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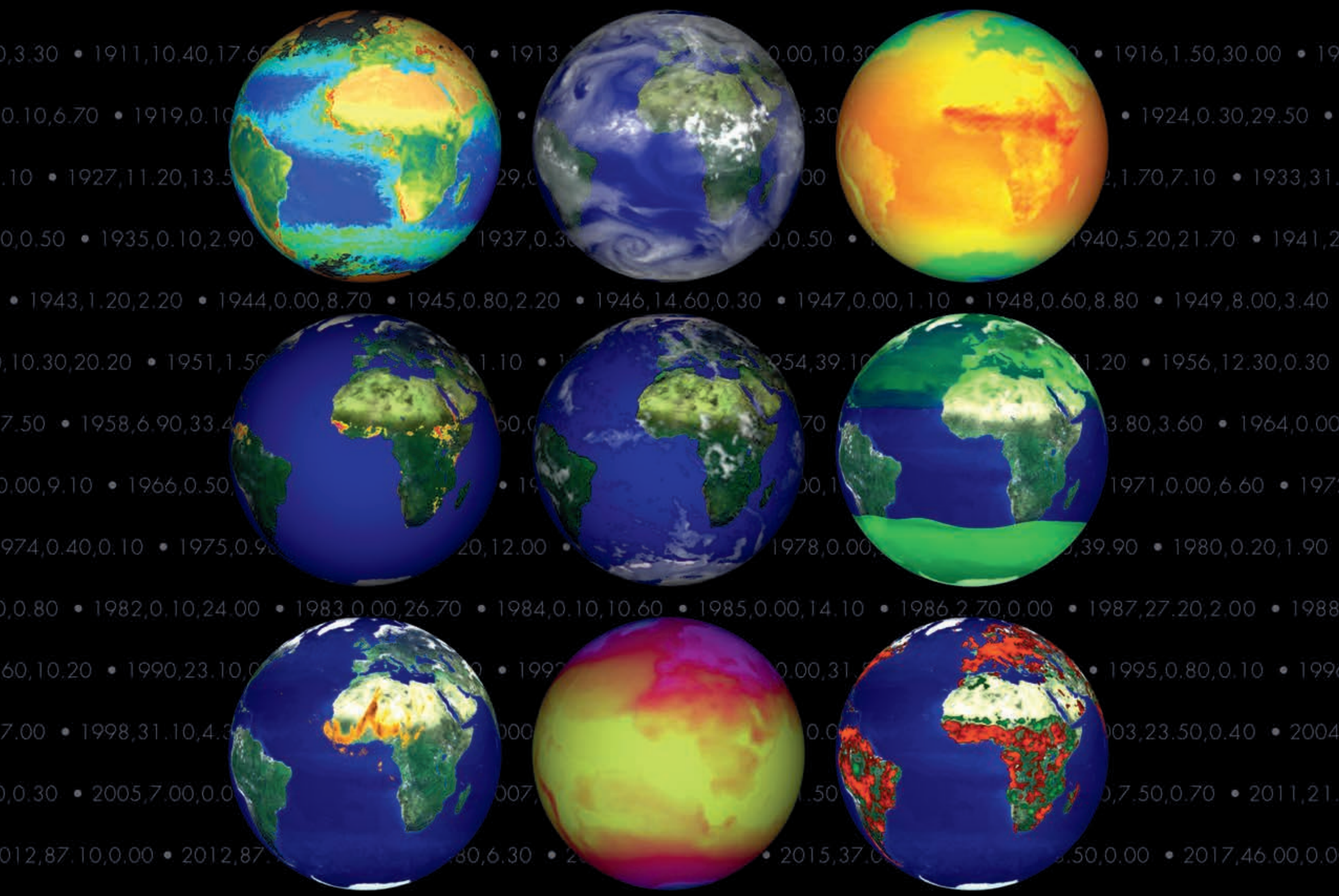
MechEConnects | Winter 2019 | MIT

# Health of the Planet



MechEConnects
News from the MIT
Department of Mechanical Engineering

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For the past two years, the senior Pappalardo Apprentices have been fabricating an 1897 steam engine designed by Nathanael Greene Herreshoff. They used Herreshoff's own drawings from the MIT Hart Nautical Collections. Their engine is now on display at the MIT Museum. Credit: Tony Pulsone


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## 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:**
NASA's Terra 9-globe dataset captures various data and measurements related to the health of the planet. The datasets include, from left to right, top to bottom: biosphere, water vapor, temperature, fires, clouds, methane, aerosols, radiant energy, and vegetation index anomalies. In the background of the image is data from NOAA's Contiguous U.S. Extremes in Maximum Temperature report.

Credit: NASA/Goddard Space Flight Center, The SeaWiFS Project and GeoEye, Scientific Visualization Studio

Dear Alumni, Students, Faculty, and Friends,

I am delighted to be introducing the first issue of MechE Connects during my tenure as Department Head of MIT's Department of Mechanical Engineering. As many of you know, I assumed my new role on July 1, 2018 after Professor Gang Chen stepped down as Department Head. I'd like to take this opportunity to thank Professor Chen for all he has done to strengthen our department during his five years as Department Head. I'd also like to thank the many members of the extended MechE community who have shared their ideas for ensuring our department remains a global leader in mechanical engineering.

Prior to starting my role as Department Head, I had the privilege of serving alongside Professor Pierre Lermusiaux as co-chair for MechE's Strategic Planning Committee. One of the initiatives to come out of the extensive research the committee conducted was to identify four unifying MechE Grand Challenges that address the biggest needs and issues facing our world. These challenges build upon our expertise and provide opportunities for major global impact through interdisciplinary collaborations. This issue of MechE Connects focuses on the research our faculty, students, and alumni are working on in one of the MechE Grand Challenges: Health of the Planet.

**Improving the health of our planet will require creative solutions for the many complex issues facing our climate, oceans, agricultural production, and food and water security.**

Improving the health of our planet will require creative solutions for the many complex issues facing our climate, oceans, agricultural production, and food and water security. Mechanical engineers play a vital role in developing these solutions. From minimizing greenhouse gas emissions to protecting our oceans and developing sustainable agricultural practices, the members of our community we highlight in this issue are committed to finding solutions that make our world a better place. Using their diverse expertise, these MechE faculty, students, and alumni are developing technologies that aim to solve problems such as climate change, resource depletion, access to food, and the destruction of ecosystems.

In the coming years, MIT will participate in a number of initiatives and programs to support the research being conducted in these areas. In addition to existing programs like the MIT Environmental Solutions Initiative, MIT Energy Initiative, and the Climate CoLab, during the 2019-2020 academic year MIT will host six new symposia that address major climate challenges. I am honored to have been chosen by President Reif to serve on the MIT Climate Symposia Organizing Committee and ensure that MechE is included in Institute-wide efforts to improve the health of our planet.

We hope you enjoy this issue of MechE Connects and thank you for your continued support.

Sincerely,

Evelyn Wang, Gail E. Kendall Professor and Department Head

# Tackling Greenhouse Gases

By Mary Beth O'Leary

The images are ubiquitous: a coastal town decimated by another powerful hurricane, satellite images showing shrinking polar ice caps, a school of dead fish floating on the surface of warming waters, swaths of land burnt by an out-of-control wildfire. These dire scenes share a common thread – they offer tangible evidence that climate change is affecting every corner of the globe.

According to NASA, Earth's surface temperature has risen 0.9° C since the dawn of the Industrial Revolution. Researchers agree that the rise in temperatures has one primary culprit: increased greenhouse gas emissions.

Greenhouse gases like carbon dioxide, nitrous oxide, and methane all trap heat in our atmosphere. The occurrence of these gases in our atmosphere has increased

exponentially since the late 1800s due to growth in fossil fuels use across the energy, manufacturing, and transportation industries.

A report from the UN Intergovernmental Panel on Climate Change (IPCC), released on October 8, 2018 warned that if Earth's temperature rises greater than 1.5° C, the effects would be catastrophic. Entire ecosystems could be lost, sea levels would be higher, and extreme weather events would become even more common. According to the IPCC, avoiding this scenario "would require rapid, far-reaching and unprecedented changes in all aspects of society," including a 45% decrease in carbon dioxide ($CO_2$) levels by 2030.

Researchers across MIT are working on a myriad of technologies that reduce greenhouse gas emissions in every industry. Many faculty are looking at sustainable energy. Associate Professor Tonio Buonassisi and his team in the Photovoltaic Research Lab hope to harness the power of the sun while Professor Alexander Slocum has conducted research in making offshore wind turbines more efficient and economically viable.

In addition to exploring sustainable forms of energy that do not require fossil fuels, a number of faculty members in MIT's Department of Mechanical Engineering are turning to technologies that store, capture, convert, and minimize greenhouse gas emissions using very different approaches.

Image: Polar bears in the Arctic.
Credit: John Guthrie

## Improving energy storage with ceramics

For renewable energy technologies like concentrated solar power (CSP) to make sense economically, storage is crucial. Since the sun isn't always shining, solar energy needs to somehow be stored for later use. But CSP plants are currently limited by their steel based infrastructure.

"Improving energy storage is a critical issue that presents one of the biggest technological hurdles toward minimizing greenhouse gas emissions," explains Asegun Henry, Noyce Career Development Professor and associate professor of mechanical engineering.

An expert in heat transfer, Henry has turned to an unlikely class of materials to help increase the efficiency of thermal storage: ceramics.

Currently, CSP plants are limited by the temperature at which they can store heat. Thermal energy from solar power is stored in liquid salt. This liquid salt can't exceed a temperature of 565° C since the steel pipes it flows through will get corroded.

"There has been a ubiquitous assumption that if you're going to build anything with flowing liquid, the pipes and pumps have to be made out of metal," says Henry. "We essentially questioned that assumption."

Henry and his team, which recently moved from Georgia Tech, have developed a ceramic pump that allows liquid to flow at much higher temperatures. In January 2017, he was entered into the Guinness Book of World Records for the "highest operating temperature liquid pump." The pump was able to circulate molten tin between 1,200° C and 1,400° C.

"The pump now gives us the ability to make an all ceramic infrastructure for CSP plants, allowing us to flow and control liquid metal," adds Henry.

Rather than use liquid salt, CSP plants can now store energy in metals, like molten tin, which have a higher temperature range and won't corrode the carefully chosen ceramics. This opens up new avenues for energy storage and generation. "We are trying to turn up the temperature so hot that our ability to turn heat back into electricity gives us options," explains Henry.

One such option, would be to store electricity as glowing white hot heat like that of a lightbulb filament. This heat can then be turned into electricity by converting the white glow using photovoltaics – creating a completely greenhouse gas-free energy storage system.

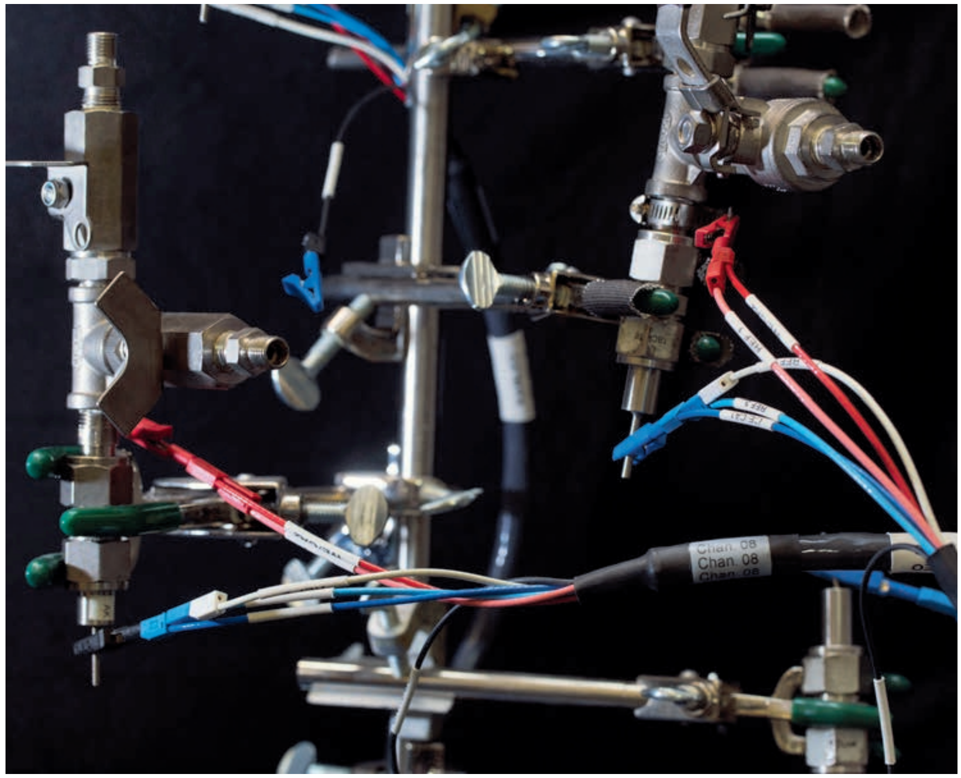
Associate Professor Asegun Henry is researching how to use hot metals like molten tin to store heat from a concentrated solar power system so it can be used to generate electricity as needed.
Credit: Rob Felt, Georgia Tech

Improving energy storage is a critical issue that presents one of the biggest technological hurdles toward minimizing greenhouse gas emissions.

"This system can't work if the pipes are temperature limited and have a short lifetime," adds Henry. "That's where we come in, we now have the materials that can make things work at crazy high temperatures."

The record-breaking pump's ability to minimize greenhouse gas emissions goes beyond altering the infrastructure of solar plants. Henry also hopes to use the pump to change the way hydrogen is produced.

Hydrogen, which is used to make fertilizer, is created by reacting methane with water, producing $CO_2$. Henry is researching an entirely new hydrogen production method which would involve heating tin hot enough to split methane directly and create hydrogen, without introducing other chemicals or making $CO_2$. Rather than emit $CO_2$, solid carbon particles would form and float on the surface of the liquid. This solid carbon is something that could then be sold for a number or purposes.




This capture and conversion device developed by Assistant Professor Betar Gallant uses electrochemical cells that convert harmful gases into more benign materials. Credit: John Freidah

## Converting pollutants into valuable materials

Capturing greenhouse gases and turning them into something useful is a goal shared by Betar Gallant, assistant professor of mechanical engineering.

The Paris Agreement, which seeks to minimize greenhouse gas emissions on a global scale, stated that participating countries need to consider *every* greenhouse gas, even those emitted in small quantities. These include fluorinated gases like sulfur hexafluoride and nitrogen trifluoride. Many of these gases are used in semiconductor manufacturing and metallurgical processes like magnesium production.

Fluorinated gases have up to 23,000 times the global warming potential of $CO_2$ and have lifetimes in the thousands of years. "Once we emit these fluorinated gases, they are virtually indestructible," says Gallant.

With no current regulations on these gases, their release could have lasting impact on our ability to curtail global warming. After the ratification of the Paris Agreement, Gallant saw a window of opportunity to use her background in electrochemistry to capture and convert these harmful pollutants.

"I'm looking at mechanisms and reactions to activate and convert harmful pollutants into either benign storable materials or something that can be recycled and used in a less harmful way," she explains.

Her first target: fluorinated gases. Using voltage and currents, along with chemistry, she and her team looked into accessing a new reaction space. Gallant created two systems based on the reaction between these fluorinated gases and lithium. The result was a solid cathode that can be used in batteries.

"We identified one reaction for each of those two fluorinated gases, but we will keep working on that to figure out how these reactions can be modified to handle industrial-scale capture and large volumes of materials," she adds.

Gallant recently used a similar approach for capturing and converting $CO_2$ emissions into carbon cathodes.

"Our central question was: can we find a way to get more value out of $CO_2$ by incorporating it into an energy storage device?" she says.

In a recent study, Gallant first treated $CO_2$ in a liquid amine solution. This prompted a reaction that created a new ion-containing liquid phase, which fortuitously could also be used as an electrolyte. The electrolyte was then used to assemble a battery along with lithium metal and carbon. By discharging the electrolyte, the $CO_2$ could be converted into a solid carbonate while delivering a power output at about three volts.

As the battery continuously discharges, it "eats up" all the $CO_2$ and constantly converts it into a solid carbonate that can be stored, removed, or even charged back to the liquid electrolyte for operation as

Assistant Professor Betar Gallant
Credit: John Freidah

a rechargeable battery. This process has the potential for reducing greenhouse gas emissions and adding economic value by creating a new usable product.

The next step for Gallant is taking the understandings of these reactions and actually designing a system that can be used in industry to capture and convert greenhouse gases.

"Engineers in this field have the know-how to design more efficient devices that either capture or convert greenhouse gas emissions before they get released into the environment," she adds. "We started by building the chemical and electrochemical technology first, but we're really looking forward to pivoting next to the larger scale and seeing how to engineer these reactions into a practical device."

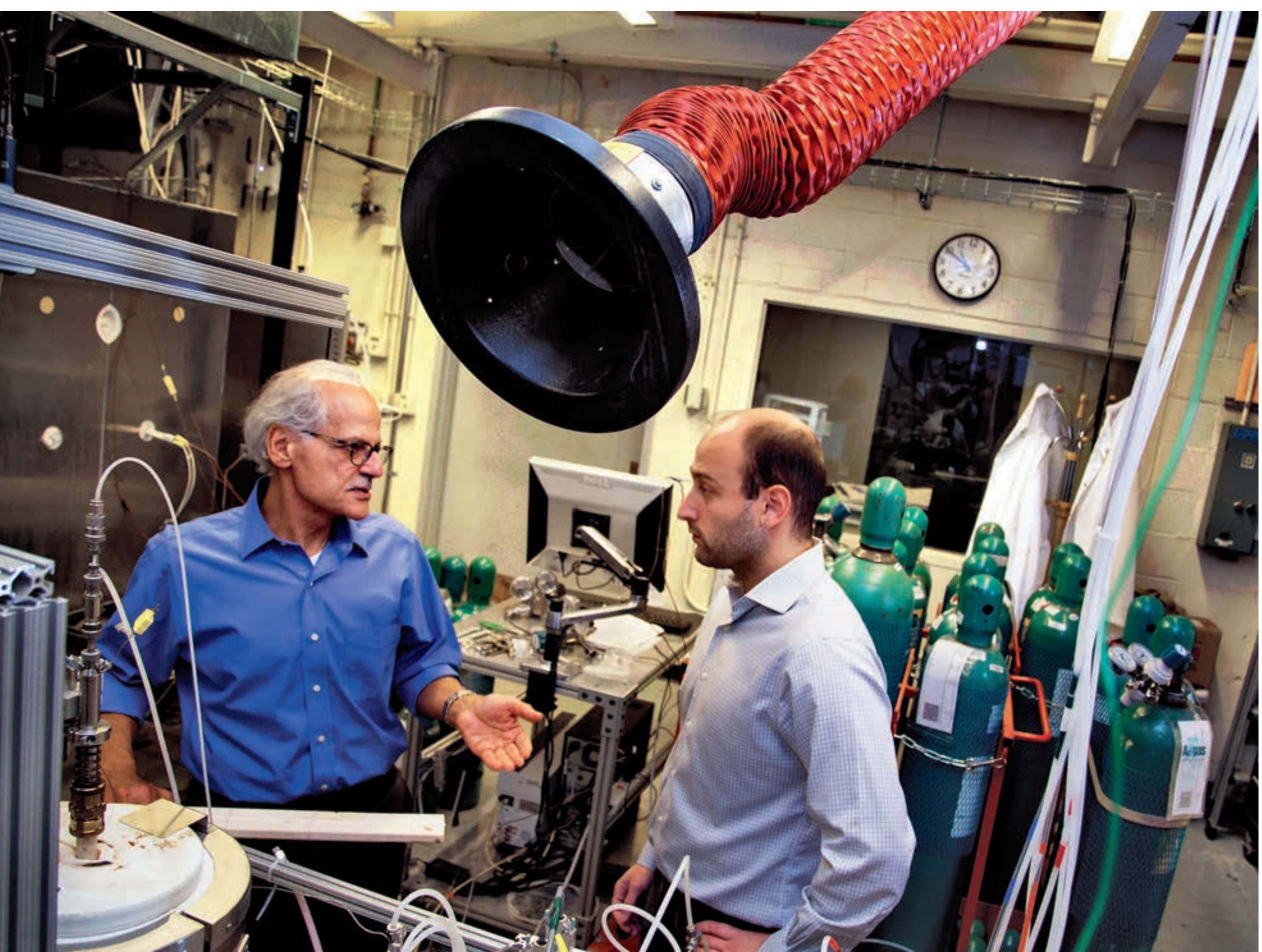
## Closing the carbon cycle

Designing systems that capture $CO_2$ and convert it back to something useful has been a driving force in Ahmed Ghoniem's research over the past fifteen years. "I have spent my entire career on the environmental impact of energy and power production," says Ghoniem, Ronald C. Crane Professor of Mechanical Engineering.

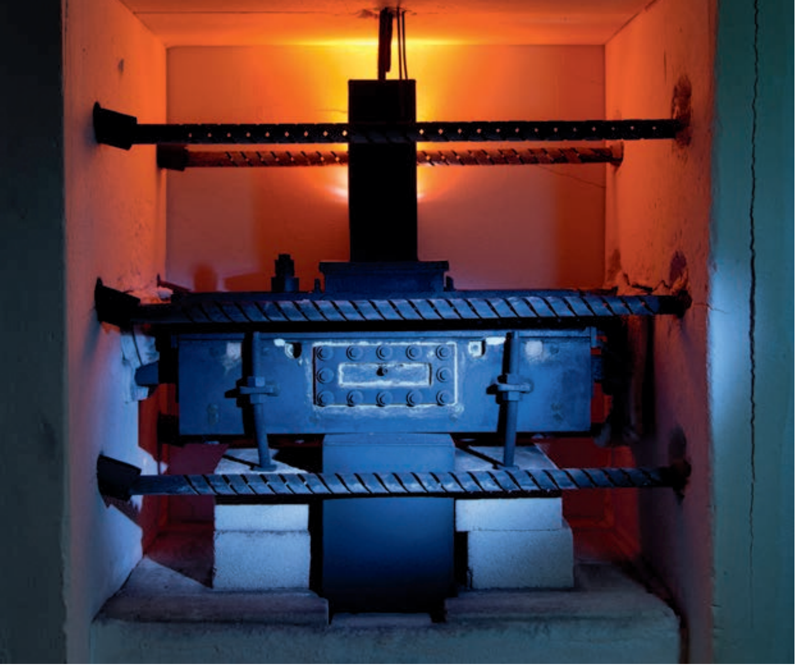
In the 1980s and 1990s, the most pressing issue for researchers working in this sphere was creating technologies that minimized the emission of criteria pollutants like nitric oxides. These pollutants produced ozone, particular matter, and smog. Ghoniem worked on new combustion systems that significantly reduced the emission of these pollutants.

Since the turn of the 21st century, his focus shifted from criteria pollutants, which were successfully curbed, to $CO_2$ emissions. The quickest solution would be to stop using fossil fuels. But Ghoniem acknowledges with 80% of energy production worldwide coming from fossil fuels, that's not an option: "The big problem really is, how do we continue using fossil fuels without releasing so much $CO_2$ in the environment?"

In recent years, he has worked on methods for capturing $CO_2$ from power plants for underground storage, and more recently for recycling some of the captured $CO_2$ into useful products, like fuels and chemicals. The end goal is to develop systems that efficiently and economically remove $CO_2$ from fossil fuel combustion while producing power.



Professor Ahmed Ghoniem, left, meets with postdoc Georgios Dimitrakopoulos in the Center of Energy and Propulsion Research/ Reacting Gas Dynamics Laboratory.
Credit: John Freidah



This lab scale reactor from Professor Ahmed Ghoniem's lab is designed to test ceramic membranes for a number of applications, including oxy-combustion for carbon capture. Credit: John Freidah

As economies grow, the need for material increases, further contributing to greenhouse gas emissions. To assess the carbon footprint of a product from material production through to disposal, engineers have turned to life cycle assessments (LCA). These LCAs suggest ways to boost efficiency and decrease environmental impact. But, according to Gutowski, the approach many engineers take in assessing a product's life-cycle is flawed.

"My idea is to close the carbon cycle so you can convert $CO_2$ emitted during power production back into fuel and chemicals," he explains. Solar and other carbon-free energy sources would power the reuse process, making it a closed-loop system with no net emissions.

In the first step, Ghoniem's system separates oxygen from air, so fuel can burn in pure oxygen – a process known as oxy-combustion. When this is done, the plant emits pure $CO_2$ that can be captured for storage or reuse. To do this, Ghoniem says, "We've developed ceramic membranes, chemical looping reactors, and catalysts technology, that allow us to do this efficiently."

Using alternative sources of heat, such as solar energy, the reactor temperature is raised to just shy of 1,000° C to drive the separation of oxygen. The membranes Ghoniem's group are developing allow pure oxygen to pass through. The source of this oxygen is air in oxy-combustion applications. When recycled $CO_2$ is used instead of air, the process reduces $CO_2$ to CO that can be used as fuel or to create new hydrocarbon fuels or chemicals, like ethanol which is mixed gasoline to fuel cars. Ghoniem's team also found that if water ($H_2O$) is used instead of air, it is reduced to hydrogen, another clean fuel.

The next step for Ghoniem's team is scaling up the membrane reactors they've developed from something that is successful in the lab, to something that could be used in industry.

## Manufacturing, human behavior, and the "rebound" effect

While Asegun Henry, Betar Gallant, Ahmed Ghoniem, and a number of other MIT researchers are developing capture and reuse technologies to minimize greenhouse gas emissions, Professor Timothy Gutowski is approaching climate change from a completely different angle: the economics of manufacturing.

Timothy Gutowski understands manufacturing. He has worked on both the industry and academic side of manufacturing, was the director of MIT's Laboratory for Manufacturing and Productivity for a decade, and currently leads the Environmentally Benign Manufacturing research group at MIT. His primary research focus is assessing the environmental impact of manufacturing.

"If you analyze the global manufacturing sector, you see that the making of materials is globally bigger than making products in terms of energy usage and total carbon emitted, " says Gutowski.

"Many LCAs ignore real human behavior and the economics associated with increased efficiency," claims Gutowski.

For example, LED light bulbs save a tremendous amount of energy and money compared to incandescent light bulbs. Rather than use these savings to conserve energy, many use these savings as a rationale to increase the number of light bulbs they use. Sports stadiums in particular capitalize on the cost savings offered by LED light bulbs to wrap entire fields in LED screens. In economics, this phenomenon is known as the 'rebound effect.'

When placed under high temperatures and exposed to $CO_2$ , these ceramic membranes allow pure oxygen to pass through, leaving behind CO that can be used as fuel. Credit: John Freidah

"When you improve efficiency, the engineer may imagine that the device will be used in the exact same way as before and resources will be conserved," explains Gutowski. But this increase in efficiency often results in an increase in production.

Another example of the rebound effect can be found in airplanes. Using composite materials to build aircrafts instead of using heavier aluminum can make airplanes lighter, thereby saving fuel. Rather than utilize this potential savings in fuel economy to minimize the impact on the environment, companies use this potential weight savings to add other features to the airplane. These could include, increasing the number of seats, adding entertainment equipment, or carrying more fuel to increase the length of the journey. In the end, there are cases where a composites airplane actually weighs more than an original aluminum airplane.

"Companies often don't think 'I'm going to save fuel,' they think about ways they can economically take advantage of increased efficiency," adds Gutowski.

Gutowski is working across disciplines and fields to develop a better understanding of how engineers can improve life cycle assessments by taking economics and human behavior into account.

"The goal is to implement policies so engineers can continue to make improvements in efficiency, but these improvements actually result in a benefit to society and reduce greenhouse gas emissions," he explains.

Professor Timothy Gutowski (center) is joined by Julie Newman (left), MIT's Director of Sustainability, and graduate student Julien Barber (right) at a panel discussing class 2.S999, Solving for Carbon Neutrality at MIT. Credit: MIT Office of Sustainability

## 'A global problem'

The diversity of approaches to tackling climate change is reflective of the size of the problem. No one technology is going to act as a panacea for minimizing greenhouse gas emissions and staying below the crucial 1.5° C global temperature increase threshold outlined by the UN.

"Remember, global warming is a global problem," says Ghoniem. "No one country can solve it by itself, we must do it together."

In September 2019, the UN Climate Summit will convene and challenge nations across the world to throw their political and economic weight behind solving climate change. On a smaller scale, MIT is doing its part to minimize its environmental impact.

Last spring, Gutowski and Julie Newman, Director of Sustainability at MIT, co-taught a new class entitled 2.S999, Solving for Carbon Neutrality at MIT. Teams of students proposed realistic scenarios for how MIT can achieve carbon neutrality. "The students were doing real work on finding ways MIT can keep our carbon down," recalls Gutowski.

Whether it's a team of students in class 2.S999 or the upcoming UN Climate Summit, finding ways to minimize greenhouse gas emissions and curtail climate change is a global responsibility. "Unless we all agree to work on it, invest resources to develop and scale solutions, and collectively implement these solutions, we will have to live with the negative consequences," adds Ghoniem.

Alumni Profile:

# Nicholas Mabey SM '93

## Enacting Change Through Policy

By Mary Beth O'Leary

Nicholas Mabey SM '93
Credit: Wilson Center

The North Sea is one of the world's richest offshore wind power resources. With thirteen countries sharing its coastline, tapping into this potential requires a mix of diplomacy and engineering. Where others might see a political mine field, Nicholas Mabey SM '93 sees opportunity.

"We have to design solutions where you take into consideration both existing technologies and the various political structures at play," explains Mabey, co-founder and Chief Executive of E3G, an environmental think tank headquartered in London.

Rather than having thirteen different sets of grids and policies, Mabey and E3G helped establish the North Seas Countries Offshore Grid Initiative. The result was a unified approach to harnessing wind power in the North Seas.

This is just one example of how Mabey has blended his unique combination of expertise in engineering, economics, and politics with his passion for finding solutions to climate change.

Mabey first became interested in climate change while completing his degree in mechanical engineering from the University of Bristol. After graduation, Mabey noticed a trend: there were no mechanical engineering jobs in renewable energy.

"I had tried to find renewable energy work in the UK but there wasn't any," recalls Mabey. "So I started to look at the economics and politics of renewable energy to figure out why something that would clearly be more cost effective and environmentally friendly wasn't being done."

That search led him to the MIT Technology and Policy Program, a degree program that combines graduate-level study in a subject like mechanical engineering with a thesis focused on technology policy issues.

"My time at MIT gave me the confidence to tackle big difficult problems by using both quantitative methods and a qualitative understanding of real-world limitations and uncertainty," says Mabey.

This confidence led Mabey to a job in government. He helped build the UK's first-ever environmental diplomacy network. As a senior advisor in the UK Prime Minister's Strategy Unit, he worked on a wide range of international and environmental issues.

While working in government, Mabey noticed a disconnect between technology companies, academia, and government. All three sectors were trying to solve issues on their own without consulting each other. Mabey and several colleagues saw a gap in how institutions approached environmental problems and came up with the idea for E3G to connect the dots.

"We founded E3G to act as a broker between mainstream institutions," he adds. As was the case with the North Seas Countries Offshore Grid Initiative, E3G approaches problems by connecting government leaders, policy makers, and technological experts.

For Mabey, this approach to finding solutions for climate change draws upon his diverse career experiences. "In a sense, co-founding E3G combined the engineering and design approach I learned at MIT with the political approach I learned working in government," he explains.

In addition to helping thirteen countries establish a single grid for wind power, E3G has helped the Chinese government establish pilots of low carbon economy at a regional level and supported the creation of a public green investment bank in the UK.

Whatever the problem Mabey is crafting policies for, he believes mechanical engineers will play a vital role. "I think mechanical engineers are at the heart of responding to the challenges we face due to climate change," adds Mabey. "There's a confluence of a problem with climate change along with amazing new technologies and mechanical engineers sit directly between the two."

Student Spotlight:

# Julia Sokol, PhD Candidate

## Conserving resources, cutting costs, and improving crop yield in agriculture

By Mary Beth O'Leary

Julia Sokol
Credit: Tony Pulsone

When it comes to the health of the planet, agriculture and food production play an enormous role. According to the Food and Agriculture Organization of the United Nations, roughly 37% of land worldwide is used for agriculture and food production, with 11% of the Earth's land surface used specifically for crop production. Finding ways to make agriculture more sustainable and efficient is crucial not only for the environment, but also for global food supply.

Julia Sokol, a PhD student in mechanical engineering, is hoping to improve sustainability and yield by focusing on one aspect of agriculture: irrigation. "The global population keeps growing, so we need greater agricultural productivity," says Sokol, who works on a drip irrigation project at MIT's Global Engineering and Research (GEAR) Lab. "That's our focus – to make that happen, especially in developing areas."

Sokol grew up far away from any farm. Born in Russia, she moved to New York City when she was ten years old. After receiving her bachelor's in mechanical engineering at Harvard University, Sokol spent some time in industry, first as a research assistant at Schlumberger, then working at a small sustainability consulting firm. Wanting a stronger technical foundation, she applied to MIT for graduate school.

During her master's program, Sokol took the course 2.76, Global Engineering, which was taught by associate professor and principal investigator of the GEAR Lab, Amos Winter. Having developed an interest in water-related issues, Sokol jumped at the opportunity to work with Winter on the GEAR Lab's energy efficient drip irrigation project.

"I was really excited to join the project," says Sokol. "It perfectly combines my passion for sustainability with my interest in fundamental research in fluid mechanics and system design."

Rather than flood irrigation – in which water is pumped from a source to flood a field – drip irrigation has a central pump that moves water through a network of pipes. Emitters attached to the pipes release water uniformly throughout the field, resulting in higher crop yield and less water consumption when compared to flood irrigation.

"The goal of drip irrigation is to provide water at a low enough flow rate for the roots to actually start absorbing it immediately, instead of it evaporating or percolating back down to an aquifer," explains Sokol.

The emitters used in drip irrigation disperse water evenly, as opposed to flood irrigation which often causes crops to get water-logged. "These drip emitters need to provide a uniform flow rate throughout the field so all crops get the same amount of water," adds Susan Amrose, a research scientist at the GEAR Lab.

The research team first focused on the geometrical features of these emitters. They developed a mathematical model describing how the geometrical features interact with the membranes inside them. Based on this model, they optimized the emitters to get the lowest possible pressure required to ensure the water flows to crops at the right rate.

Commercial emitters require a minimum activation pressure of 1 bar to provide a constant flow rate for the crops. Thanks to the changes the team made inside the emitter, they lowered the activation pressure to just 0.15 bar. This reduction in the pressure needed to activate the drippers cut the power needed to operate the central pump in half.

"Reducing the pressure lowers the cost of the system overall, which is beneficial to the farmer, and of course it also helps reduce greenhouse gas emissions," says Sokol.

For off-grid drip irrigation systems that operate via solar power, the use of the new emitters could reduce costs to the farmer by 40%. "For farmers in developing countries, this cost savings reduces the barrier to a water conserving and yield increasing technology," adds Amrose.

The team has conducted a number of field trials in Morocco and Jordan where they work with NGO partners and private farmers to test the newly designed emitters and optimized irrigation system.

"The biggest takeaway from these field trials was how much our system reduced energy and cost while providing high uniformity of flow rate to crops," explains Sokol.

According to Amrose, Sokol has been instrumental in the development and testing of these emitters. "She brings the whole package – she is an excellent designer, she can be in the field fixing hardware, and she is also incredibly good theoretically working with models," Amrose says.

In the coming year, Sokol and the GEAR Lab team will continue to make improvements to the design of the emitters that reduce costs, conserve resources, and improve crop yield. They will return to Morocco and Jordan this spring to test redesigned, optimized inline emitters which are bonded inside irrigation tubes.

At a treated wastewater irrigation site in Jordan, Julia Sokol installs a datalogger and sensors to record pressure and flow data in irrigation pipes. Credit: Susan Amrose

## Talking Shop:
# Professor Thomas Peacock

## Understanding the Environmental Impact of Deep-Seabed Mining

In the large swath of the Pacific Ocean between Hawaii and Baja California, the ocean floor is peppered with baseball-sized nodules that contain more cobalt, copper, and nickel than all the land-based mines globally. As demand for more materials steadily climbs and the quality of land based resources declines, government and industry have started investigating the potential of these resources 5,000 meters below the surface of the ocean. The topic of obtaining the mineral-packed nodules from the deep-seabed is referred to as deep-sea mining, although unlike typical land-based mining, there is no drilling in nodule collection.

Relatively little is known about the environmental impact of seabed mining, however. The International Seabed Authority, an independent organization established by the UN, has turned to researchers like Thomas Peacock, professor of mechanical engineering at MIT, to ensure the full effects of seabed mining are understood prior to drafting regulations.

**How did you first get interested in studying seabed mining?**

My training is in fluid dynamics and I tend to work on ocean-related problems. Most of my research has been fundamental in nature. But I started looking for opportunities to work on a societal problem. I identified deep-sea mining as a topic to work on because one of the largest issues I see facing society is pressure on raw material supplies. Given continued population growth and urbanization, before we can achieve a global circular economy it seems there will continue to be an increased demand for minerals over the coming decades. Mining the seabed could open up a new world of possibilities for getting these materials, but we need to determine what the impact would be in comparison to land-based mining activities. To get my project started, I received a seed grant from the MIT Environmental Solutions Initiative, and I have also received a great deal of support from the MIT International Policy Lab.

Professor Thomas Peacock (left) with graduate students Rohit Balasaheb Supekar (center) and Carlos Munoz Royo (right). Credit: John Freidah

**How do you mine the ocean floor thousands of meters below sea level?**

My research focuses on the collection of polymetallic nodules that sit on the seabed floor. These nodules contain nickel, cobalt, and copper. They grow at a rate of one centimeter every million years. To get the nodules, the proposed process is to use a collector device that acts as a vacuum and sucks up the top 10 or so centimeters of the seabed. The collector then separates the nodules from the sediment and these nodules will be transported via a riser pipe system to a surface operation vessel that will do some further handling of the nodules before they are shipped to shore.

While aboard the research vessel Sally Ride off the coast of San Diego, Peacock and a team of researchers studied sediment plumes to assess the environmental impacts of deep-sea mining. Credit: John Freidah

As the collector moves across the seabed floor, it stirs up sediment and creates a dust cloud or plume that's carried away and distributed by ocean currents. My focus has been researching the dynamics of these sediment plumes.

**What are the environmental concerns with deep-seabed mining?**

The dynamics of the deep ocean are very slow. The natural rate of sedimentation in the ocean is one millimeter every one thousand years. After the collector removes the upper layer of the seabed, that area is unlikely to recover on a reasonable timescale. From a biologist's perspective, the concern is that if there is a biological community specific to the area, it might be irretrievably disrupted due to mining.

Since plumes of sediment are kicked up by the collector and transported away, there is also a concern about how sediment from plumes could impact sea life where it settles on other parts of the seabed. To determine to what extent sea life is being negatively impacted, we need to understand how these plumes would be transported throughout the ocean.

**How do you use your background in fluid dynamics to gain more insight on the environmental impacts of seabed mining?**

We've done a lot of work on the dynamics of the mining plumes and use mathematical models for describing the behavior of the plumes near where they're discharged by the collector. That knowledge can be used as an input to a numerical model that simulates the ocean currents transporting the plumes around. We collaborate with Pierre Lermusiaux, professor of mechanical engineering and ocean science and engineering, who has the expertise in these ocean models.

**Have you been able to put these models into practice in field experiments?**

Yes, I oversaw an expedition called PLUMEX in March of this year that was the first field study of a sediment plume discharged by an operational vessel after the useful nodules have been obtained. The ship resources were generously supplied by the University of California, through collaboration with my colleague Professor Matthew Alford at the Scripps Institution of Oceanography. We had other researchers from MIT, the USGS, the University of Hawaii and the ISA involved.

The field experiments we conducted off the coast of San Diego showed us that we can use the models that we've developed to make reasonable predictions about how these plumes behave, which will be essential in understanding seabed mining's environmental impact. My group at MIT, the Environmental Dynamics Lab (ENDLab) will continue this research by contributing to an important prototype collector vehicle study in the deep Pacific Ocean this spring.

It's great to have researchers join the conversation early and help make informed decisions so we can fully understand the environmental impact of mining resources from the ocean and compare it to the environmental impact of mining resources on land.

Class Close-Up:

# 2.981 New England Coastal Ecology

By Mary Beth O'Leary

A close-up of a dog whelk, or *Nucella lapillu*, a common snail predator of the rocky intertidal. Credit: MIT Sea Grant

In early January 2018, a nor'easter pummeled the East Coast. Many streets in Boston became impassable due to a record-breaking high tide. Seawater rushed down Seaport Boulevard in Boston's Seaport District. A deluge of water poured down the steps leading down to the Aquarium subway station, forcing the station to close.

Less than a week later in a dry classroom on MIT's campus, a group of students discussed how coastal cities like Boston can cope with worsening floods due to sea level rise. "We live in a coastal city, so obviously we are being significantly impacted by sea level rise," says Valerie Muldoon, a third-year mechanical engineering student. "We talked about the bad nor'easter earlier in January and brainstormed ways to mitigate the flooding."

Muldoon and her fellow students were enrolled in course 2.981, New England Coastal Ecology, during MIT's Independent Activities Period in January 2018. The course is offered through the MIT Sea Grant College Program that is affiliated with MIT's Department of Mechanical Engineering.

Instructors Juliet Simpson, Research Engineer at MIT Sea Grant, and Carolina Bastidas, Research Scientist at MIT Sea Grant, use the four-week class as an introduction to the biological makeup of coastal ecosystems, the crucial role these areas play in protecting the environment, and the effects human interaction and climate change have had on them.

"We want to give a taste of coastal communities in New England to the students at MIT – especially those who come from abroad or other parts of the US," says Bastidas, a marine biologist who focuses her research primarily on coral and oyster reefs.

"I was so excited to see a Course 2 class on coastal ecology," says Muldoon, who is a double minor in energy studies and environment and sustainability. "I'm passionate about protecting the environment, so the topic really resonated with me."

The course begins with an introduction to the different types of coastal ecosystems found in the New England area such as rocky intertidal regions, salt marshes, eelgrass meadows, and kelp forests. In addition to providing an overview of the

Valerie Muldoon (left), a third-year mechanical engineering student, and biological engineering student Jenna Melanson (right) at a field trip in Odiorne Point State Park, New Hampshire. Credit: MIT Sea Grant

makeup of each environment, the course instructors also discuss the physiology of the countless organisms who live in them.

Halfway through the course, students learn about how human impacts like climate change, eutrophication, and increased development have affected coastal habitats.

"We focus on climate change as it impacts coastal communities like rocky shores and salt marshes," says Simpson, a coastal ecologist who studies how plants and algae respond to human interference. "There are a lot of interesting implications of sea level rise for intertidal organisms."

Sea level rise, for example, has forced organisms that live in salt marshes to migrate upland. Changes in both water and air temperature also have a drastic effect on the inhabitants of coastal regions. "As temperatures rise, all of those organisms are going to need to adapt or the communities are going to change, possibly dramatically," explains Simpson.

Protecting coastal ecosystems has far-reaching implications that go beyond the animals and plants that live there. These ecosystems offer a natural defense against climate change.

Many coastal ecosystems are natural hot spots for carbon capture and sequestration. Salt marshes and seagrass meadows all capture vast amounts of carbon that can be stored for several thousand years in peat.

"I was shocked at how much carbon the plants in these ecosystems can hold through sequestration," recalls Muldoon.

Protecting these areas is essential to continue this natural sequestration of carbon and prevent carbon already stored there from leaking out. Coastal ecosystems are also instrumental in protecting coastal cities, like Boston, from flooding due to sea level rise.

MechE alumna Jorlyn Le Garrec uses a hydrophone to measure the sounds of a rocky shore community.
Credit: MIT Sea Grant

"We talk about the ecology of coastal cities and how flooding from storms and sea level rise impacts human communities," adds Simpson.

The class culminates in a field trip to Odiorne Point State Park in New Hampshire where students get to interact with the communities they've learned about. Using fundamental techniques in ecology, students collect data about the species living in the salt marsh and rocky shore nearby.

While the effects of climate change on coastal ecosystems often paint a dire picture, the instructors of 2.981 want students to focus on the positive. "Rather than have students focus on the gloom and doom aspect, we want to encourage them to come up with novel solutions for dealing with climate change and carbon emissions," adds Bastidas.

Muldoon sees a special role for mechanical engineers in developing such solutions. "I think it's so important for mechanical engineering students to take classes like this one because we are definitely going to be needed to help mitigate the problems that come with sea level rise," she explains.

Bastidas and Simpson will expand the class' scope beyond New England in a new course which will be offered in Fall 2019 entitled 2.982, Ecology and Sustainability of Coastal Ecosystems.

# News & Awards

Alumni (from left to right) Michael Ambrogi '85, Steven Kosowsky '83, John Sununu '86, SM '87, and Larry Butkus '85 at the unveiling of a memorial plaque for MechE Undergraduate Officer, Peggy Garlick. Credit: Tony Pulsone

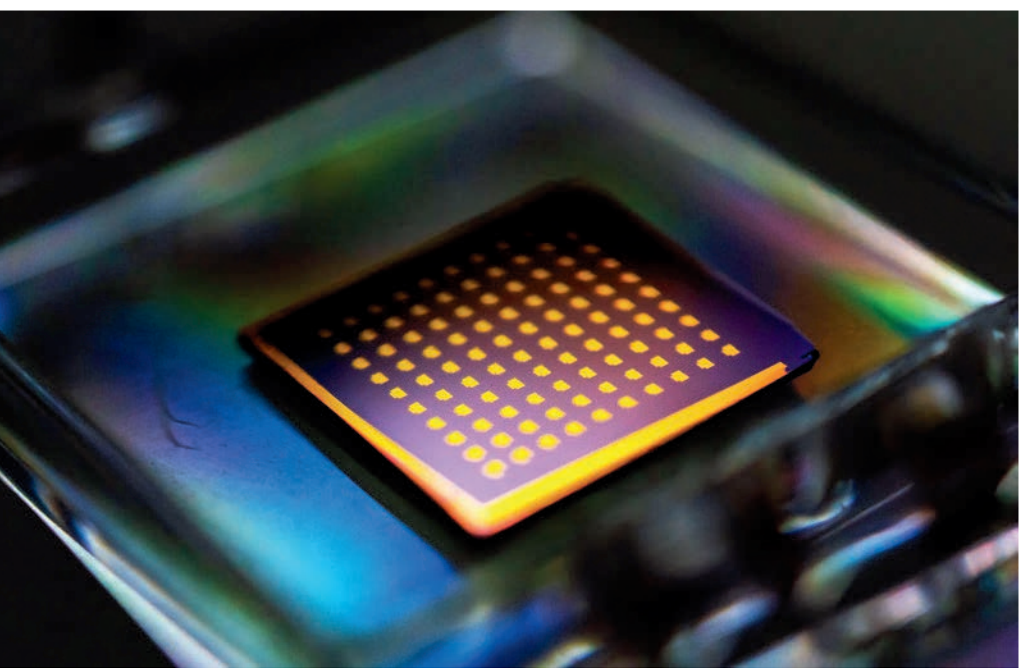
## Departmental News

• Evelyn Wang, Gail E. Kendall (1978) Professor and director of MIT's Device Research Laboratory, has been named head of MIT's Department of Mechanical Engineering. Her leadership team includes Professor Pierre Lermusiaux, associate department head for research and operations, and Associate Professor Rohit Karnik, associate department head for education.

• In September, the MIT-Woods Hole Oceanographic Institution Joint Program celebrated its 50th anniversary with a two-day event in Woods Hole.

• A group of alumni gathered in the Department of Mechanical Engineering's Undergraduate Office on September 5, 2018 for the unveiling of a memorial plaque honoring the life of Peggy Garlick, former Undergraduate Officer for MechE.

• In October, MechE hosted the first-ever Rising Stars in Mechanical Engineering Workshop which introduced thirty-four of the brightest women graduate students, post-docs, and early-career researchers from across the nation to the world of academia.



Associate Professor Jeehwan Kim's team has developed a technique to harvest 2-inch diameter wafers of 2D material within just a few minutes. Credit: Peng Lin

## Research News

• A fabrication technique described in the journal *Advanced Materials* and developed by Associate Professor Rohit Karnik could be integrated into manufacturing to make large-scale membranes that filter out small molecules and salts.

• A team of researchers led by Professor Nicholas Makris produced wide-ranging acoustic images of cod shoals. The images, which were reported in the journal *Fish and Fisheries*, could help researchers identify populations on the brink of collapse.

• A new design from Professor Yang Shao-Horn and Professor Douglas Hart could greatly extend the shelf life of single-use metal-air batteries for electric vehicles, off-grid storage, and other applications. Their findings are reported in the journal *Science*.

• In a *Science Advances* study, Professor Nicholas Fang used the ancient art of kirigami to manipulate light at the nanoscale, potentially opening up new possibilities for the creation of new light-based communications.

• Associate Professor Jeehwan Kim has developed an efficient method for making single-atom-thick, wafer-scale materials. These 2D materials, described in the journal *Science*, could be used to make an electronic device within an hour.

Participants from the Rising Stars in Mechanical Engineering Workshop in October. Credit: Tony Pulsone

## Faculty Awards

• Professor John B. Heywood received the 2018 Society of Automotive Engineers Excellence in Oral Presentation Award.

• Associate Professor Alexandra Techet has been named a Fellow by The American Society of Mechanical Engineers.

• The American Society of Mechanical Engineers honored Professor Alexander Slocum with the 2018 Ruth and Joel Spira Outstanding Design Educator Award.

• Associate Professor Xuanhe Zhao received a *Materials Today* Rising Star Award.

• Associate Professor Asegun Henry received The American Society of Mechanical Engineers' 2018 Bergles-Rohsenow Young Investigator Award in Heat Transfer for introducing and formulating phonon transport based on correlation instead of scattering.

## Student Awards

• PhD candidate Krithika Ramchander has been awarded a J-WAFS fellowship to develop a low-cost, point-of-use water filter for rural communities in India.

• Using a yo-yo design he developed in class 2.008, Design and Manufacturing II, senior Alex Hattori won second place in the 3A division at the 2018 World Yo-Yo Contest in Shanghai.

• At the fifth annual Mechanical Engineering Research Exhibition on September 28, 2018, graduate students gained valuable practice presenting their research. Awards were given to students Daniel Gonzalez, Chu Ma, Mo Chen, Cameron McBride, and Carson Tucker.

## Alumni News

• Derek Straub MEng '15, Additive Manufacturing Lead at MIT's Lincoln Laboratory, has been named to *Manufacturing Engineering Magazine's* 30 Under 30 list.

• Shreya Dave '09, SM '12, PhD '16 was named one of *MIT Technology Review's* 35 Innovators Under 35.

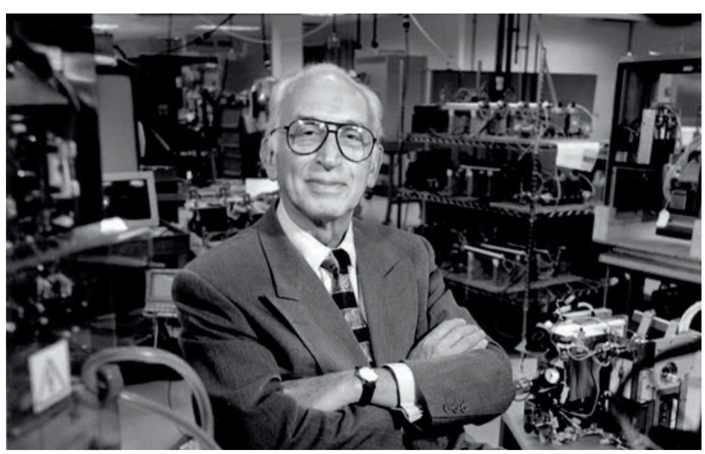
• Meredith Silberstein '05, SM '08, PhD '11 and Ethan Crumlin '05, SM '07, PhD '12 were selected for the US Department of Energy's 2018 Early Career Research Program.

## In Memoriam

• Shih-Ying Lee, a longtime mechanical engineering professor and expert in process control, measurement, and instrumentation, passed away peacefully on July 2, 2018. Lee '43, SCD '45 had recently celebrated his 100th birthday in April.

• Colt Richter '16 passed away in July 2018. Richter loved to fly, served as a volunteer emergency medical technician at MIT, sung in the Ohms a cappella group, and was on the Presidential Advisory Cabinet.

• George Nicholas Hatsopoulos '49, SM '50, ME '54, SCD '56, senior lecturer emeritus in mechanical engineering and MIT Corporation life member emeritus passed away in September 2018 at the age of 91.



George Hatsopoulos, senior lecturer emeritus and MIT Corporation life member emeritus, has passed away at 91. Credit: Jim Harrison

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