically provides only qualitative information.

Bardhan’s team demonstrated that both biomarkers can be detected with surface-enhanced Raman spectroscopy (SERS) in real time in vivo in living tumors tagged with gold nanostars. The biomarker status also was quantified ex vivo in whole tumor sections with SERS, and the researchers achieved near-cellular level resolution with high accuracy.

Gold nanoparticles are biocompatible and safe, and are already in phase III clinical trials to treat multiple cancers and have shown complete remission in prostate cancer patients.

“This would not replace traditional histology but complement it,” Bardhan said. “Incorporating this technique with histology can provide better prognosis and important information for patient-tailored therapies, planning and monitoring.”

Cancer immunotherapies that inhibit checkpoint receptors such as PD-L1 are safer than chemotherapy and radiation and show better patient outcomes. But fewer than 25 percent of patients who receive immunotherapy





Combining surface-enhanced Raman spectroscopy with tagged gold nanostars improves ability to target cancer patients who will benefit from immunotherapy. Assistant Professor of Chemical and Biomolecular Engineering Rizia Bardhan (left) and Yu-Chuan Ou, a fifth-year Ph.D. student, discuss the ongoing research.

to block PD-L1 currently respond to it. Repeat biopsies have been the only way to test whether it is working.

Using this multimodal technique in tandem with classic analysis of tumor samples spares patients from a treatment that won't help them, Bardhan said.

The research lays the foundation for work that combines two modes of analysis – SERS and PET scanning – with tagged gold nanostars. Bardhan received a prestigious Congressionally Directed

Medical Research Programs Career Development Award to develop such a multimodal, multiplexed imaging platform for melanoma diagnosis and treatment evaluation.

This work was done in collaboration with Orrin H. Ingram Professor of Engineering Anita Mahadevan-Jansen, professor of biomedical engineering. The work was recently published in *Nanoscale*, a journal of the Royal Society of Chemistry (United Kingdom).

**The study also successfully and simultaneously diagnosed a second biomarker, epidermal growth factor receptor (EGFR), in triple-negative breast cancer, a highly aggressive disease.**



## \$6.7 million project looks to reengineer concrete with seawater and polymer composites

When Florence Sanchez refers to concrete as a pedestrian material, she doesn't mean we walk on it, though we do.

Sanchez uses "pedestrian" because this infrastructure workhorse is everywhere – sidewalks, roads, housing, office towers, bridges, ports, levees, shopping centers, parking garages, curbs, suburban driveways. Concrete is easy to take for granted, and most people do.

Sanchez, associate professor of civil and environmental

engineering, is not most people. That's why she is playing a key role in a major international project to revolutionize production of concrete using seawater, sea sand and fiber-reinforced polymer composites.

She is a co-Principal Investigator on a \$6.7 million grant from the Hong Kong Research Grants Council to a multi-university team of experts in materials science, chemistry, civil engineering, material deterioration, complex modeling, and other specialties. In all, about two dozen researchers

from eight countries are involved in the ambitious effort, funded by Hong Kong's equivalent of the National Science Foundation. The five-year project also creates opportunities for graduate student and faculty exchanges.

The impact could be huge – concrete is the second most-used substance in the world, behind water. Concrete production is resource-heavy in raw materials and costs to transport them. Fresh water and river sand or crushed stone fines

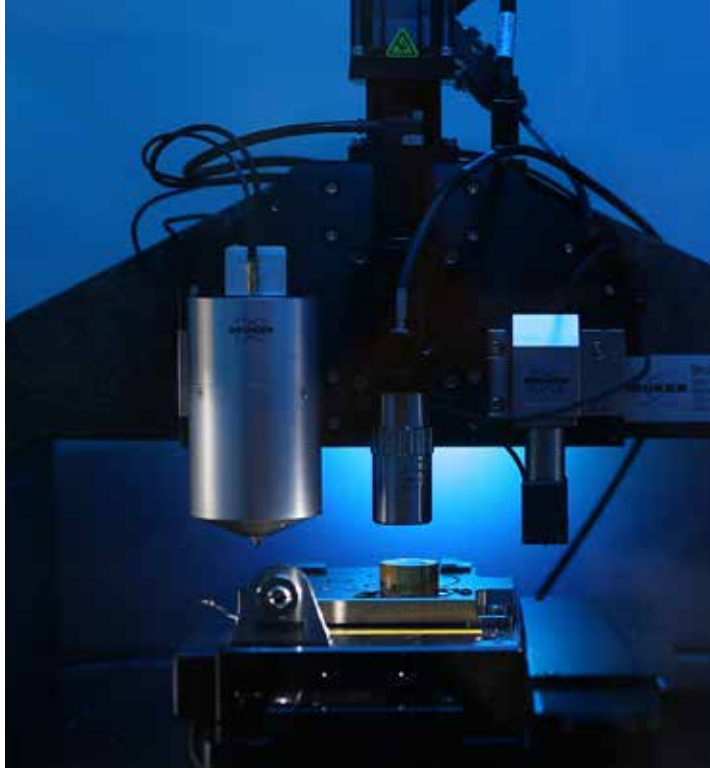


Photo Above, Florence Sanchez, associate professor of civil engineering, and research engineer Lesa Brown examine high-resolution images of structures and interfaces within concrete.

Left, a new nanoindenter, which measures and tests minute volumes of a material's mechanical properties, plays a key role in new concrete research. The nanoindenter and the lab's large 3D printer were purchases as part of the Vanderbilt TIPs project, "Materials Durability and Environmental Research Facilities Hub."

“Concrete is probably one of the most complex materials and one of the best to study. We are surrounded by it but we don't see it.”

**Florence Sanchez**

already are scarce in marine, island and coastal communities, where the steel used to reinforce concrete erodes more quickly.

The supply of fresh water and sand is not infinite. Rapidly growing middle classes in countries such as India and China and economic development across the globe have created pressure to find more sustainable production methods and materials.

The team's key challenge is understanding and predicting the life-cycle behavior of structures made from seawater-sea salt concrete and fiber-reinforced polymer composites, or FRPs. They also will develop a life-cycle design methodology based on multiscale physics modeling of

material and structure degradation that includes accelerated lab tests in controlled environments and field exposure tests over a limited period.

“This project combines structural engineering with materials science and applied research and fundamental science,” said Sanchez, an expert in molecular dynamics simulation of composite materials. She is deputy leader for one of five primary project research areas – material deterioration and constitutive modeling.

Specifically, she will investigate how the materials react with each other and their target environments at the molecular level. Of particular interest are chemical, mechanical, and environmental

interactions at interfaces of the new concrete components with each other and the FRP that will replace traditional steel rebar as reinforcement.

These highly durable composites do not corrode, though they do slowly deteriorate in aggressive environments. FRP is predicted to retain 75 percent of its strength after 100 years, according to the research proposal, at a life-cycle cost that may be half that of steel reinforcement.

“Concrete is probably one of the most complex materials and one of the best to study,” Sanchez said. “We are surrounded by it but we don't see it, but without this we wouldn't have infrastructure.”



# Studying radiation effects on 3D electronics

Three-dimensional integration dramatically reduces the size and weight of electronics. It also eliminates the significant power consumption and signal slowdown of conventional chip-to-chip electronic connections on circuit boards.

But as industry looks to enhance performance and capabilities by building up, stacking multiple integrated

circuits creates complex problems. Putting 3D integrated circuits in space adds even greater dimensions of entanglement.

Vanderbilt already has the world's largest university-based program in radiation effects on microelectronics, and now the Vanderbilt Institute for Space and Defense Electronics will lead an international team of researchers investigating how radiation affects 3D electronics and systems.

The three-year \$3 million basic research grant is from the Defense Threat Reduction Agency, an arm of the U.S. Department of Defense, but the work has significant implications beyond classic national defense. Space-based electronics are core components of communication systems, supporting near global adoption of mobile devices, and will become more vital to Internet of Things applications, from medical implants to smart appliances, autonomous vehicles and entire automated buildings.

The nature of 3D circuitry introduces new paths through which the radiation travels on the way to specific layers, said ISDE Associate Director Mike Alles. This may shield or enhance the effects and also introduces the potential for more, simultaneous errors due to a single radiation particle.

"This complicates the process because each layer is seeing a bit of different radiation environment locally," said Alles, principal investigator on the project. "These types of integrated structures are relatively new and still developing, so there is a lot of interest in understanding the associated reliability implications."

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## LOCK CLOSURE STUDY SPOTLIGHTS HIGH COST OF INFRASTRUCTURE FAILURE

Unscheduled lock closures create costly ripple effects across the shipper supply chain – adding more than \$1 billion in additional transportation expenses annually and disrupting state economies along U.S. inland waterways.

The study by researchers from the Vanderbilt Engineering Center for Transportation and Operational Resiliency and colleagues at the University of Tennessee examines four geographically different locks on inland waterways. It also highlights how the interconnected nature of inland waterways – a strength that helped shape the country – is now a vulnerability.

Most of the 170 locks and dams along 12,000 miles of connected inland waterways have exceeded their design life of 50 years and suffer from "a persistent lack of reinvestment and environmental stresses associated with

extreme weather events that magnify the system's vulnerability," the study said, causing choke points that affect commercial users first.

The findings, said Janey Camp, associate research professor of civil and environmental engineering, demonstrate the importance "of a single component of our aging infrastructure system."

An outage, for purposes of the study, is based on a one-year closure that triggers long-term changes by shippers and carriers. For outages at LaGrange Lock & Dam (Illinois) and Lock & Dam 25 (Missouri), for example, trucking to alternative locations would mean an additional 500,000 loaded truck trips per year and an additional 150 million truck miles in the affected states. The extra financial burden on the shipper supply chain would exceed \$1.5 billion annually.



"This study was a terrific opportunity to explore how disruptions to the transportation network can quickly propagate across the country," said Craig Philip, research professor of civil and environmental engineering and the Vanderbilt principal investigator on the study, which was released by the National Waterways Foundation and the Maritime Administration.

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## Application deadlines:

Nov. 15 (for spring '19); June 15 (for fall '19)

Contact Dr. Joanne Wang at

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VANDERBILT



School of Engineering

VANDERBILT UNIVERSITY SCHOOL OF ENGINEERING | NASHVILLE, TENNESSEE

## MODELING RISK TO MAKE FUTURE AIR TRAVEL SAFER

Statistically, airline travel is the safest mode of transportation but that doesn't make the list of what can go wrong any less troubling.

Low visibility, bird strikes, incorrect landing approach speed, runway debris, airframe icing, engine fires, unexpected weather and sensor malfunctions are but a handful of potential accident causes. They also are among more than 60 incident scenarios identified by an ambitious NASA project to develop the next generation National Airspace System, known as NextGen NAS.

Vanderbilt risk and reliability engineering experts will be involved in simulating many of them. They are playing a key role in a \$10 million, five-year project to integrate complex data sources that will be the future of air traffic management systems. The project is part of NASA's Aeronautics University Leadership Initiative, which gives top academic centers and their industry collaborators a larger role in shaping best practices and translating them into commercial use.

"It is a most consequential project," said John R. Murray Sr. Professor of Engineering Sankaran Mahadevan, professor of civil and environmental engineering and leader of the Vanderbilt team. "Any system you take that has capacities to meet demands is uncertain."

International air travel is expected to double in the next 20 years as aeronautic systems themselves become more complex and automated. Most simply, NASA and the grant recipients want to identify, quantify and prioritize risks that can be best anticipated and address those that would do the most to improve safety.

The project, "Information Fusion for Real-Time National Air Transportation System Prognostics under Uncertainty," is led by Arizona State University. Yongming Liu, ASU professor of mechanical and aerospace engineering and the lead project investigator, is a former Ph.D. student of Mahadevan, as is the lead researcher from Southwest Research Institute and Optimal Synthesis Inc., another collaborating partner.

The group met with NASA and industrial officials at Vanderbilt in August 2018 for an annual review, during which agency officials said "work so far has been great in the spirit of entrepreneurship and the technical progress has been amazing."



# Smart prosthetic ankle improves gait, stability on stairs and rough terrain

**Mike Sasser's left leg is a prosthetic one though you wouldn't know it. After a decade of practice, he moves surely and swiftly through his busy days as a consultant and father.**

Until he encounters uneven ground or a flight of stairs. Then, because using a prosthetic on such terrain can mean taking a tumble, Sasser must intently focus on balance.

A new smart prosthetic ankle from the lab of Michael Goldfarb, H. Fort Flowers Professor of Mechanical Engineering, made a huge difference, said Sasser, who worked for years with Goldfarb and his team to test the device.

"I've tried hydraulic ankles that had no sort of microprocessors, and they've been clunky, heavy and unforgiving for an active person," Sasser said. "This isn't that. It actually lifts the toe for you. There's a definite market for this."

His optimism is shared. Goldfarb, graduate student Harrison Bartlett and postdoctoral scholar Brian Lawson launched startup Synchro Motion LLC to commercialize the ankle. In late August 2018, the team placed second in 36|86 Student Edition, a pitch contest for university-generated companies and part of the high profile annual entrepreneurship conference Nashville. Synchro Motion also was the first to finish the National Science Foundation's National Innovation Corps program from Vanderbilt University's new I-Corps site.

I-Corps teams receive grants to help them explore the commercial potential of devices they've designed. Through the program, participants determine if their invention is truly different from existing technology and, once validated, develop a go-to-market commercialization.

Prosthetic ankles available now are static, meaning users can't adjust their feet to different terrains. Many swing the prosthetic leg outward ever so slightly during regular walking to make up for feet that don't naturally roll through the motion of walking.

The smart ankle has a tiny motor, actuator, sensors and chip that work together to either conform to the surface the foot is contacting or remain stationary, depending on what the user needs.

Goldfarb also developed the world's first easily portable, wearable robot – the Indego exoskeleton – which was just selected as a finalist for the R&D 100 Awards. He said the problem with finding workable prosthetic ankles is so pervasive that many amputees wear only one type of shoe after finding something that works best with their device.

*(continued next page)*





Graduate student Harrison Bartlett calibrates a new smart prosthetic ankle that moves with users over rough terrain and stairs, actually lifting the toes.

“It actually lifts the toe for you.”  
**Mike Sasser**

“Our prosthetic ankle is intelligent, so you can wear a dress shoe, a running shoe, a flat – whatever you’d like – and the ankle adapts,” said Goldfarb, co-director of the Center for Rehabilitation Engineering and Assistive Technology. “You can walk up slopes, down slopes, up stairs, and down

stairs, and the device figures out what you’re doing and functions the way it should.”

Lawson handled the electrical engineering on the ankle; Bartlett worked with Sasser, gathering sensor feedback and making adjustments based on both the data and Sasser’s user experience.

As part of the I-Corps program, the team also interviewed nearly 100 potential users to understand what would make the ankle a success.

“I talked to one person whose favorite restaurant was at the top of a long flight of stairs, so they haven’t eaten there in 10 years,” Bartlett said. “Another sat on benches throughout an amusement park while their family enjoyed the rides because they couldn’t be sure about navigating that with their prosthetic. We want to return people to any of the life activities they want to do.”

Robert Grajewski, Evans Family Executive Director of the Wond’ry, also advised the prosthetic ankle team.

“Not only is this team’s technology innovative and unique, it’s designed to help people,” he said. “We knew they had the energy and drive to turn this into a successful business.”

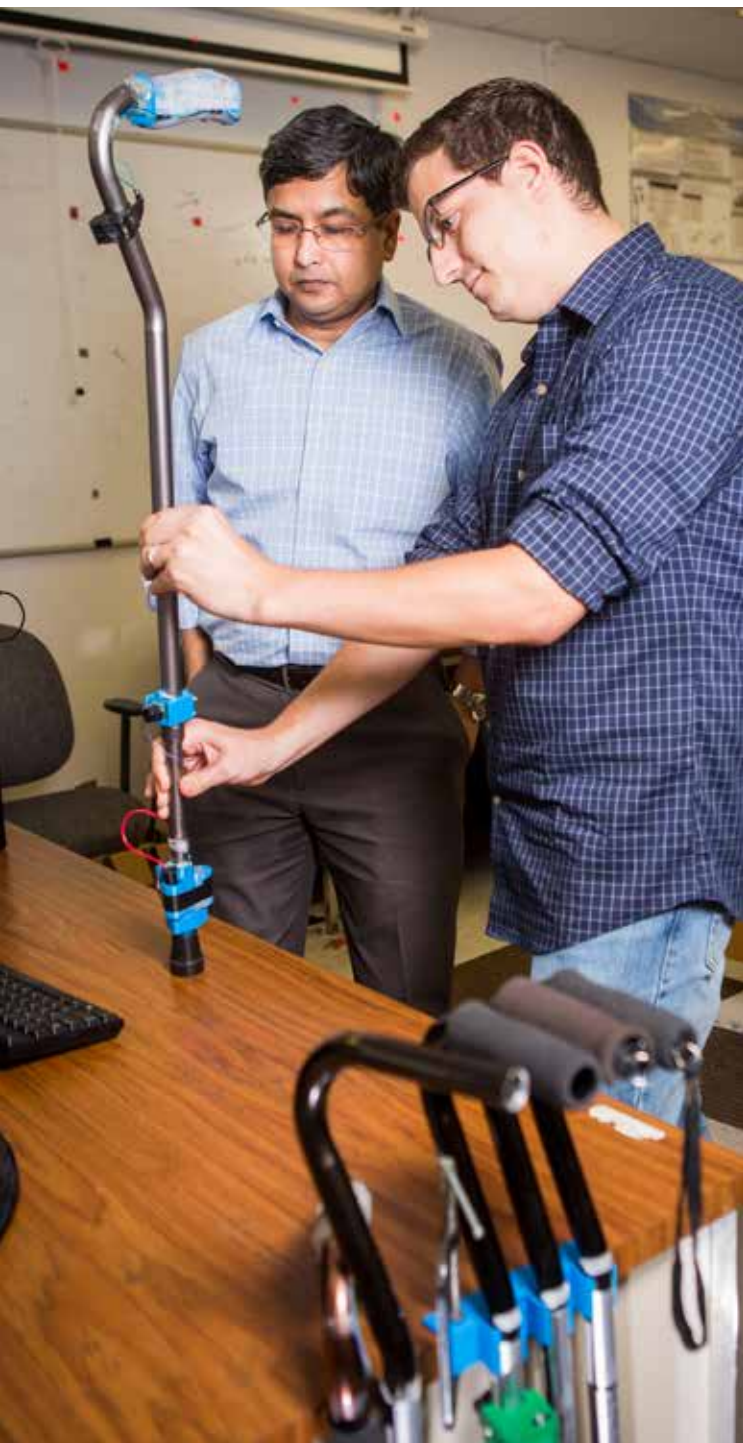
**\$30,000**

The average  
hospital cost  
for a fall injury.

Synchro Motion LLC, a startup launched to commercialize the smart ankle technology, takes second place in a prominent pitch competition after wrapping its I-Corps training.







Nilanjan Sarkar, chair and professor of mechanical engineering, and graduate student Joshua Wade developed IntelliCane, an instrumented walking aid to help therapists collect richer data about patient gait during their everyday lives, enabling quicker intervention if risks of falling increase.

## FLAGGING FALLING RISKS MORE QUICKLY

Reality television aside, falling isn't funny.

It is a serious and costly public health issue that grows in significance as the U.S. population ages. One out of three adults over 65 years of age falls each year; after age 80 the number climbs to one out of two. Many older adults don't survive a serious fall, and treating the resultant hip and other bone fractures, brain injury, and loss of independence among those who do costs more than \$50 billion annually.

When Nilanjan Sarkar, professor of mechanical engineering, realized the scope of the problem, he and his lab set out to engineer a solution. Their answer is an instrumented cane that analyzes gait to determine the risk of falling while still providing support.

The IntelliCane™ can quantitatively calculate falling risk as accurately as a physical therapist can observing the user in person, said Sarkar, who also is chair of the Department of Mechanical Engineering.

"Initially, my thought was to design something to prevent falls, but after more thought and a little experimenting we quickly realized that this was not practical," he said. "The next best thing was to determine how to reliably estimate the fall risk so that intervention can be applied when a person's risk gets so high that they could fall at any time."

Physical therapists estimate falling risk by observing the patient walking back and forth between two lines under different conditions—slow and fast, looking right and left, stepping over obstacles, blindfolded, and up and down steps among them. The therapist uses a standardized rating scale to evaluate patient steadiness and make an overall risk estimate.

But this test cannot always capture a patient's full experience throughout the day, or from day to day, or within their usual environment.

Sarkar and Joshua Wade, a staff research scientist in Sarkar's Robotics and Autonomous Systems Lab, wanted to develop a tool that could help therapists collect much richer data about their patients' gaits as they went about their everyday lives and enable therapists to intervene more quickly. Illnesses that cause balance disorders range from ear infections, head injuries and poor blood circulation to Parkinson's, spinal stenosis and stroke, and these patients also could benefit from such a device.

The engineers rigged an off-the-shelf offset cane with inertial and force sensors connected to a wireless microcontroller that provides real-time user data. An algorithm analyzes the data and extracts information about gait steadiness.

The Vanderbilt Center for Technology Transfer and Commercialization has applied for a patent on the technology. Sarkar and Wade formed Adaptive Technology Consulting to commercialize it and are seeking grants and selecting advisers.





# NIH-funded project is developing steerable robotic needles for lung biopsies

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What started as graduate school research with steerable needles in blocks of gelatin could help pulmonologists more accurately reach sites in the peripheral lung to biopsy them.

A collaboration between that doctoral student – now Professor of Mechanical Engineering Robert Webster III; Dr. Fabien Maldonado a pulmonologist at Vanderbilt University Medical Center; and a colleague at the University of North Carolina received a \$2 million National Institutes of Health R01 grant.

Engineering Ph.D. student Patrick Anderson also is deeply involved in the project. He was among several Vanderbilt Institute for Surgery and Engineering affiliates who gave technical demonstrations of works in progress

during the 2017 VISE Symposium.

“The device combines multiple needles into a flexible structure,” said Anderson, who also was part of the first cohort to take part in a novel NIH-funded training grant for VISE research. “Normally a lung biopsy is an invasive procedure that goes through the ribs and is really painful for the patient.”

“We want to shrink the tools and make them really small,” Anderson said. “We connect them together and control them outside of the body using robot arms. The tools can be flexible or stiff depending on what you want to do with them and they can move in many different ways.”

Significantly, each tool is less than 2 millimeters in diameter, meaning

patients will need only a bandage – not sutures – after the procedure.

Webster’s work on this dates back to 2004 when he began to design a beveled, steerable tip needle.

“We were just doing things in blocks of gelatin to see if we could get steerable needles to go where we wanted them to go. At the time, we had no idea that the lung was where this technology would be most useful for doctors—we were thinking about applications in the prostate and liver,” he said.

Once at Vanderbilt, Webster continued the work but needed a clinical collaborator to help advance the system.

Enter Fabien Maldonado, M.D., an interventional pulmonologist who commonly uses bronchoscopy to



Left, Robert Webster III, professor of mechanical engineering, left, and Dr. Fabien Maldonado, a VUMC pulmonologist, lead a team to develop a steerable robotic needle to more safely biopsy lung nodules that are difficult to reach. Above, Patrick Anderson, a mechanical engineering Ph.D. student, demonstrates the robotic technology at a VISE symposium.

diagnose and treat lung diseases who joined VUMC in 2015. He reached out to Webster on the recommendation of a colleague.

A definitive diagnosis of lung cancer requires biopsy and early diagnosis greatly improves the likelihood of survival. Existing approaches make accurate biopsy challenging or impossible for many hard-to-reach nodules. This system will harness the capabilities of steerable needles to extend the range of bronchoscopes and reliably and safely access nodules throughout the lung, including in the peripheral zone, Maldonado said.

“It will be technically innovative in that it will combine three types of continuum devices that have not previously been unified, will integrate biopsy collection with a bevel tip steerable needle for the first time ever, and will provide a novel physician interface for visualizing and controlling steerable needles in the lung,” Webster said.

This project is funded by National Institutes of Health Grant R01EB024864.

## NEW SPACE OPENS FOR ENGINEERING AND SURGERY COLLABORATION

The Vanderbilt Institute for Surgery and Engineering is moving into its own dedicated space that features a mock operating room and large open areas for research collaboration.

VISE’s new 7,000-square-foot home is a joint effort between the School of Engineering and Vanderbilt University Medical Center. Affiliated clinicians and engineering faculty will maintain their existing offices but work together with post-doctoral students, graduate students and medical students in the new space to accelerate the translation of techniques and methods from the lab to patients.

“This is space that is project-oriented,” said Cornelius Vanderbilt Chair in Engineering Benoit Dawant, director of VISE. “It is in the medical center, close to engineering labs and offices, and close to other campus groups with whom we collaborate.”

Housed in Medical Center North, VISE now will be adjacent to the Vanderbilt Institute for Imaging Sciences, which likewise draws an interdisciplinary group of experts from VUMC and the engineering school as well as the College of Arts and Science.

Among other features of the new space, there will be a small machine shop, a wet lab, development labs, a conference room and offices for staff and postdocs.

Institute staff will begin moving in late October 2018; the official grand opening celebration will be Dec. 12 during VISE’s 7th Annual Surgery, Intervention, and Engineering Symposium.



The Vanderbilt Institute for Surgery and Engineering moves into new, dedicated space this fall. Artist renderings show the large collaborative spaces and a mock operating room.



# Numbers of note

**80%** of graduates have job offers before graduation\*

**5:1**  
graduate faculty ratio

**35**  
student engineering organizations

**53%** of undergrads participate in research projects outside the classroom

**14:1**  
undergraduate:faculty ratio

**38.7%**  
first-year students are women

**#17** best undergraduate engineering program among private research universities\*\*\*

**#10** most innovative universities in the world\*\*

**11.2%** undergraduate international students

**105** faculty honors from 33 societies

**24%**  
undergraduate minority students

**13** institutes, centers and groups

\*U.S. citizen and permanent residents (Class of 2018)

\*\*Reuters, Oct. 2018

\*\*\*US News and World Report, Sept. 2018





# 29%

of the Class of 2018 studied or interned abroad for at least a month\*

\*includes study abroad, exchange and overseas service learning programs

## Innovation to Commercialization

41

### 101

U.S. patent applications filed

### 62

Invention disclosures received

### 25

U.S. patents issued

### 12

License agreements executed

## \$1,135,542

Revenue generated from VUSE technologies

These figures were provided by Vanderbilt's Center for Technology Transfer and Commercialization for the most recent fiscal year (July 1, 2017 through June 30, 2018).

# Selected Honors and Leadership

Unless otherwise noted, the following lists organizations to which Vanderbilt School of Engineering faculty have been elected to as fellows (as of Sept. 1, 2018).

American Academy of Environmental Engineers and Scientists

American Academy of Forensic Sciences

American Association for the Advancement of Science (AAAS)

American Geophysical Union

American Heart Association

American Institute of Aeronautics and Astronautics

American Institute of Chemical Engineers

American Institute for Medical and Biological Engineering

American Physical Society

American Society of Civil Engineers (ASCE)

American Society for Engineering Education

American Society for Laser Medicine and Surgery

American Society of Mechanical Engineers

American Vacuum Society

American Welding Society

Association of Women in Science

Biomedical Engineering Society

Council on Basic Cardiovascular Sciences of the American Heart Association

Electrochemical Society

Engineering Mechanics Institute

Heart Rhythm Society

Geological Society of America

Institute of Electrical and Electronics Engineers (IEEE)

Institute of Physics (U.K.)

Institute of Transportation Engineers

International Society for Magnetic Resonance in Medicine

International Society for Optical Engineering (SPIE)

Materials Research Society

Microscopy Society of America

National Academy of Engineering, Members

National Academy of Inventors

National Academy of Sciences, Advisory Committee Members

National Academy of Sciences, National Associate

Optical Society of America

Prognostics and Health Management Society

Royal Danish Academy of Sciences and Letters

Royal Society of Chemistry (U.K.)

Royal Swedish Academy of Engineering Sciences

U.S. Air Force Scientific Advisory Board, Member

U.S. Nuclear Waste Technical Review Board, Presidential Appointee

# Research Groups

As the engineering arm of an internationally recognized research university, Vanderbilt University School of Engineering fosters strong partnerships inside the university and with its research peers. The combination of innovative research, commitment to education and collaboration with a distinguished medical center creates an invigorating atmosphere where students tailor their education to meet their goals and researchers join to solve complex questions affecting our health, culture and society. Vanderbilt is ranked 20th in federal research and development funding obligations among U.S. colleges and universities.

## **Biophotonics Center at Vanderbilt**

**Anita Mahadevan-Jansen**, Orrin H. Ingram Professor of Engineering, Professor of Biomedical Engineering  
[vanderbilt.edu/vbc](http://vanderbilt.edu/vbc)

## **Center for Rehabilitation Engineering and Assistive Technology**

**Michael Goldfarb**, H. Fort Flowers Professor of Mechanical Engineering

**Karl Zelik**, Assistant Professor of Mechanical Engineering  
[engineering.vanderbilt.edu/create](http://engineering.vanderbilt.edu/create)

## **Consortium for Risk Evaluation with Stakeholder Participation**

**David Kosson**, Cornelius Vanderbilt Professor of Engineering, Professor of Civil and Environmental Engineering  
[cresp.org](http://cresp.org)

## **Institute for Software Integrated Systems**

**Janos Sztipanovits**, E. Bronson Ingram Professor of Engineering  
[isis.vanderbilt.edu](http://isis.vanderbilt.edu)

## **Institute for Space and Defense Electronics**

**Ron Schrimpf**, Orrin H. Ingram Professor of Engineering  
[isde.vanderbilt.edu](http://isde.vanderbilt.edu)

## **Laboratory for Systems Integrity and Reliability**

**Douglas Adams**, Daniel F. Flowers Professor, Distinguished Professor of Civil and Environmental Engineering  
[vu.edu/lasir](http://vu.edu/lasir)

## **Multiscale Modeling and Simulation Group**

**Peter Cummings**, John R. Hall Professor of Chemical Engineering  
[my.vanderbilt.edu/mums](http://my.vanderbilt.edu/mums)

## **Vanderbilt Center for Environmental Management Studies**

**Mark Abkowitz**, Professor of Civil and Environmental Engineering, Professor of Engineering Management

## **Vanderbilt Center for Transportation and Operational Resiliency**

**Craig Philip**, Research Professor of Civil and Environmental Engineering  
[vanderbilt.edu/vector](http://vanderbilt.edu/vector)

## **Vanderbilt Institute for Data Science**

**Douglas Schmidt**, Co-director, associate provost for research development and technologies and Cornelius Vanderbilt Professor of Engineering, Professor of professor of computer engineering and computer science

**Andreas Berlind**, Co-director, Associate Professor of Physics and Astronomy

## **Vanderbilt Institute for Energy and Environment**

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[vanderbilt.edu/viee](http://vanderbilt.edu/viee)

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[vanderbilt.edu/viibre](http://vanderbilt.edu/viibre)

## **Vanderbilt Institute of Nanoscale Science and Engineering**

**Sandra Rosenthal**, Jack and Pamela Egan Professor of Chemistry, Professor of Chemical and Biomolecular Engineering

**Sharon Weiss**, Deputy Director, Cornelius Vanderbilt Professor of Engineering, Professor of Electrical Engineering  
[vanderbilt.edu/vinse](http://vanderbilt.edu/vinse)

## **Vanderbilt Institute for Surgery and Engineering**

**Benoit Dawant**, Cornelius Vanderbilt Professor of Engineering, Professor of Electrical Engineering  
[vanderbilt.edu/vise](http://vanderbilt.edu/vise)

## **Vanderbilt University Institute of Imaging Science**

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