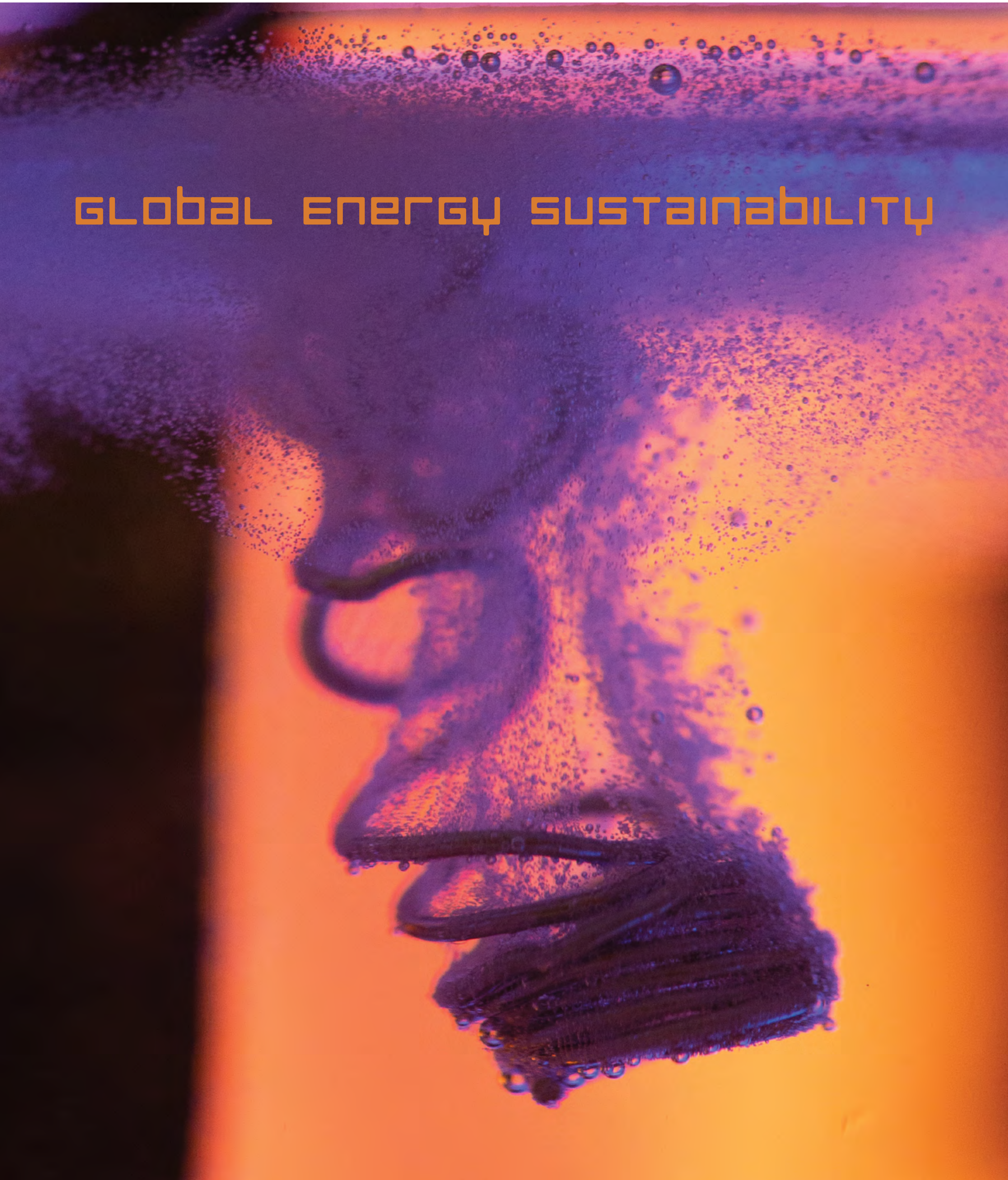
MIT MECHE

MechEConnects

Winter 2020



MechEConnects

News from the MIT
Department of Mechanical Engineering

Winter 2020 | ▸ meche.mit.edu

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Junior Julia Wyatt leaps over a dune in Jordan's Wadi Rum desert. Wyatt worked at an AI traffic management startup in Tel Aviv, Israel this past summer. Credit: Wilson Spearman

MITMECHE

About MechE

One of the six founding courses of study at MIT, mechanical engineering embodies the motto "mens et manus" – mind and hand. Disciplinary depth and breadth, together with hands-on discovery and physical realization, characterize our nationally and internationally recognized leadership in research, education, and innovation.

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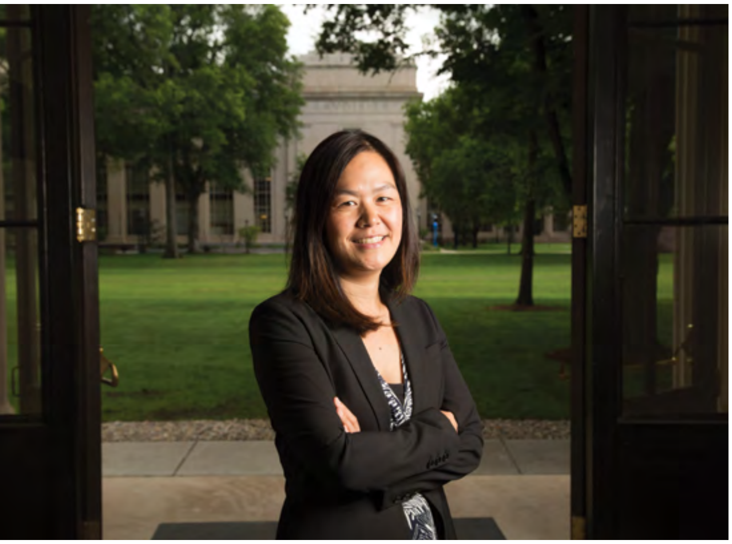
Cover:
Hydrogen bubbles are produced at an electrode during water electrolysis in MIT's Electrochemical Energy Lab. The lab, which is led by Professor Yang Shao-Horn, focuses on gaining an atomic-level understanding of reactions occurring at electrified interfaces during electrochemical water splitting. Credit: John Freidah



Dear Alumni, Students, Faculty, Staff, and Friends,

Several years ago, Professor Pierre Lermusiaux and I served as co-chairs for the department's strategic planning committee. Given the diversity of research in mechanical engineering, one of our goals was to identify unifying grand challenge areas for which our researchers could develop solutions. When looking at areas where we could have the most impact, it became clear that global energy sustainability should be its own grand challenge.

While there is naturally overlap between energy research and one of our other grand challenge areas – health of the planet – we felt that the complexity and scope of developing sustainable energy technologies warranted its own attention. Finding scalable ways to utilize renewable resources for energy and creating solutions to reduce carbon emissions requires a multifaceted approach. Government policies, economic trends, and existing infrastructures all play a role in determining whether or not new energy technologies can be implemented.

Researchers at MIT's Department of Mechanical Engineering have a long history of developing energy solutions for a range of applications. John Lienhard, Abdul Latif Jameel Professor of Water, is working to make desalination more energy efficient. Associate Professor Cullen Buie recently developed a technique to identify electricity-producing bacteria for possible energy harvesting. When President Obama visited MIT in 2009, he met with Professor Alexander Slocum, who presented his research on energy storage for off-shore wind farms.

Finding scalable ways to utilize renewable resources for energy and creating solutions to reduce carbon emissions requires a multifaceted approach.

In March 2019, it was announced that MIT received $30 million from USAID to launch the new Center of Excellence in Energy at three partner universities in Egypt. Two of our faculty, Ahmed Ghoniem, Ronald C. Crane Professor, and Professor Daniel Frey, will lead the Center's collaborative research projects, educational programs, and entrepreneurial activities, all designed to address energy challenges. Given that Egypt is particularly vulnerable to the effects of climate change, the Center presents a unique opportunity for researchers at MIT. As Professor Ghoniem put it when the launch was announced: "If we learn how to solve these problems there, we can learn to scale the solutions and use them in many other places that need them as well."

In this issue of MechE Connects, we highlight some of the technologies our faculty, alumni, and students are developing to promote sustainable energy. From renewable energy conversion to energy efficient windows and cleaner combustion, members of the MechE community are conducting groundbreaking research that could have lasting impact in the fight against climate change.

We hope you enjoy this issue. As always, thank you for your continued support of our department.

Sincerely,

Evelyn Wang, Gail E. Kendall Professor and Department Head

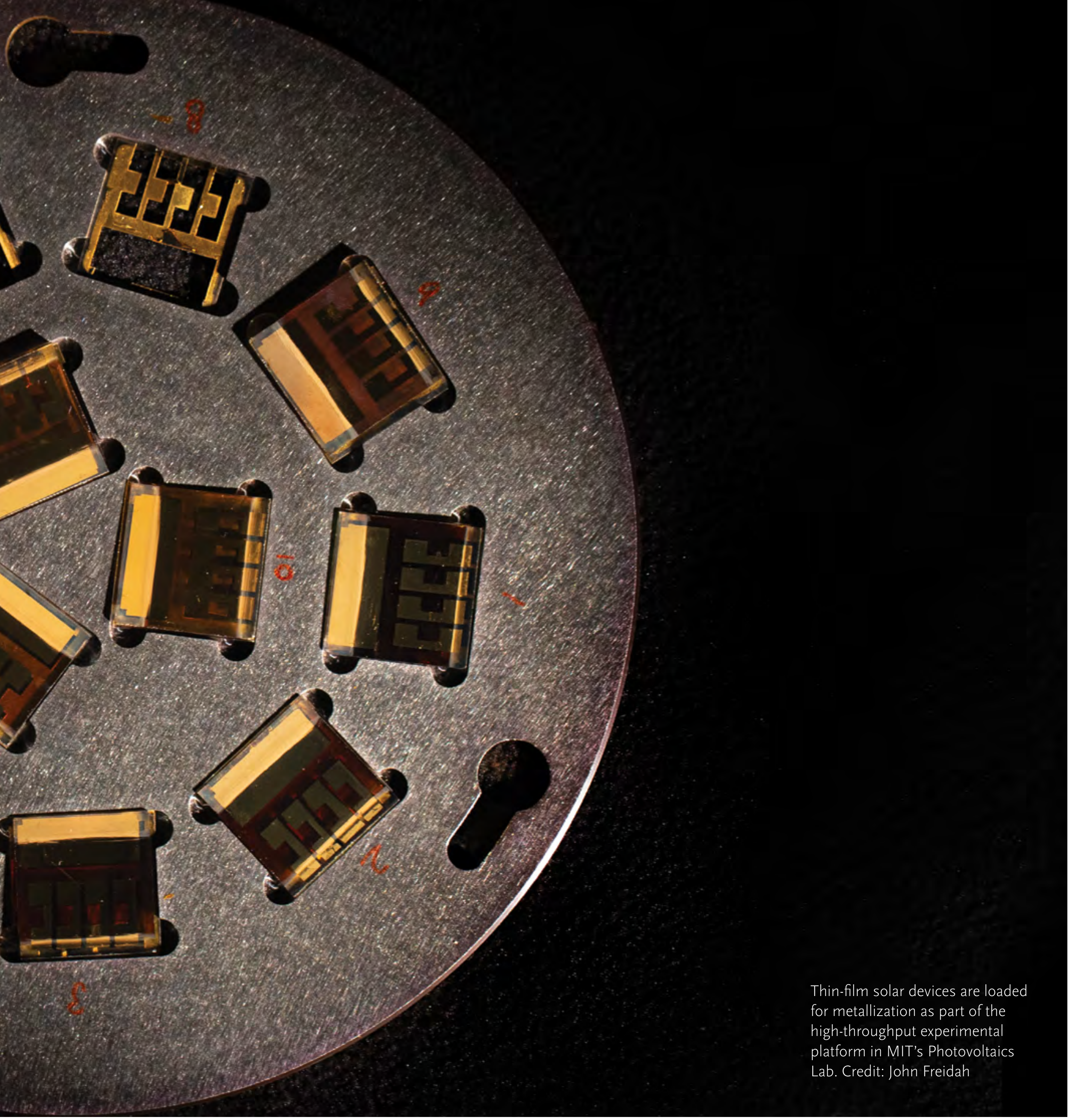
GOING CLEAN

The race to develop renewable energy conversion and storage technologies

By Mary Beth Gallagher

In the early 20th century, just as electric grids were starting to transform daily life, an unlikely advocate for renewable energy voiced his concerns about burning fossil fuels. Thomas Edison expressed dismay over using combustion instead of renewable resources in a 1910 interview for Elbert Hubbard's anthology, *Little Journeys to the Homes of the Great.*

"This scheme of combustion to get power makes me sick to think of — it is so



Thin-film solar devices are loaded for metallization as part of the high-throughput experimental platform in MIT's Photovoltaics Lab. Credit: John Freidah

wasteful," Edison said. "You see, we should utilize natural forces and thus get all of our power. Sunshine is a form of energy, and the winds and the tides are manifestations of energy. Do we use them? Oh, no! We burn up wood and coal, as renters burn up the front fence for fuel."

Over a century later, roughly 80% of global energy consumption still comes from burning fossil fuels. As the impact of climate change on the environment becomes increasingly drastic, there is a mounting sense of urgency for researchers and engineers to develop scalable renewable energy solutions.

"Even one hundred years ago, Edison understood that we cannot replace combustion with a single alternative," adds Reshma Rao PhD '19, a postdoctoral associate in MIT's Electrochemical Energy Lab, who included Edison's quote in her doctoral thesis. "We must look to different solutions that might vary temporally and geographically depending on resource availability" she says.

Rao is one of many researchers across MIT's Department of Mechanical Engineering that have entered the race to develop energy conversion and storage technologies from renewable sources such as wind, wave, solar, and thermal.

Harnessing energy from waves

When it comes to renewable energy, waves have other resources beat in two respects. First, unlike solar, waves offer a consistent energy source regardless of the time of day. Second, waves provide much greater energy density than wind due to water's heavier mass.

Despite these advantages, wave energy harvesting is still in its infancy. Unlike wind and solar, there is no consensus in the field of wave hydrodynamics on how to efficiently capture and convert wave energy. Dick K.P. Yue, Philip J. Solondz Professor of Engineering, is hoping to change that.

"My group has been looking at new paradigms," explains Yue. "Rather than tinkering with small improvements, we want to develop a new way of thinking about the wave energy problem."

One aspect of that paradigm is determining the optimal geometry of wave energy converters – known as WECs. Graduate student Emma Edwards has been developing a systematic methodology to determine what kind of shape WECs should be.

"If we can optimize the shape of WECs for maximizing extractable power, wave energy could move significantly closer to becoming an economically viable source of renewable energy," says Edwards.

Another aspect of the wave energy paradigm that Yue's team is working on is how to determine the optimal configuration for WECs in the water. Grgur Tokić PhD '16, an MIT alum and current postdoctoral associate working in Yue's group, is building a case for optimal configurations of WECs in large arrays, rather than as stand-alone devices.

Before being placed in the water, WECs are tuned for their particular environment. This tuning involves considerations like predicted wave frequency and prevailing wind direction. According to Tokić and Yue, if WECs are configured in an array, this tuning could occur in real-time, maximizing energy harvesting potential.

In an array, 'sentry' WECs could gather measurements about waves such as amplitude, frequency, and direction. Using wave reconstructing and forecasting, these WECs could then communicate information about conditions to other WECs in the array wirelessly, enabling them to tune minute-by-minute in response to current wave conditions.

"If an array of WECs can tune fast enough so they are optimally configured for their current environment, now we are talking serious business," explains Yue. "Moving toward arrays opens up the possibilities of significant advances and gains many times over non-interacting, isolated devices."

By examining the optimal size and configuration of WECs using theoretical and computational methods, Yue's group hopes to develop potentially game-changing frameworks for harnessing the power of waves.

Deployment of the Fred. Olsen Ltd. "Lifesaver" Wave Energy Conversion to the Navy's Wave Energy Test Site in the waters off of Windward Oahu, Hawaii. Credit: U.S. Navy

Professor Tonio Buonassisi, right, and research scientist Dr. Shijing Sun in front of the solar cell fabrication facilities in MIT's Photovoltaics Lab. Credit: John Freidah

Accelerating the discovery of photovoltaics

The amount of solar energy that reaches the Earth's surface offers a tantalizing prospect in the quest for renewable energy. Every hour, an estimated 430 quintillion Joules of energy is delivered to Earth from the sun. That's the equivalent of one year's worth of global energy consumption by humans.

Tonio Buonassisi, professor of mechanical engineering, has dedicated his entire career to developing technologies that harness this energy and convert it into usable electricity. But time, he says, is of the essence. "When you consider what we are up against in terms of climate change, it becomes increasingly clear we are running out of time," he says.

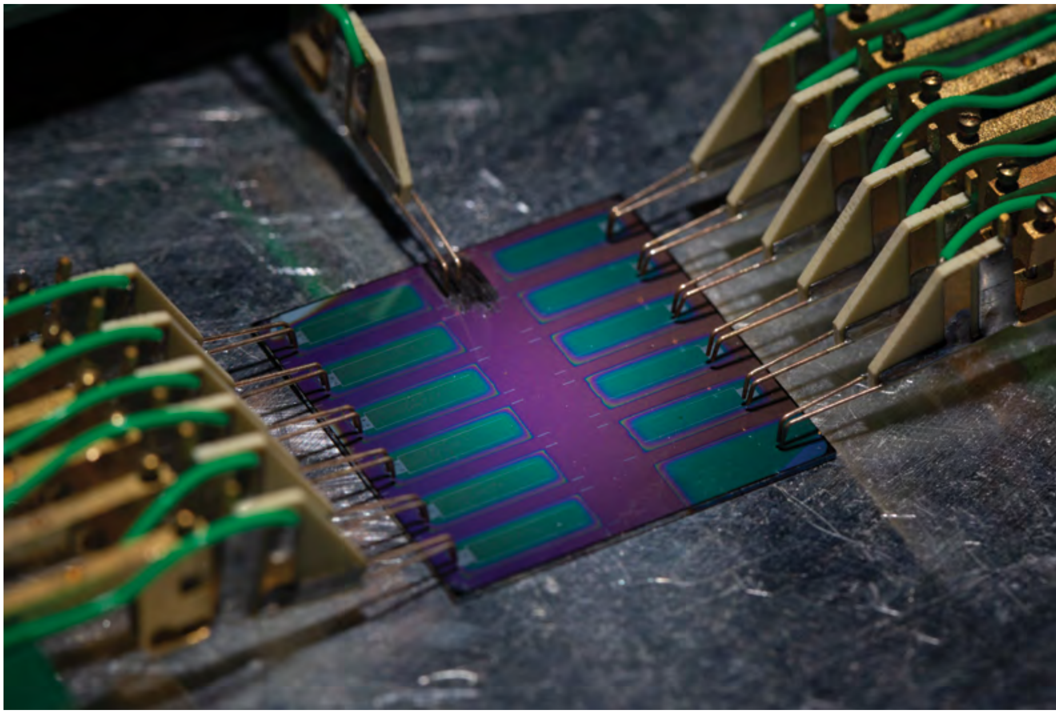
For solar energy to have a meaningful impact, according to Buonassisi, researchers need to develop solar cell materials that are efficient, scalable, cost-effective, and reliable. These four variables pose a challenge for engineers – rather than develop a material that satisfies just one of these factors, they need to create one that ticks off all four boxes and can be moved to market as quickly as possible. "If it takes us 75 years to get a solar cell that does all of these things to market, it's not going to help us solve this problem. We need to get it to market in the next 5 years," Buonassisi adds.

To accelerate the discovery and testing of new materials, Buonassisi's team has developed a process that uses a combination of machine learning and high-throughput experimentation, which enables a large quantity of materials to be screened at the same time. The result is a ten-fold increase in the speed of discovery and analysis for new solar cell materials.

"Machine learning is our navigational tool," explains Buonassisi. "It can debottleneck the cycle of learning so we can grind through material candidates and find one that satisfies all four variables."

Shijing Sun, a research scientist in Buonassisi's group, used a combination of machine learning and high-throughput experiments to quickly assess and test perovskite solar cells.

"We use machine learning to accelerate the materials discovery and developed



Novel perovskite-inspired materials being tested for their photovoltaic potential in MIT's Photovoltaics Lab. Credit: John Freidah

> If in the next five years we can develop that material using our set of productivity tools, it can help us secure the best possible future that we can.

an algorithm that directs us to the next sampling point and guides our next experiment," Sun says. Previously, it would take three-to-five hours to classify a set of solar cell materials. The machine learning algorithm can classify materials in just five minutes.

Using this method, Sun and Buonassisi made ninety-six tested compositions. Of those, two perovskite materials hold promise and will be tested further.

By using machine learning as a tool for inverse design, the research team hopes to assess thousands of compounds that could lead to the development of a material that enables the large-scale adoption of solar energy conversion. "If in the next five years we can develop that material using our set of productivity tools, it can help us secure the best possible future that we can," adds Buonassisi.

New materials to trap heat

While Buonassisi's team is focused on developing solutions that directly convert solar energy into electricity, researchers including Gang Chen, Carl Richard Soderberg Professor of Power Engineering, are working on technologies that convert sunlight into heat. Thermal energy from the heat is then used to provide electricity.

"For the past twenty years, I've been working on materials that convert heat into electricity," says Chen. While much of this materials research is on the nanoscale, Chen and his team at the NanoEngineering Group are no strangers to large scale experimental systems. They previously built a to-scale receiver system that used concentrating solar thermal power (CSP).

In CSP, sunlight is used to heat up a thermal fluid, such as oil or molten salt.

That fluid is then either used to generate electricity by running an engine, such as a steam turbine, or stored for later use.

Over the course of a four-year project funded by the U.S. Department of Energy, Chen's team built a CSP receiver at MIT's Bates Research and Engineering Center in Middleton, Massachusetts. They developed the Solar Thermal Aerogel Receiver – nicknamed STAR.

The system relied on mirrors known as Fresnel reflectors to direct sunlight to pipes containing thermal fluid. Typically, for fluid to effectively trap the heat generated by this reflected sunlight, it would need to be encased in a high-cost vacuum tube. In STAR, however, Chen's team utilized a transparent aerogel that can trap heat at incredibly high temperatures – removing the need for expensive vacuum enclosures. While letting in over 95% of the incoming sunlight, the aerogel retains its insulating properties, preventing heat from escaping the receiver.

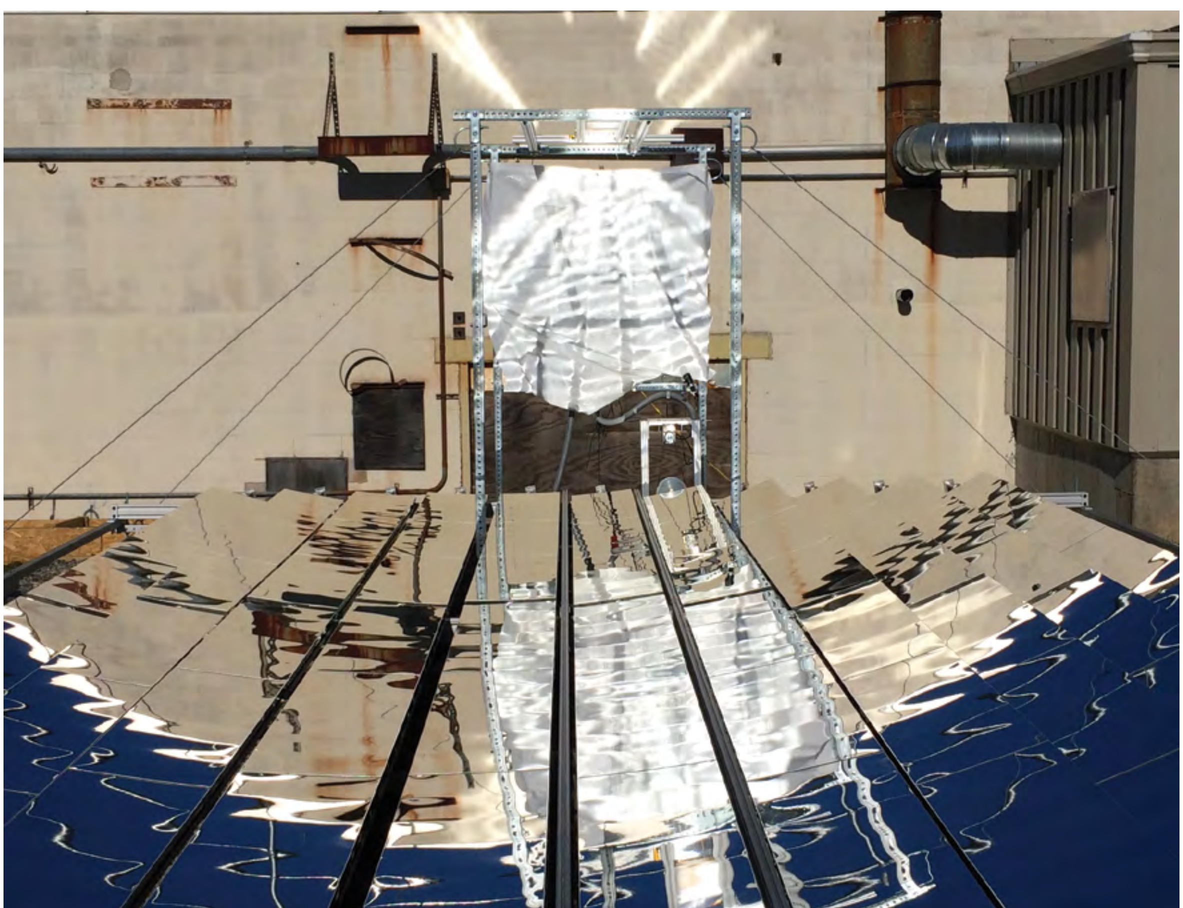
In addition to being more efficient than traditional vacuum receivers, the aerogel receivers enabled new configurations for the CSP solar reflectors. The reflecting mirrors were flatter and more compact than conventionally used parabolic receivers, resulting in a savings of material.

"Cost is everything with energy applications, so the fact STAR was cheaper than most thermal energy receivers, in addition to being more efficient, was important," adds Svetlana Boriskina, a research scientist working on Chen's team.

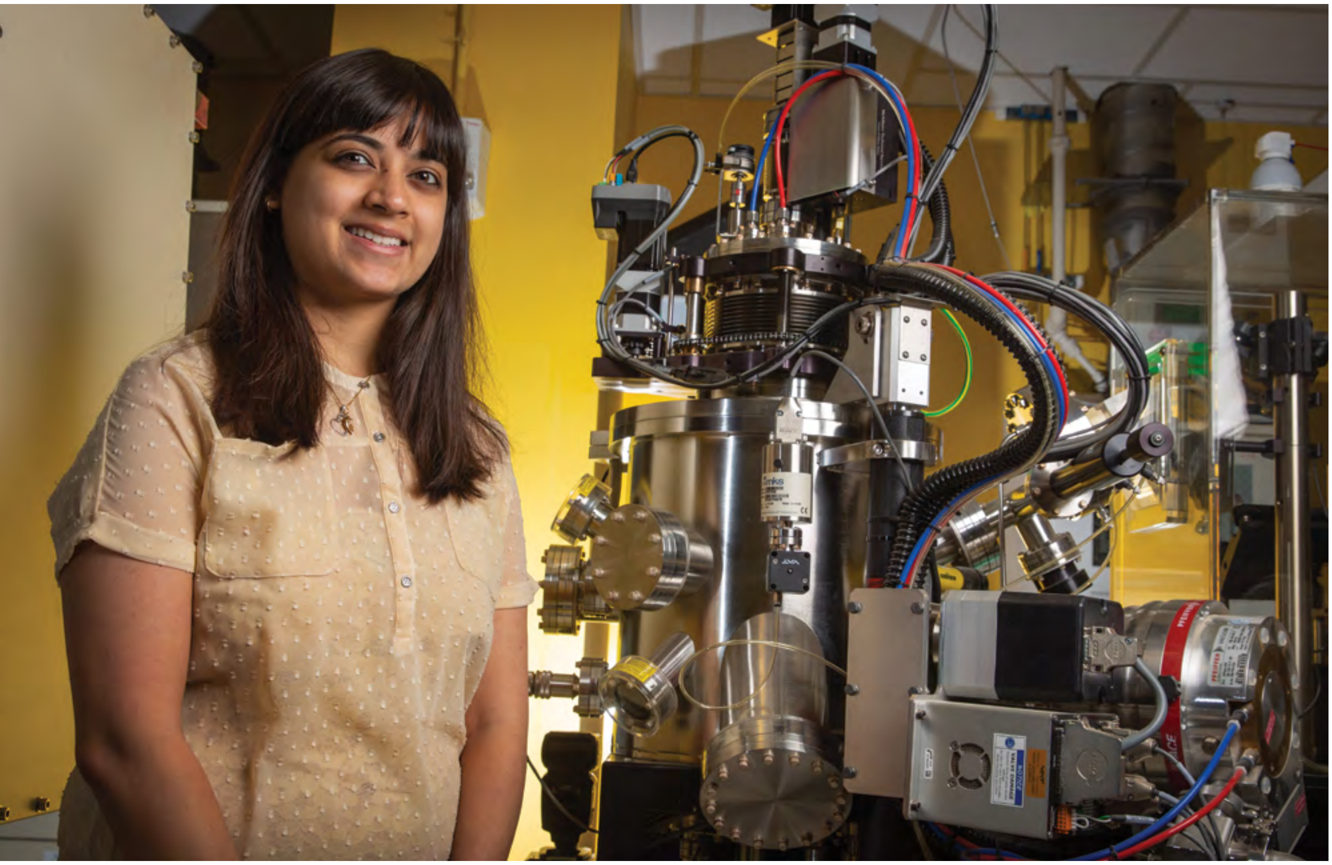
After the conclusion of the project in 2018, Chen's team has continued to explore solar thermal applications for the aerogel material used in STAR. They recently used the aerogel in a device that contained a heat absorbing material. When placed on a roof on MIT's campus, the heat absorbing material, which was covered by a layer of the aerogel, reached an amazingly high temperature of 220°C. The outside air temperature, for comparison, was a chilly 0°C. Unlike STAR, this new system doesn't require Fresnel reflectors to direct sunlight to the thermal material.

"Our latest work using the aerogel enables sunlight concentration without focusing optics to harness thermal energy," explains Chen. "If you aren't using focusing optics, you can develop a system that is easier to use and cheaper than traditional receivers."

The aerogel device could potentially be further developed into a system that powers heating and cooling systems in homes.



Built at MIT's Bates Research and Engineering Center in Middleton, Massachusetts, the STAR – Solar Thermal Aerogel Receiver – utilized a transparent aerogel that trapped heat reflected from rows of mirrors. That heat could then be converted into usable energy. Credit: MIT NanoEngineering Group



Postdoc Reshma Rao stands next to a pulsed laser deposition system, which is used to deposit well-defined thin films of catalyst materials. Credit: Tony Pulsone

Solving the storage problem

While CSP receivers like STAR offer some energy storage capabilities, there is a push to develop more robust energy storage systems for renewable technologies. Storing energy for later use when resources aren't supplying a consistent stream of energy – for example when the sun is covered by clouds or there is little-to-no wind – will be crucial for the adoption of renewable energy on the grid. To solve this problem, researchers are developing new storage technologies.

Asegun Henry, Robert N. Noyce Career Development Professor, who like Chen has developed CSP technologies, has created a new storage system that has been dubbed 'sun in a box.' Using two tanks, excess energy can be stored in white hot molten silicon. When this excess energy is needed, mounted photovoltaic cells can be actuated into place to convert the white hot light from the silicon back into electricity.

"It's a true battery that can work with any type of energy conversion," adds Henry.

Betar Gallant, ABS Career Development Professor, meanwhile, is exploring ways to improve the energy density of today's electrochemical batteries by designing new storage materials that are more cost-effective and versatile for storing cleanly generated energy. Rather than develop these materials using metals that are extracted through energy-intensive mining, she aims to build batteries using more earth-abundant materials.

"Ideally, we want to create a battery that can match the irregular supply of solar or wind energy that peaks at different times, without degrading as today's batteries do," explains Gallant.

In addition to working on lithium-ion batteries like Gallant, Yang Shao-Horn, W.M. Keck Professor of Energy, and postdoctoral associate Reshma Rao are developing technologies that can directly convert renewable energy to fuels.

"If we want to store energy at scale going beyond lithium ion batteries, we need to use resources that are abundant," Rao explains. In their electrochemical technology, Rao and Shao-Horn utilize one of the most abundant resources – liquid water.

Using an active catalyst and electrodes, water is split into hydrogen and oxygen in a series of chemical reactions. The hydrogen becomes an energy carrier and can be stored for later use in a fuel cell. To convert the energy stored in the hydrogen back into electricity, the reactions are reversed. The only by-product of this reaction is water.

"If we can get and store hydrogen sustainably, we can basically electrify our economy using renewables like wind, wave, or solar," says Rao.

Rao has broken down every fundamental reaction that takes place within this process. In addition to focusing on the electrode-electrolyte interface involved, she is developing next-generation catalysts to drive these reactions.

"This work is at the frontier of the fundamental understanding of active sites catalyzing water splitting for hydrogen-based fuels from solar and wind to decarbonize transport and industry," adds Shao-Horn.

Securing a sustainable future

While shifting from a grid powered primarily by fossil fuels to a grid powered by renewable energy seems like a herculean task, there have been promising developments in the past decade. A report released prior to the UN Global Climate Action Summit in September showed that, thanks to $2.6 trillion of investment, renewable energy conversion has quadrupled since 2010.

In a statement after the release of the report, Inger Andersen, Executive Director of the UN Environment Program, stressed the correlation between investing in renewable energy and securing a sustainable future for humankind. "It is clear that we need to rapidly step up the pace of the global switch to renewables if we are to meet international climate and development goals," Andersen said.

No single conversion or storage technology will lead to the shift from fossil fuels to renewable energy. It will require a tapestry of complementary solutions from researchers both here at MIT and across the globe.

> If we can get and store hydrogen sustainably, we can basically electrify our economy using renewables like wind, wave, or solar.

A three-electrode cell setup to measure the activity of catalysts for electrochemical water splitting. Oxygen is produced at the planar Ruthenium Dioxide electrode and hydrogen is produced at the platinum wire. Credit: John Freidah

Student Spotlight:

Peter Godart '15, SM '19, PhD Candidate

Using aluminum debris to power desalination after natural disasters

There are about a dozen aluminum pellets in the palm of Peter Godart's hand. He has been working on harnessing enough energy from these small pellets to power desalination and generate electricity to those who need it most – survivors of natural disasters.

"There's a lot of energy in aluminum debris from natural disasters," Godart explains. "If you pelletize aluminum and treat it with a small amount of gallium and indium, it becomes reactive with water." The resulting reaction generates enough steam and hydrogen to provide the high pressure required for reverse osmosis, a common method of desalination. Godart has named this system Heat-Driven Reverse Osmosis (HDRO).

"Peter's work is significant in that it provides an economical way to recycle materials while providing clean energy and fresh water," adds Douglas Hart, professor of mechanical engineering and Godart's advisor. "It is inexpensive, robust, efficient, and clean – producing no toxic emissions or waste."

The device Godart has constructed to facilitate this system comprises two tube-like vessels connected by pipes. The aluminum fuel reacts with water inside one vessel. The resulting steam and hydrogen creates enough pressure to force seawater through a semipermeable membrane via reverse osmosis. After clean water is generated through this process, the remaining hydrogen can be stored and later used in a fuel cell to provide back-up electricity.

"The beautiful thing about this system is it's super compact, making it ideal for small-scale disaster efforts," Godart explains. "It could also conceivably be something campers, hikers, or sailors have on hand in the event of an emergency."

Aluminum fuel has been a driving force in Godart's academic career. As a mechanical engineering undergraduate at MIT, he took the class 2.013, Engineering Systems Design. During the class, he worked with aluminum fuel. "That experience really inspired me to start thinking about alternative sources of energy," he recalls.

After earning his bachelor's degree, Godart fulfilled a childhood dream and took a position at NASA's Jet Propulsion Lab (JPL) working on the team responsible for operating the Mars Curiosity Rover. While at JPL, he also managed a project that looked into using aluminum fuel to power a lander that could someday be sent to Europa.

One day, Godart had an epiphany about his career path. Rather than focus on energy applications for space exploration, he realized he wanted to devote his attention to researching solutions for problems caused by anthropogenic climate change here on Earth. He called Hart, who was Godart's instructor in class 2.013, went back to the East Coast, and enrolled in graduate school.

PhD candidate Peter Godart turns an aluminum soda can into usable fuel. Credit: Tony Pulsone

"I came back to MIT and immediately started working on energy applications related to climate change mitigation and adaptation," recalls Godart. The spate of destructive hurricanes in 2017, including Hurricane Maria, shaped his work on HDRO.

Godart recently traveled to Puerto Rico while pursuing his other passion – jazz music. Since the age of six, he has played the piano and written music. As an Emerson Fellow at MIT since his freshman year, he has composed and performed music with the MIT Festival Jazz Ensemble, the MIT Wind Ensemble, and numerous small groups on campus and around Boston. This past year, Godart traveled with the MIT Festival Jazz Ensemble to perform in Puerto Rico with saxophonist Miguel Zenon and went with the MIT Wind Ensemble to the Dominican Republic.

"I got to see first-hand the aftermath of Hurricane Maria," he says. Seeing the resulting trash that had accumulated in parts of Puerto Rico reinvigorated his current research focus. "I want to take the world's aluminum trash that's sitting in landfills and extract the energy from it."

In addition to looking into how to turn things like soda cans into usable fuel, Godart has shifted to studying the technoeconomics of how aluminum energy conversion can be implemented in different regions of the world. While he examines ways to make aluminum waste more valuable locally, Godart will continue to experimentally work on his HDRO system. He was recently named a Martin Family Society Fellow for Sustainability, a Hugh Hampton Young Fellow, and a J-WAFS Fellow for Water Solutions.

The beautiful thing about this system is it's super compact, making it ideal for small-scale disaster efforts.

These aluminum pellets can be used to generate enough energy to power desalination and generate electricity for natural disaster survivors. Credit: Tony Pulsone

Alumni Profile:

RJ Scaringe SM '07, PhD '09

Building the world's first all-electric adventure vehicle

Last November, much of the buzz at the Los Angeles Auto Show was generated by a company few people had heard of. According to RJ Scaringe SM '07, PhD '09 founder and CEO of Rivian Automotive, that was entirely by design. "Prior to the LA Auto Show, the world didn't know much about us," explains Scaringe. "We took the decision as a company to be completely quiet as we were building our product portfolio and developing new technologies."

After maintaining a low profile for the better part of a decade, Rivian unveiled its first two products at the auto show: the R1T pickup truck and the R1S SUV. Both vehicles are fully electric and powered by a battery that lasts 400 driving miles when fully charged. Since unveiling these products, Rivian has announced over $1.5 billion of investments from companies like Amazon, Ford, and Cox Automotive. This fall, they also announced a plan to manufacture 100,000 electric delivery vehicles for Amazon – the largest-ever project of its kind.

The launch of the R1T and R1S in 2020 will be the culmination of a journey that has its roots in MIT's Sloan Automotive Lab, where Scaringe conducted his master's and doctoral research under Professor Wai Cheng. He studied how to extend the load limit of homogeneous charge compression ignition engines, an internal combustion engine with low emissions.

"RJ was a low-key but productive student," recalls Cheng. Cheng remembers one of Scaringe's fellow students describing him as the nicest guy around, except on the basketball court where he demonstrated his ambitious side. "That comment sums up his personality and drive," adds Cheng.

After graduating with his doctoral degree in 2009, Scaringe's drive led to him founding Rivian. In its first two years, Rivian's main focus was on developing an electric sports car. But in 2011, Scaringe took a step back to reexamine his company's priorities.

"It became increasingly clear that we weren't answering a question that the world needs an answer to," says Scaringe. He and his team took the bold move to scrap their work on an electric sports car and really consider what the world needs. They landed on their raison d'être: to develop electric vehicles that promote an active lifestyle and facilitate trips that generate lifelong memories.

"We wanted to embed vehicles with a technology platform that helps drive sustainability and gets more electrically powered miles on the road," Scaringe explains. It was at that point the company pivoted to the development of electric trucks and SUVs, and subsequently went radio silent as they developed the R1T and R1S.

Both cars have four motors that enable complete control of torque at each wheel – ensuring a level of control suitable for

We wanted to embed vehicles with a technology platform that helps drive sustainability and gets more electrically powered miles on the road.

The R1T pickup truck is powered by a smart battery management system that makes real-time adjustments to improve both the performance and health of the battery system. Credit: Rivian Automotive

off-roading. These four motors are powered by a smart battery management system (BMS).

Rivian's BMS observes driver and vehicle behavior such as the duration and frequency of charging periods. Using this information, the BMS makes real-time adjustments to improve both the performance and health of the battery. "We use the statistical knowledge of how the vehicle is being used to adjust the control algorithms within the BMS," Scaringe explains.

For Rivian, promoting sustainable energy doesn't stop with the end of a vehicle's life. Their batteries have been designed to have 'second-life' applications in energy storage. "We see second-life applications becoming much more important, which is why we are including them in our front-end designs," Scaringe adds.

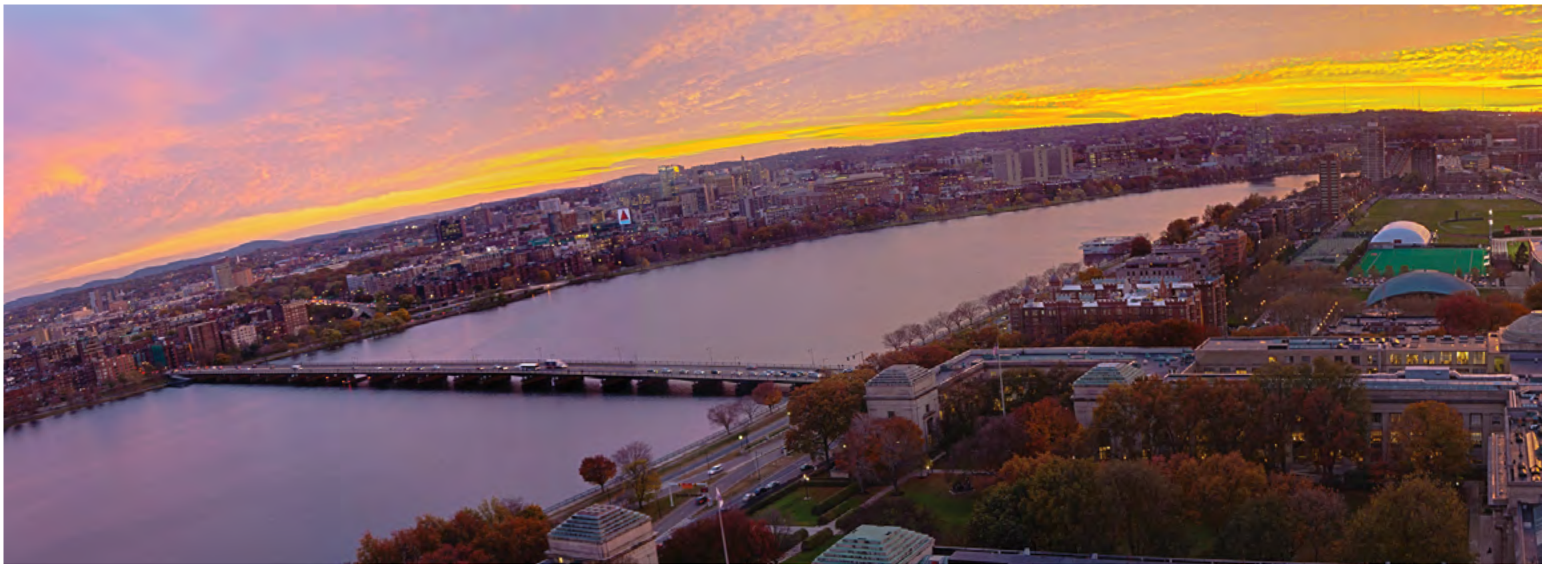
Rivian has already begun to test these second-life applications. Through a partnership the Honnold Foundation, they are using batteries from their test vehicles to provide energy storage for a sustainable solar microgrid in Puerto Rico.

Much of Scaringe and Rivian's focus has now shifted to how to produce the R1T and R1S at scale and launch commercialization. "It's a complex orchestra of activity," he says. Rivian will begin selling vehicles to consumers in 2020, opening a new chapter in their mission to facilitate adventures while promoting sustainability.

Class Close-Up: 2.S999

Solving for carbon neutrality at MIT

Students propose plans to make MIT's campus carbon neutral by 2060



While so many faculty and researchers at MIT are developing technologies to reduce carbon emissions and increase energy sustainability, one class puts the power in students' hands. In class 2.S999, Solving for Carbon Neutrality at MIT, teams of students are tasked with developing a plan to achieve carbon neutrality on MIT's campus by 2060.

"It's a 'roll up your sleeves and solve a real problem' kind of class," says Timothy Gutowski, professor of mechanical engineering and co-instructor for the class.

In nearly every class, students hear from guest lecturers who offer their own expert view on energy sustainability and carbon emissions. In addition to faculty and staff from across MIT, guest lecturers include local government officials, industry specialists, and economists. Whether it's the science and ethics behind climate change, the evolution of the electric grid, or the development of MIT's upgraded Central Utilities Plant, these experts introduce students to considerations on a campus, regional, national, and global level.

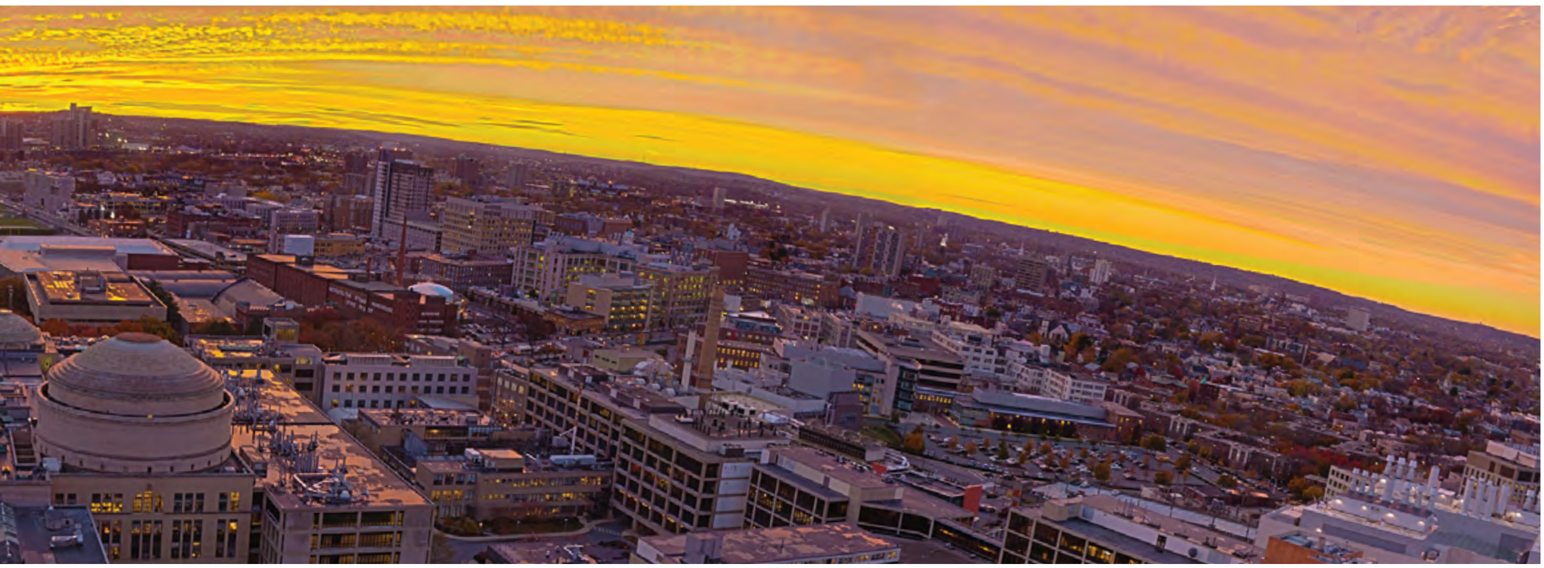
"It's essential to expose students to these different perspectives so they understand the complexity and the multidisciplinary nature of this challenge," says Julie Newman, Director of MIT's Office of Sustainability and co-instructor.

In one class, students get the opportunity to embody different perspectives through a debate about the installation of an offshore wind farm near a small coastal town. Each student is given a particular role to play in a debate. Caroline Boone, a junior studying mechanical engineering, played the role of a beachfront property owner who objected to the installation.

"It was a really good way of grasping how those negotiations happen in the real world," recalls Boone. "The fact of the matter is, you're going to have to work with groups who have their own interests – that requires compromise and negotiation."

Armed with these negotiation skills along with insights from different experts, students are divided into teams and charged with developing a strategy that outlines year-by-year how MIT can achieve carbon neutrality by 2060. "The final project uses the campus as a test bed for engaging and exposing students to the complexity of solving for these global issues in their own backyard," Newman adds.

The final project uses the campus as a test bed for engaging and exposing students to the complexity of solving for these global issues in their own backyard.



Student teams took a number of approaches in their strategies to achieve carbon neutrality. Tom Hubschman's team focused on the immediate impact MIT could have through power purchase agreements – also known as PPAs.

"Our team quickly realized that given the harsh New England environment and the limited space on campus, building a giant solar or wind farm in the middle of Cambridge wasn't a sound strategy," says Hubschman, a mechanical engineering graduate student. Instead, his team built their strategy around replicating MIT's current PPA with a 650 acre solar farm in North Carolina.

Boone's team, meanwhile, took a different approach by developing a plan that didn't include PPAs. "Our team was a bit contrarian in not having any PPAs, but we thought it was important to have that contrasting perspective," she explains. Boone's role within her team was to examine building energy use on campus. One takeaway from her research was the need for better controls and sensors to ensure campus buildings run efficiently.

Regardless of their approach, each team had to deal with a level of uncertainty with regards to the efficiency of New England's electric grid. "Right now, the electricity produced by MIT's own power plant emits less carbon than the current grid," adds Gutowski. "But the question is, as new regulations are put in place and new technologies are developed, when will there be a crossover in the grid emitting less carbon than our own power plant?" Students have to build this uncertainty into the predictive modeling for their proposed solutions.

In the two years that the class has been offered, student projects have been helpful in shaping the Office of Sustainability's own strategy. "These projects have reinforced our calculations and confirmed our strategy of using PPAs to contribute to greenhouse gas reduction off-site as we work toward developing on-site solutions," explains Newman.

This spring, Gutowski and Newman will work with a number of universities in South America on launching similar classes for their curricula. They will visit Ecuador, Chile, and Columbia, encouraging university administrators to task their students with solving for carbon neutrality on their own campus.

Talking Shop:

Assistant Professor Sili Deng

Understanding combustion

Much of the conversation about energy sustainability is dominated by clean energy technologies like wind, solar, and thermal. However, with roughly 80% of energy use in the United States coming from fossil fuels, combustion remains the dominant method of energy generation.

"People think of combustion as a dirty technology, but it's currently the most feasible way to produce electricity and power," explains Sili Deng, assistant professor of mechanical engineering and Brit (1961) & Alex (1949) d'Arbeloff Career Development Professor.

Deng is working toward understanding the chemistry and flow that occurs within combustion in an effort to improve technologies for current or near-future energy conversion applications. "My goal is to find out how to make the combustion process more efficient, reliable, safe, and clean," she adds.

MechE Connects spoke with Deng, who is the principal investigator at the Deng Energy and Nanotechnology Group, to discuss her combustion research.

How did you first become interested in studying combustion?

I was interested in engineering at very early age since my dad is an electrical engineer. When I was young, he actually built a remote control for our TV using just a few sensors and controllers. As an undergraduate at Tsinghua University, I studied thermal engineering. One day, I was talking about my research interests with a friend and she said 'What if you could increase the efficiency of energy utilization by just 1%? Considering how much energy we use globally each year, you could make a huge difference.' That conversation really opened my eyes and it led me to become a combustion scientist.

My expertise is on chemically reacting flow within combustion with two main focuses: the first is figuring out how to control the combustion process and the second is figuring out how to reduce or eliminate soot formation.

How are you trying to control the combustion process?

I focus on understanding and controlling the chemistry-flow interactions during the combustion process. The details of combustion are much more complicated than our general understanding of fuel and air combining to form water, carbon dioxide, and heat. Instead, there are hundreds of chemical species and thousands of reactions involved, depending on the type of fuel, fuel/air mixing, and flow dynamics. How these chemical species evolve in the flows determines the heat generation and emissions.

My group utilizes both experimental and computational tools to build a fundamental understanding of the combustion process that can guide the design of combustors for high performance and low emissions. We also try to embrace the artificial intelligence approaches and combine them with our physically derived models to predict and control the combustion processes.

> My goal is to find out how to make the combustion process more efficient, reliable, safe, and clean.

You also work on producing nanomaterials that can be used for renewable energy applications. What technologies do you use to create these materials?

I use a technology known as flame synthesis. In flame synthesis, you produce nanomaterials within the flame itself by adding precursors to it. Perhaps the biggest application of this in industry has been using titanium tetrachloride to synthesize titanium dioxide, a white pigment that is used widely in paint and sunscreen. I'm hoping to create a similar type of reaction to develop new materials that can be

Assistant Professor
Sili Deng
Credit: Tony Pulsone

used for things like renewable energy, water treatment, pollution reduction, and catalysts.

I've been experimenting with different precursors and flame conditions to see what kind of products come out of it. Combustion is a very rich process and there are many controlling parameters including what type of fuel is used, oxidizers, temperature, control time, and the morphology of the flame. We're experimenting with these parameters in the hopes of developing useful materials via combustion.

One of the more notorious by-products of combustion is soot. How are you working toward eliminating or reducing soot?

I'm looking at how soot is generated and flows within the flame itself. Once soot leaves the site of combustion, it is difficult to contain. There isn't much you can do to prevent haze or smog from developing, which is why I'm zeroing in on understanding soot at the site of combustion.

Inside a flame, there is a chemical soup with a lot of radicals. When you burn a candle, for example, you have hydrocarbons from the vapor produced by melting wax that's mixing with oxygen. The yellow light you see around the flame comes from soot particles generated in incomplete combustion. By understanding exactly how this soot is generated within a flame, we're hoping to develop methods to reduce or eliminate it before it gets out of the combustion channel.

How do you hope to take your research in combustion and develop real-world applications that work toward making combustion cleaner and more efficient?

As I grow my lab at MIT, I'm most excited at the prospect of collaborating with colleagues both within MechE and across the Institute to come up with new applications. There's an opportunity to combine the fundamental research on combustion that my lab is doing with the materials, devices, and products being developed across areas like materials science and automotive engineering.

We have awhile to go before clean energy technologies like wind and solar are our primary source of energy. While clean energy technologies are continuing to be developed, it's crucial that we continue to work toward finding ways to improve combustion technologies.

Research Focus:

Preventing energy loss in windows

In the quest to make buildings more energy efficient, windows present a particularly difficult problem. According to the Department of Energy, heat that either escapes or enters windows accounts for roughly 30% of the energy used to heat and cool buildings. Researchers are developing a variety of window technologies that could prevent this massive loss of energy.

“The choice of windows in a building has a direct influence on energy consumption,” says Nicholas Fang, professor of mechanical engineering. “We need an effective way of blocking solar radiation.”

Fang is part of a massive collaboration that is working together to develop smart adaptive control and monitoring systems for buildings. The research team, which includes researchers from the Hong Kong University of Science and Technology and Leon Glicksman, professor of building technology and mechanical engineering at MIT, has been tasked with helping Hong Kong achieve its ambitious goal to reduce carbon emissions by 40% by 2025.

“Our idea is to adapt new sensors and smart windows in an effort to help achieve energy efficiency and improve thermal comfort for people inside buildings,” Fang explains.

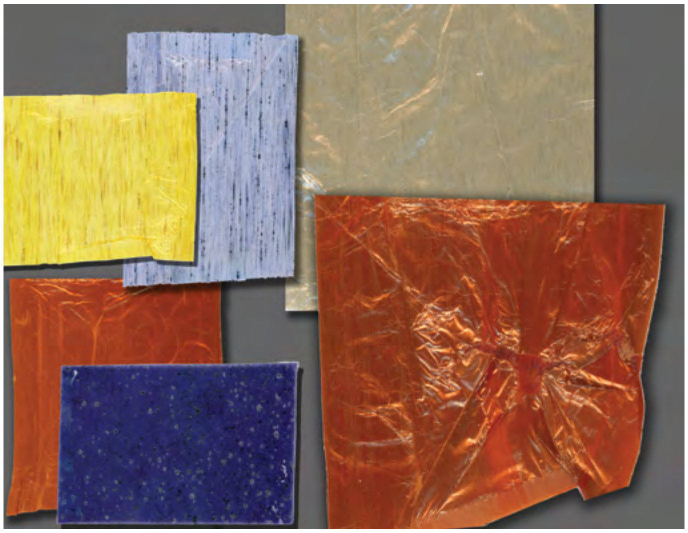
His contribution is the development of a smart material that can be placed on a window as a film that blocks heat from entering. The film remains transparent when the surface temperature is under 32°C, but turns milky when it exceeds 32°C. This change in appearance is due to thermochromic microparticles that change phases in response to heat. The smart window’s milky appearance can block up to 70% of solar radiation from passing through the window, translating to a 30% reduction in cooling load.

In addition to this thermochromic material, Fang’s team is hoping to embed windows with sensors that monitor sunlight, luminance, and temperature. “Overall, we want an integral solution to reduce the load on HVAC systems,” he explains.

Like Fang, graduate student Elise Strobach is working on a material that could significantly reduce the amount of heat that either escapes or enters through windows. She has developed a high clarity silica aerogel that, when placed between two panes of glass, is 50% more insulating than traditional windows and lasts up to a decade longer.

“Over the course of the past two years, we’ve developed a material that has demonstrated performance and is promising enough to start commercializing,” says Strobach, who is a PhD candidate in MIT’s Device Research Laboratory. To help in this commercialization, Strobach has founded the start-up AeroShield Materials.

A smart window developed by Professor Nicholas Fang includes thermochromic material that turns frosty when exposed to temperatures of 32°C or higher, such as when a researcher touches the window with her hand.
Credit: Courtesy of the researchers



The visual and thermal properties of polyethylene can be tweaked to produce colorful films with a wide range of heat-radiating capabilities. Credit: Felice Frankel

Lighter than a marshmallow, AeroShield's material comprises 95% air. The rest of the material is made up of silica nanoparticles that are just one or two nanometers large. This structure blocks all three modes of heat loss: conduction, convection, and radiation. When gas is trapped inside the material's small voids, it can no longer collide and transfer energy through convection. Meanwhile, the silica nanoparticles absorb radiation and re-emit it back in the direction it came from.

"The material's composition allows for a really intense temperature gradient that keeps the heat where you want it, whether it's hot or cold outside," explains Strobach.

Strobach also sees possibilities for combining AeroShield technologies with other window solutions being developed at MIT, including Fang's work and research being conducted by Gang Chen, Carl Richard Soderberg Professor of Power Engineering, and research scientist Svetlana Boriskina.

"Buildings represent one third of US energy usage, so in many ways windows are low hanging fruit," explains Chen.

Chen and Boriskina previously worked with Strobach on the first iteration of the AeroShield material for their project developing a solar thermal aerogel receiver. More recently, they have developed polymers that could be used in windows or building facades to trap or reflect heat, regardless of color.

These polymers were partially inspired by stained glass windows. "I have an optical background so I'm always drawn to the visual aspects of energy applications," says Boriskina. "The problem is, when you introduce color it affects whatever energy strategy you are trying to pursue."

Using a mix of polyethylene and a solvent, Chen and Boriskina added various nanoparticles to provide color. Once stretched, the material becomes translucent and its composition changes. Previously disorganized carbon chains reform as parallel lines, which are much better at conducting heat.

While these polymers need further development for use in transparent windows, they could possibly be used in colorful, translucent windows that reflect or trap heat, ultimately leading to energy savings. "The material isn't as transparent as glass, but it's translucent. It could be useful for windows in places you don't want direct sunlight to enter – like gyms or classrooms," Boriskina adds.

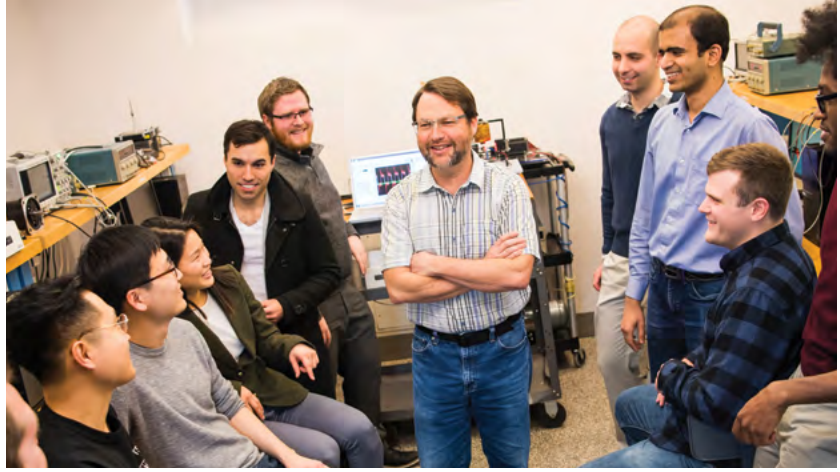
Boriskina is also using these materials for military applications. Through a three-year project funded by the U.S. Army, she is developing lightweight, custom-colored, and unbreakable polymer windows. These windows can provide passive temperature control and camouflage for portable shelters and vehicles.

For any of these technologies to have a meaningful impact on energy consumption, researchers must improve scalability and affordability. "Right now the cost barrier for these technologies is too high – we need to look into more economical and scalable versions," Fang adds.

If researchers are successful in developing manufacturable and affordable solutions, their window technologies could vastly improve building efficiency and lead to a substantial reduction in building energy consumption worldwide.

The choice of windows in a building has a direct influence on energy consumption.

News & Awards



Professor David Trumper has been honored as a Committed to Caring graduate student mentor. Credit: Joseph Lee

Departmental News

• This past summer, four mechanical engineering graduate students received real-world experience working on a project in industry through the MechE Alliance's recently launched Industry Immersion Project Program.

Research News

• A team of researchers including Professor Gareth McKinley have found how to produce uniformly spaced bubbles in liquid. The findings could have implications for the development of microfluidic devices. The research was published in *PNAS*.

• The Varanasi Research Group has developed a new approach to minimize the contact between droplets and surfaces, potentially preventing icing or soaking. Their work was published in *ACS Nano*.

• MIT engineers including Professor John Hart and Professor Neville Hogan have designed 3-D-printed mesh materials whose flexibility and toughness emulates and supports softer tissues such as muscles and tendons.

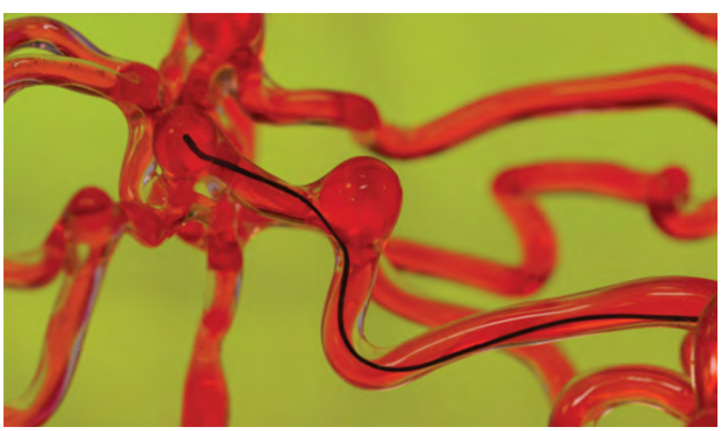
• A robotic thread developed by Associate Professor Xuanhe Zhao can be steered magnetically through blood vessels in the brain and deliver clot-reducing therapies in response to stroke or other brain blockages. The findings were published in *Science Robotics*.

• A team of researchers including Assistant Professor Wim van Rees have designed 3-D printed mesh-like structures that morph into predetermined shapes in response to changes in ambient temperature. The materials could be used to design deployable structures, such as tents or coverings.

• A microfluidic tissue model developed by Professor Roger Kamm finds that Alzheimer's damage allows toxins to enter the brain, further harming neurons.

• Assistant Professor Giovanni Traverso has developed a gel cushion used to elevate polyps during endoscopy that could reduce the risk of tearing the colon lining.

A robotic thread (in black) developed by Associate Professor Xuanhe Zhao can be steered magnetically through blood vessels in the brain. Credit: Courtesy of the researchers



Faculty News

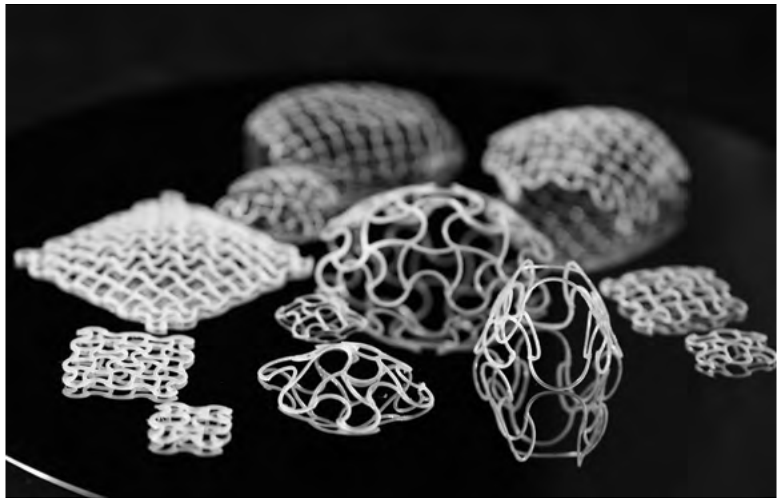
• ASME has honored Professor Gang Chen with the Frank Kreith Energy Award for significant contributions to a secure energy future with particular emphasis on innovations in conservation and/or renewable energy.

• Assistant Professor Betar Gallant has been appointed to the ABS Career Development Professorship. She was also recently awarded the Army Research Office Young Investigator Award for development of high-energy density fluorinated gas battery chemistries.

• Professor David Trumper has been honored as a Committed to Caring graduate student mentor for promoting a healthy work-life balance and offering a positive outlook with his graduate students.

• Giovanni Traverso recently joined the department as assistant professor of mechanical engineering. Traverso works on ingestible and implantable robotics, drug delivery, and biomedical devices.

• Captain Rob Bebermeyer has been named the director for Naval Construction and Engineering and the Curriculum Officer for the 2N program at MIT.



A team of researchers including Assistant Professor Wim van Rees designed 3-D printed mesh-like structures that morph shapes in response to changes in temperature. Credit: J. William Boley

• Professor Anette 'Peko' Hosoi has been awarded a Capers and Marion McDonald Award in Mentoring.

• Associate Professor Jeehwan Kim has been selected for the DARPA Young Faculty Award Program.

• ASME has given Professor John Lienhard the Edward F. Obert Award in recognition of an outstanding paper on thermodynamics. Lienhard was honored for his paper, "Entropy Generation Minimization for Energy-Efficient Desalination."

• Hank Marcus, Professor Emeritus of Marine Systems, has been appointed by Secretary of Transportation Elaine Chao to serve as Chairman of the Advisory Board to the United States Merchant Marine Academy.

Alumni News

• Inkbit, co-founded by MechE alum Davide Marini PhD '03, is overcoming traditional constraints to 3-D printing by giving its machines "eyes and brains."

• WalkWise, a start-up founded by MechE alum Peter Chamberlain SM '16, has been chosen to be part of the TechStars Accelerator Program. WalkWise is smart walker attachment that gathers fitness and health data to help keep seniors safe, healthy, and independent.

Student News

• The MIT team, which includes a number of mechanical engineering students, placed first among U.S. universities at the 2019 SpaceX Hyperloop Pod Competition.

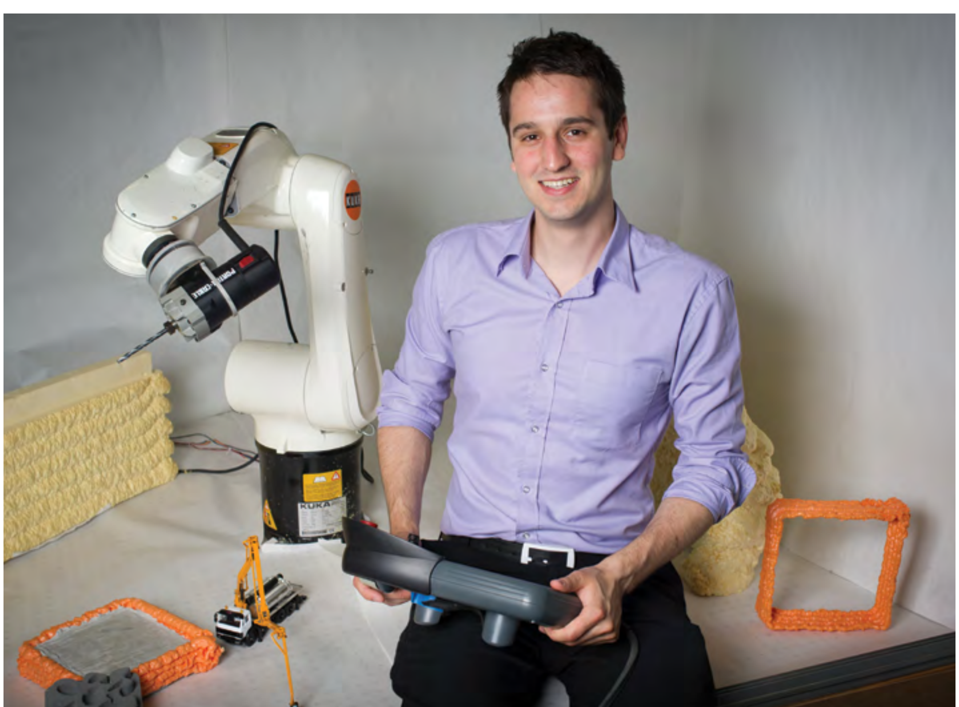
• At the annual MIT Ship Design and Technology Symposium in May 2019, naval construction and engineering students presented their work on real-life naval design projects.

• Graduate student Graham Leverick has been named a 2020 Siebel Foundation Scholar for academic and research excellence as well as demonstrated leadership contributions. He works with Professor Yang Shao-Horn in the Electrochemical Energy Lab.

• Graduate student James Gabbards has received a MathWorks Engineering Fellowship. He studies computational fluid dynamics under Professor Wim van Rees.

In Memoriam

• Alumnus Steven John Keating SM '12, PhD '16 passed away from brain cancer on July 19 at the age of 31. Keating inspired millions with his research-driven approach to battling cancer and his advocacy for open patient health data.



Alumnus Steven John Keating SM '12, PhD '16 passed away from brain cancer on July 19 at the age of 31. Credit: Tony Pulsone

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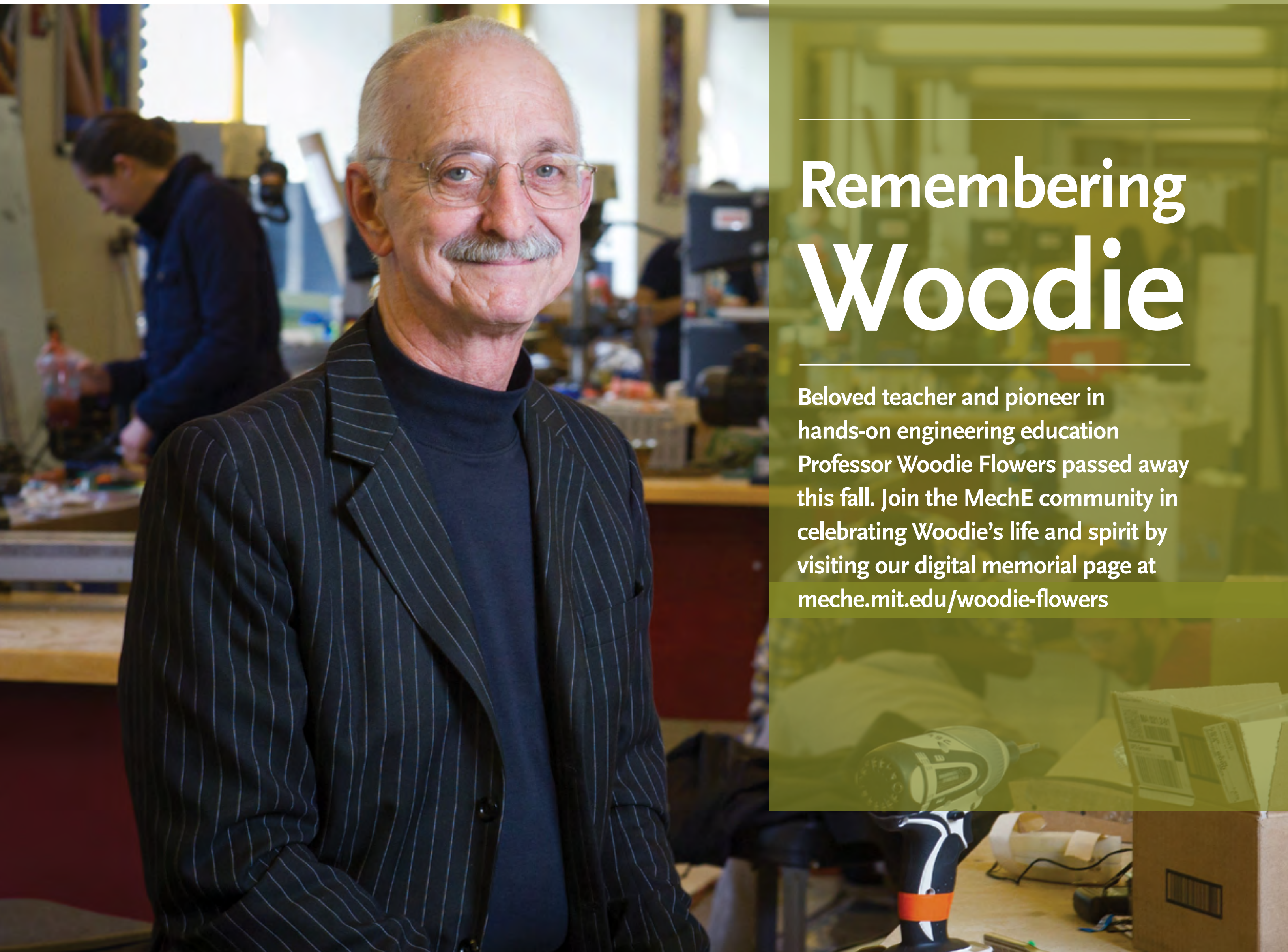

Remembering Woodie

Beloved teacher and pioneer in hands-on engineering education Professor Woodie Flowers passed away this fall. Join the MechE community in celebrating Woodie's life and spirit by visiting our digital memorial page at meche.mit.edu/woodie-flowers