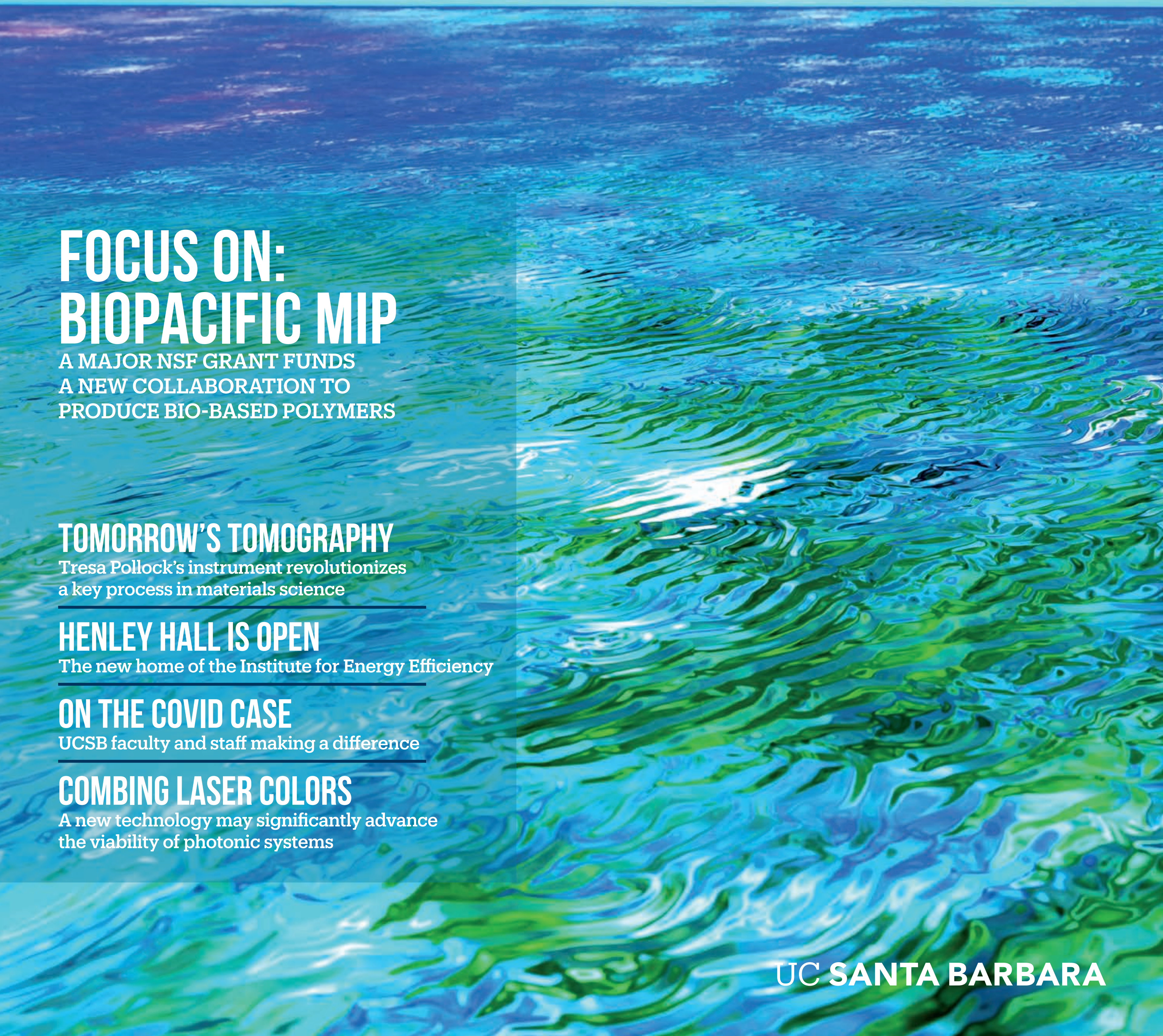
WINTER 2020

CONVERGENCE

The magazine of engineering and the sciences at UC Santa Barbara



FOCUS ON: BIOPACIFIC MIP

A MAJOR NSF GRANT FUNDS A NEW COLLABORATION TO PRODUCE BIO-BASED POLYMERS

UC SANTA BARBARA

MESSAGE FROM THE DEANS

ROD ALFERNESS
Dean and Richard A. Auhll Professor, College of Engineering

PIERRE WILTZIUS
Susan & Bruce Worster Dean of Science, College of Letters & Science

These are, indeed, extraordinary times. Yet, faced with the need to address enduring social-justice issues and control a global pandemic, UC Santa Barbara faculty, staff, and students have stood together and moved forward. This issue of *Convergence* reflects that.

We begin on page 4 by describing some of the first actions in what will be an ongoing effort in the College of Engineering and across the university to identify and eliminate institutional racism and ensure equal access and opportunity for all.

In response to the COVID-19, UCSB faculty and staff moved quickly to address the need for knowledge, equipment, testing, student services, and more. A collection of articles about some of those efforts begins on page 10, and on page 34, technology management assistant professor **Matt Beane** explains why, even with social distancing and burgeoning demand at fulfillment companies, the pandemic does not signify an immediate rise of the robots.

As difficult as 2020 has been, there are numerous positive developments to announce. Henley Hall (page 8) was completed on time in early September as the new home of the Institute for Energy Efficiency (IEE). The visually stunning building, bursting with green features, significantly expands the laboratory space available for collaborative leading-edge research aimed at finding new approaches to reducing our energy needs.

Furthermore, just six months after receiving a major National Science Foundation grant to build the nation's first NSF Quantum Foundry, UCSB was named the lead institution for an equally large NSF grant received in collaboration with UCLA to develop high-performance bio-based polymeric materials. Called the BioPolymers, Automated Cellular Infrastructure, Flow, and Integrated Chemistry: Materials Innovation Platform (BioPACIFIC MIP), the project spans multiple fields of engineering and science and leverages expertise and facilities that have long united UCSB and UCLA, especially through their respective campus headquarters of the California NanoSystems Institute. Read about this major project starting on page 17.

Elsewhere, you'll find articles about the commercial production of the groundbreaking laser-equipped TriBeam electron-microscopy instrument developed by materials professor and CoE associate dean **Tresa Pollock** (page 26), two CoE alumni who are in a global competition to design a sensor system for a Venus rover vehicle (page 4), and a new optics chip developed by IEE director and electrical and computer engineering professor **John Bowers** and colleagues, which simplifies and integrates a complex optical system into a small, energy-efficient package (page 32).

In our Faculty Q & A on page 28, **Beth Pruitt,** mechanical engineer and director of the UCSB Center for BioEngineering, tells us about her research aimed at understanding the mechanics and dynamics of heart-muscle tissue and cells.

We hope you enjoy the issue. Stay well, and may we all continue to move forward together.

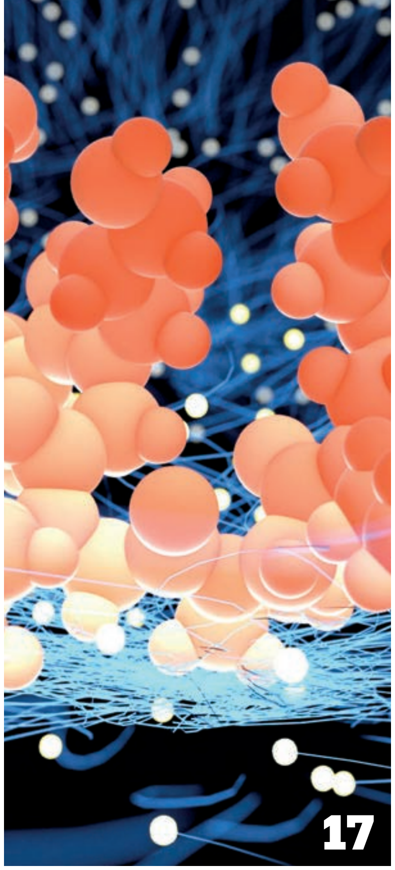
Sincerely,

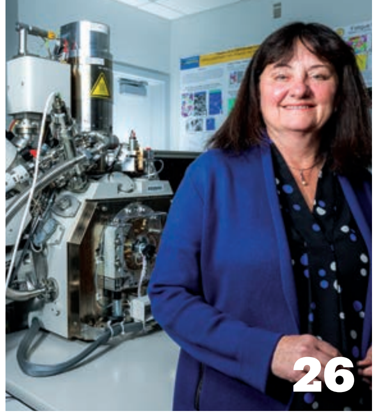
Rod Alferness

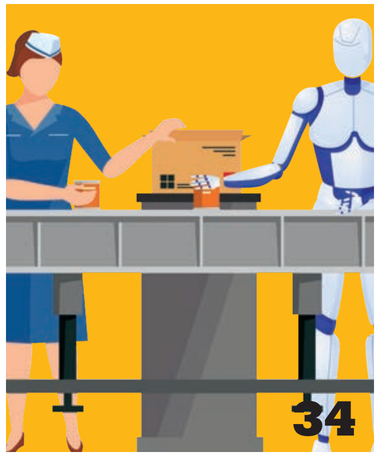
Rod Alferness

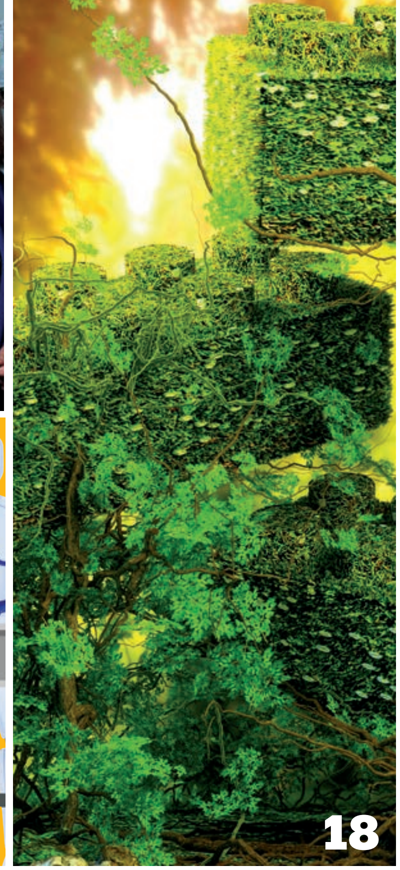
Pierre Wiltzius

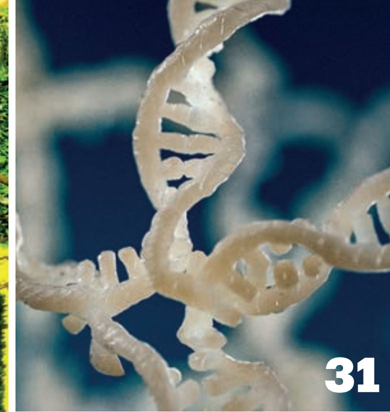
P. Wiltzius











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Issue 26, Winter 2020

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Cover Illustration: Artist's concept illustration evokes the Pacific Ocean, with four colors representing the four elements of the Bio PACIFIC MIP (page 17), by **Brian Long**

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UC SANTA BARBARA
College of Engineering

NEWS BRIEFS

TOWARD EQUITY AND EQUALITY

In the wake of the nationwide protests that followed George Floyd's death at the hands of police in Minneapolis on May 25 and continue today, UC Santa Barbara and the College of Engineering, like institutions across the nation, took action to begin to address the problems of enduring societal and institutional racism that stand in the way of full equity, inclusion, justice, and opportunity for all.

Some important actions were taken immediately, while others will occur more slowly, over time, to ensure appropriate responses that point toward meaningful, sustainable, effective action and reflect an ongoing and expanded commitment to ensuring that diversity, equity, and equality are demonstrably present in every corner of our university and our college.

Perhaps the single most important action the university has taken was to name **Dr. Belinda Robnett** as Vice Chancellor for Diversity, Equity and Inclusion, effective Sept. 1, 2020. The culmination of a national search that began long before the events leading to last summer's protests, Dr. Robnett's hiring at the highest level of university administration reflects the seriousness of UCSB's commitment to progress.

Dr. Robnett, formerly Associate Dean for Faculty Development and Diversity in the School of Social Sciences at UC Irvine, where she had been a professor in the Sociology Department since 1999, will lead the university's efforts to coalesce existing campus diversity and equity programs and shape future initiatives.

In the wake of the spring protests against injustice, UCSB launched a process of self-study, with the intention of identifying where it might be falling short in areas of diversity, equity, and inclusion and working with key stakeholders to address them.

Rod Alferness, dean of the College of Engineering, sent letters to university constituents and to CoE alumni and the greater CoE community expressing solidarity with all people, and especially with people of color, who were feeling the weight of societal injustice and inequality.

In the weeks immediately following George Floyd's death, the CoE drafted a statement of its commitment to diversity, which begins with the words, "We believe in the inherent value of diversity and the value of all people." It is presented prominently in the new Diversity section of the CoE website, reached via the "About" page.

Included there, too, is a collection of evolving content describing many existing programs, indicating areas where progress can be made, and listing resources to serve diverse constituencies as well as protocols for responding to acts of aggression, violence, and bias against any student.

On September 1, Dr. Belinda Robnett assumed her new position as Vice Chancellor for Diversity, Equity and Inclusion at UC Santa Barbara.

ALUMNI WIN AWARD FOR VENUS ROVER SENSOR DESIGN

Venus, the "Evening Star" planet, is Earth's closest planetary neighbor and the hottest planet in the solar system, with a surface temperature of about 900 degrees Fahrenheit. Many spacecrafts have been sent there; the longest any of them survived on its surface was a little over two hours. In 1989, NASA's *Magellan* orbiter used radar to generate a high-resolution map covering 98 percent of the planet's surface.

Now, NASA wants to return, on a mission named for the vehicle being developed for it, the Automaton Rover for Extreme Environments (AREE). The challenges are enormous, and the rover would need to be fitted with non-traditional sensors that could survive Venus's harsh environment and allow the vehicle to traverse the surface safely.

To that end, NASA launched a global competition, the suitably named Exploring Hell Challenge, asking inventors and scientists to design a novel sensor for the rover. Organizers received 572 submissions from 82 countries, and when it was all over, the judges awarded second place, and a prize of $10,000, to Team Rovetronics, comprising **Martin Grabau** and **Eric Seeberger** (both BME '17), the only American entry to place in the top five.

"I almost couldn't believe it when I saw our name listed next to second place," said Grabau, now a mechanical engineer at Goleta's FLIR Systems, where he works on cryocooler designs for cooled infrared cameras. "We knew we put together a strong submission that we were both proud of, but there are a lot of very talented people out there, so it's a huge honor that our work was considered some of the best."

"We spent a lot of time on this project, and it's extremely rewarding to have something to show for all the work we did," said Seeberger. "I was a bit surprised that we were the only American team to place, but it shows how powerful the internet is at connecting people worldwide and how much respect NASA has throughout the international community."

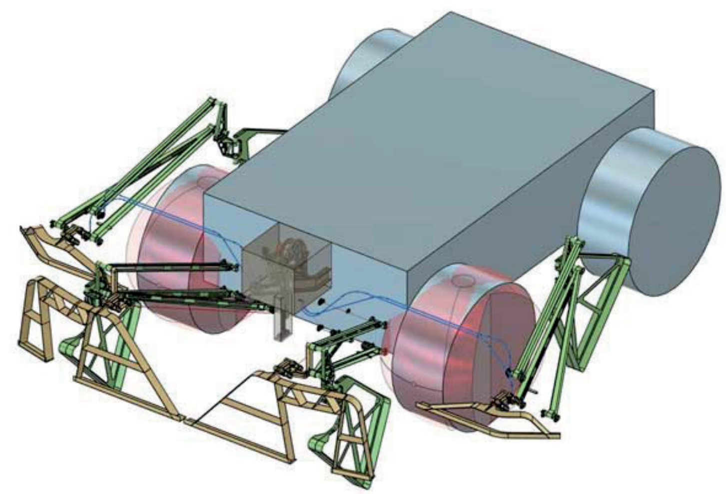


Illustration courtesy of Martin Grabau and Eric Seeberger

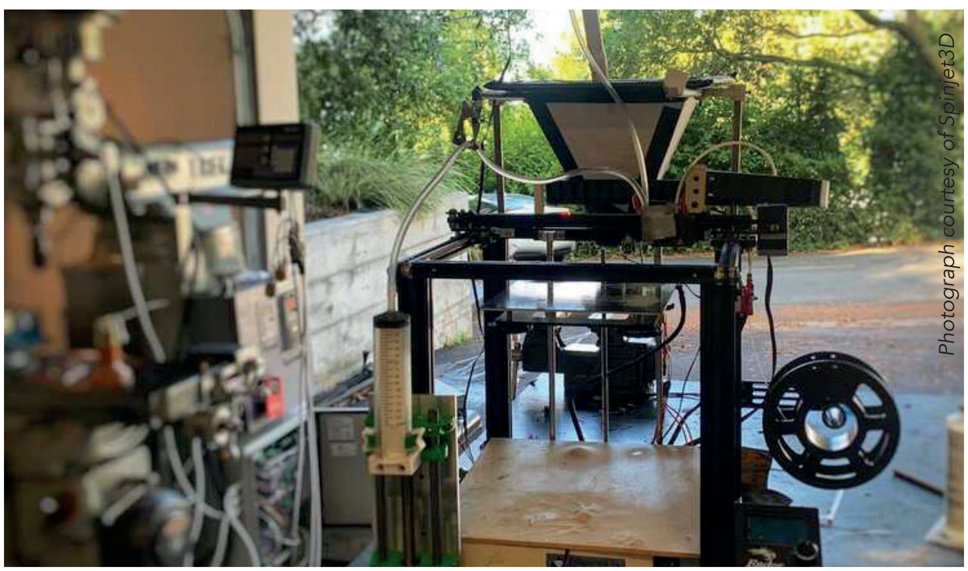
A rendering of Team Rovetronics' sensor design, which features a hinged metal unit attached to the front of the rover to identify obstacles.

"The biggest challenge early on was coming up with a solid design for the rover to detect holes on the surface of Venus, because the vehicle could get stuck or miss an obstacle," said Seeberger, who is a structural-design engineer on the F-35 program at Northrop Grumman. "There were also some flaws with the trigger mechanism, which we discovered a few days before the deadline and had to scramble to resolve."

Their final design was an all-mechanical, mostly passive sensor that they call "Skid 'n' Bump." The hinged metal unit, attached to the front of the rover, "feels" upcoming obstacles so that the machine knows what lies ahead. When the sensor detects an obstacle, it alerts the rover by pushing down on a pin protruding from the body of the vehicle. That triggers a sequence, which causes the rover to back up and then turn to avoid the obstacle.

"We're most proud of the effort we put into thinking of all the scenarios that would cause our designs to fail and coming up with elegant solutions to those issues," said Grabau. "The NASA team mentioned how impressed they were with how well we addressed problems that they hadn't fully considered."

A video featuring members of the five winning teams explaining their designs can be viewed on the competition website, **www.herox.com/VenusRover/updates.** NASA scientists will consider each of the top-five designs as the AREE project continues to develop.



Photograph courtesy of Spinjet3D

Over the summer, the members of Spinjet3D built a prototype of their printer to test different binder solutions.

SPINJET3D WINS VIRTUAL NEW VENTURE COMPETITION

On May 21, the Spinjet3D team won the 2020 Technology Management New Venture Competition (NVC) and the $10,000 First Place Award, besting four other teams in the finals of the eight-month business-plan competition for aspiring tech startups. With the UC Santa Barbara campus closed during the coronavirus outbreak, the annual competition was held remotely and viewed live by people around the world.

Team members **Anurag Pallaprolu,** a PhD student in the Electrical and Computer Engineering Department; physics major **Noah Treiman;** mechanical engineering student **Yiling Yang;** and **Piergiacomo Palmisani,** a technology management graduate student, were recognized for the new type of 3D printer they have developed.

Making metal parts, especially those that are not produced at large scale, is expensive and time-consuming. Molds have to be made by hand before the metal is poured in to create the part. Sand-mold 3D printers, which print the mold directly from common sand materials, are a time-saving alternative, but their size and hefty price tag put them beyond the reach of many metal-parts manufacturers.

The students say that their fully automated sand-mold 3D printer is faster, cheaper, more precise, and more eco-friendly than existing technology.

"We are extremely grateful to the Technology Management program for this incredible experience and opportunity," the team said in a written statement. "Our team met through NVC events, and the mentorship the program provided was invaluable. We look forward to making a positive change in the metal manufacturing industry, and we are excited to start our journey here in the Santa Barbara community."

The Spinjet3D team intended to use their winnings to finish developing the product, raise capital, and perform prototype testing over the summer.

The second-place finisher in the competition was Legtrek, which offers a new medical device combining a powered wheelchair and a powered gait trainer to serve patients who have challenges with lower-limb mobility. They earned $7,500.

Third place and a check for $5,000 went to Genesis, an AI-based startup that uses high-quality data annotation to solve the problem of bad data in machine learning. Two honorable-mention awards and $2,500 apiece went to Deadstock and Thermaform Technologies. The Thermaform team, which created a compression device to benefit seniors and others affected by circulation deficiencies, also received the People's Choice and Best of Fair awards, worth an additional $5,500 in prize money. Deadstock built an application enabling users to verify whether luxury goods, such as high-end sneakers, are authentic.

The online nature of the 2020 events still allowed students to think on their feet while interacting live with judges and audience members and answering their questions. The virtual fair attracted a global audience of 620 people from as far away as Nepal. "I salute all of our students," said **Dave Adornetto,** technology management's entrepreneurship director, during the online finals. "You all did an excellent job through very difficult challenges and circumstances. You guys never wavered, and you pushed through."

Mentored by a team of more than forty individuals who have thrived in the fast-paced world of tech entrepreneurship, students in the competition receive valuable first-hand knowledge and the opportunity to hone their entrepreneurship skills, refine their business plans, and practice pitching their stories and ideas. Pitches for all fifteen teams that participated in the New Venture Fair (from an initial field of thirty-five) can be viewed at **newventure.live.**

During the finals, teams were judged by a panel of tech entrepreneurship experts and investors made up of: Bei-Jing Guo, a graduate of UCSB's Electrical and Computer Engineering Department and an investor with Seattle Alliance of Angels, who founded her own artificial intelligence start-up after spending twenty years at Microsoft and Amazon Web Services; Kenny Van Zant, a software company executive for more than twenty years and an active angel investor; and Kevin Zhang, a partner at Upfront Ventures, the largest and longest-serving venture capital firm in Los Angeles.

"I was very pleased with the performance of all of the teams," said Adornetto. "It was a tough field this year. Ultimately, the judges honed in on the industry most ripe for disruption, but recognized the potential of all of the finalists."

PROCORE FOUNDER WINS 2020 VENKY ENTREPRENEURSHIP AWARD

The Venky Narayanamurti Entrepreneurial Leadership Award is conferred annually by the UC Santa Barbara College of Engineering to recognize an individual who has demonstrated success and leadership in the high-technology entrepreneurial community of the Central Coast. This year's winner, **Craig "Tooey" Courtemanche,** founder and CEO of Procore, a construction-management software company headquartered in Carpinteria, California, says that, for him, the first step to success is not to create a spreadsheet or go on a number-crunching bender. Rather, he says, "If you have an idea, the first thing to do is to literally go sit on the beach for a few days and think about your strengths and weaknesses. Examine who you are as a person, and don't fool yourself."

"On behalf of the UCSB College of Engineering, I offer sincere congratulations to Tooey Courtemanche for being named the recipient of the 2020 Venky Award," said **Dean Rod Alferness.** "It takes immense courage, originality, and energy to accept the challenge of steering one's startup into largely uncharted entrepreneurial waters. Dean Venky understood that, and Tooey Courtemanche embodies it."

Courtemanche began by working in construction and was later a software engineer. He founded Procore in 2002 and has since grown it to over two thousand employees operating out of fourteen offices around the world. More than one million construction projects have run on the Procore platform, which is used daily by more than 1.3 million people in over 125 countries. Courtemanche has been credited by *Forbes* with building the Cloud's hottest technology "unicorn" by bringing software to construction sites.

"We were born in the cloud in 2002, and that's something I'm really proud of," he says. "The whole concept of Procore has always been to connect everybody in construction on a platform. There was no way we were

Craig "Tooey" Courtemanche's software has changed the construction industry.

going to do that if every client had to have its own server.

"But I knew how to deploy a cloud server, an ASP server, as it was known back in the day — and I knew how to create multi-tenancy [so that multiple users could work off one server simultaneously] — and it was something I was kind of passionate about," he continues. "It was a very new idea in the late nineties. I had seen it deployed in a company called Edify, and I thought, *What a novel way to work.* It was also way less expensive to buy one computer than to buy multiple servers and databases and everything else."

When the company began, Courtemanche and Procore president (and employee number two), Steve Zahm, would go to job sites to install internet Wi-Fi access points and routers so that the builders could use their software for $95 a month.

"At the time, I was summarily known as being an idiot," Courtemanche laughs. "Who builds collaboration software for an industry that doesn't even have the internet? How is that even going to work?"

But then the iPhone and the iPad came out in 2007, and internet servers became common on job sites. "The advantages of being connected on the network were suddenly apparent," Courtemanche recalls. "Instead of logging data in job-site trailers, construction workers were actually collaborating with the data and using their device to get the job done. When we had twenty-three customers, we thought Procore would be this small business that we would use to do a cloud experiment. Looking back, we describe it as a business that went horribly right."

In receiving the Venky Award, Courtemanche said, "I am tremendously honored. I've lived in Santa Barbara for twenty years and have watched this award go to people I admire and look up to. For a guy who is a college dropout to receive this is kind of mind-blowing to me. It is really a special honor."

Courtemanche, who employs many UCSB graduates, says that he tells would-be entrepreneurs that being an entrepreneur is not the goal, but rather, what you do to accomplish the goal of bringing an idea to market. Other suggestions include, "Don't assume you know all the answers or know what you're doing; you don't. Don't be afraid of self-doubt. Ask a lot of questions of many different people. Raise enough money; no one ever raises enough money. Assume it's going to be harder and take longer than you would ever imagine."

And most important: start at the beach.

GPUs ACCELERATE RESEARCH

State-of-the-art nodes installed in the High Performance Computing campus cluster "Pod" in Elings Hall.

Researchers at UC Santa Barbara are already reaping the rewards of a new state-of-the-art graphics processing unit (GPU) computer cluster that was installed on campus in August. Originally designed to advance video games and on-screen three-dimensional rendering, GPUs are now powering scientific data processing and academic research, dramatically accelerating modeling and computations. Because it is specifically designed for basic mathematical operations and some codes, a GPU-based system can perform computations thirty to fifty times faster than conventional central processing unit (CPU) hardware can. GPUs are more efficient — performing multiple calculations simultaneously, while CPUs work through calculations a few at a time — and as a result have turbocharged computational research in a growing number of fields.

"This is a game-changer for researchers at UCSB," said **Kris Delaney,** a co-principal investigator on the grant and project scientist with the Materials Research Laboratory (MRL).

The **Center for Scientific Computing** (CSC) at the California NanoSystems Institute (CNSI) at UC Santa Barbara and the MRL are managing and maintaining the new system, which was funded by a $400,000 grant from the National Science Foundation to accelerate scientific computing. The upgrade includes twelve compute nodes, with each one supporting four high-end NVIDIA Tesla V100 GPUs that are equipped with hardware double-precision processing, large (32 GB) memory, and NVLink for fast inter-GPU communications. Ten of the nodes were added to the existing High Performance Computing (HPC) campus cluster "Pod," which has three GPU nodes as part of its complement of computing nodes and is available to be used by all UCSB researchers. The two remaining nodes became part of the delocalized Pacific Research Platform Nautilus cluster, which connects a few dozen universities along the West Coast, including UCSB.

"The improvements of GPUs are happening very fast, so we need to be constantly upgrading equipment if we want to do the latest GPU-enabled research," said CSC director, **Paul Weakliem.**

Nathan "Fuzzy" Rogers, CSC co-director, adds, "With many researchers restricted from working in their labs due to the COVID-19 pandemic, there has also been an increase in demand as they explore their research with new computational techniques."

Faster computational speeds enable not only higher throughput, but also opportunities to address new research questions. The expansion will enhance efforts to develop novel bio-based materials in the new **BioPolymers, Automated Cellular Infrastructure, Flow, and Integrated Chemistry: Materials Innovation Platform** (BioPACIFIC MIP), a collaboration between UCSB and UC Los Angeles established with a $23.7 million NSF grant. (Read more about the BioPACIFIC MIP in the special "FOCUS ON:" section, which begins on page 17.)

"These computing resources will support the computation, simulation, and data science aspects of BioPACIFIC, and they will be critical to the project's success," said **Tal Margalith,** CNSI's executive director of technology and executive director of UCSB's BioPACIFIC MIP operation.

The new cluster will also drive the development and application of novel computational research techniques in three specific projects associated with the grant.

One project, led by Delaney, is intended to develop a unique simulation methodology to predict the structures and properties of complex polymer formulations found in various consumer products, including cosmetics, liquid soaps, detergents, and paints. The methodology, which also supports efforts of the BioPACIFIC MIP, bridges pioneering simulation techniques developed by UCSB chemical engineering professors **Glenn Fredrickson** and **M. Scott Shell.** (Read more about the techniques on page 22.) Computationally intensive simulations will be used to model the molecular structures and chemistry of new materials and suggest how design criteria can be met.

"By using the cutting-edge GPUs, very large simulations become more manageable," said Delaney.

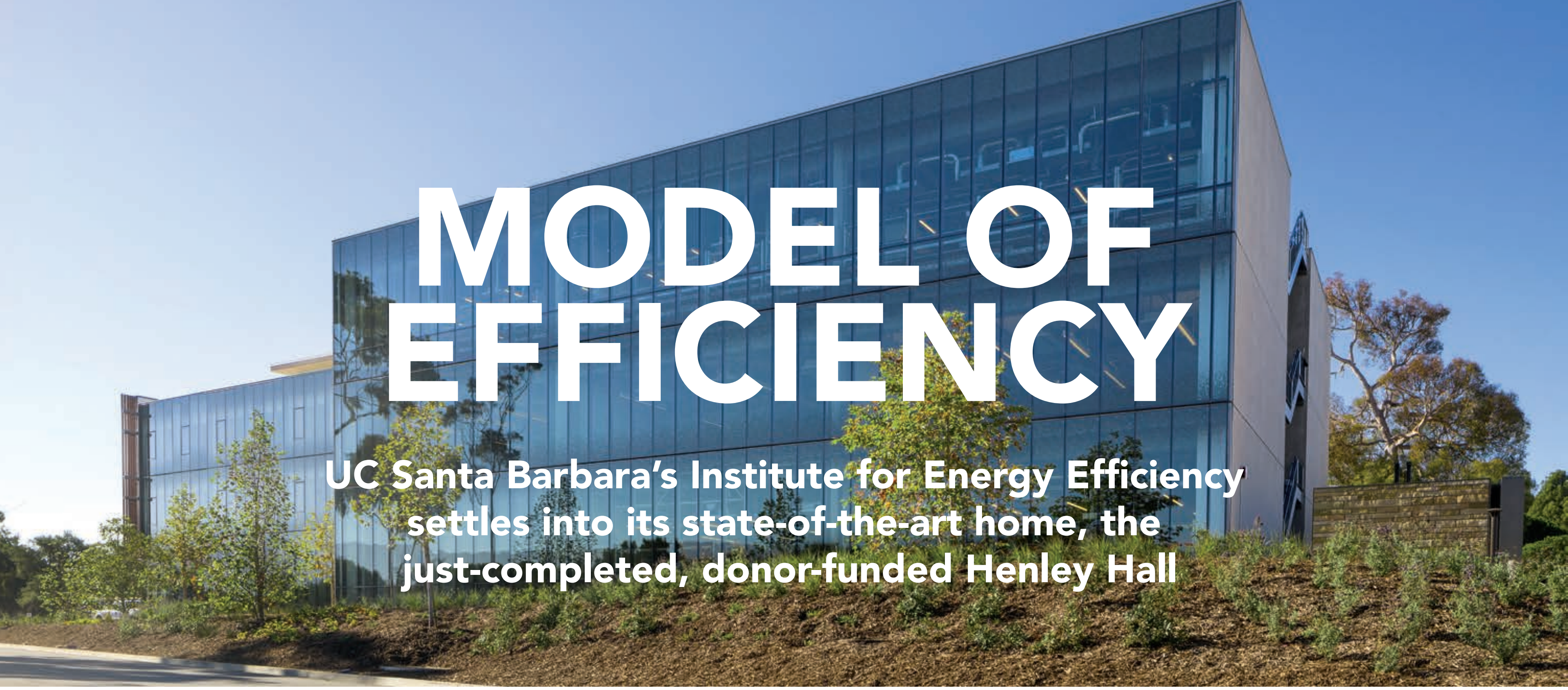
The new resources have also been directly coupled to a revolutionary microscope, the TriBeam, designed by materials professor **Tresa Pollock** and now being commercially manufactured by Thermo Fisher Scientific, the world's leading microscope manufacturer. (Read more about the instrument on page 26). The new computer cluster will help to process the terabytes of imaging data generated by the TriBeam.

"These new processing capabilities will increase the fidelity of the data gathered and provide feedback for real-time instrument control, which will allow us to hone in on specific property-controlling features in materials," said **McLean Echlin,** a research scientist in Pollock's group.

The cluster has also allowed **Yufei Ding,** an assistant professor in the Computer Science Department, to process data in her research on machine learning and quantum computing. Ding's group seeks to facilitate faster and more energy-efficient neural-network training and inference by minimizing the size of the network and modeling the associated architecture and framework.

"This new GPU cluster enables a tremendous amount of research to be completed that would not be done or would take too much time to fulfill," said Ding.

The center estimates that up to three-fourths of the people using the expanded cluster will be UCSB students. The shared resource will also be available to high school and community college students and teachers who participate in campus-sponsored programs.



MODEL OF EFFICIENCY

UC Santa Barbara's Institute for Energy Efficiency settles into its state-of-the-art home, the just-completed, donor-funded Henley Hall

Labs in the new home of the IEE will stay cooler thanks to north-facing windows (above), which receive no direct sunlight.

Award-winning multidisciplinary research conducted by those affiliated with the Institute for Energy Efficiency (IEE) in the UC Santa Barbara College of Engineering has laid the foundation for numerous important energy-saving innovations. Among them are white LED lights, increasingly energy-efficient data-center communications and interconnects, and software that reduces energy usage in buildings. It is entirely fitting, then, that those researchers and the IEE itself have a shared home in an extremely "smart" new building, Henley Hall.

The 50,000-square foot structure was completed on time in September and is, technically, open for business, although the ongoing pandemic has limited its occupation to critical research projects in accordance with public health guidelines.

Years in the making, the building was funded by donors led by Jeff and Judy Henley, whose $50 million gift to the College of Engineering in 2012 sparked the project. More than $14.5 million was contributed by Silicon Valley–based alumnae Shawn Byers and her husband, Brook Byers.

"Judy and I wanted to support the priorities of the university and the College of Engineering by advancing the work of the Institute for Energy Efficiency," Jeff Henley said in describing their initial motivation for the gift. "Getting faculty into state-of-the-art facilities was critical to achieving that goal. With Henley Hall now complete, the institute is perfectly situated to create the new opportunities for research and teaching that can lead to pioneering, world-changing discoveries. They'll also be nourishing and preparing a new generation of scientists and engineers, who will surely push the boundaries of energy efficiency even further."

"It is hard to find the words to thank Jeff and Judy Henley for our new Henley Hall," said UCSB **Chancellor Henry T. Yang.** "From the initial concept of establishing an Institute for Energy Efficiency to the idea of creating a new building as the home of IEE, Jeff provided the vision, guidance, financial support, and encouragement for well over a decade. We are also deeply grateful to Shawn and Brook Byers for joining forces with the Henleys' inspirational vision and generosity. Our Institute for Energy Efficiency is now an exemplary model, a flagship at the frontier of energy efficiency, with the participation and collaboration of award-winning faculty across the disciplines. Thanks also go to Dean of Engineering **Rod Alferness,** Director **John Bowers** and faculty of the Institute, our generous and visionary IEE Director's Council members, as well as all of our researchers, students, and staff who have contributed to the Institute since its launch in 2008."

"Henley Hall provides critical research lab space in which our faculty and graduate students will discover and innovate solutions to address society's major challenges, especially in the area of increased energy efficiency," said Alferness. "The building sets UCSB up for success by establishing a collaborative, cross-disciplinary environment, which is important because it brings together faculty with diverse backgrounds and interests in an effort to maximize the public benefit of their pioneering research. We are extremely grateful to Jeff and Judy Henley, and to Shawn and Brook Byers for their generosity and support, which made this state-of-the-art building possible."

"There's a big need for lab space on campus," said Bowers. "We have a lot of new faculty, and many new initiatives that require space to be successful. Jeff and Judy's gift started the fundraising process for the building and inspired others to make significant gifts. Together, they are making UC Santa Barbara a stronger university."

Designed by architectural firm Kieran Timberlake and built by Sundt Construction Inc., Henley Hall includes 18 labs (a combination of both wet and dry), collaborative break-out spaces, conference rooms, a 124-seat state-of-the-art lecture hall, 34 offices for faculty and postdoctoral researchers, and various administrative offices.

Intended to house 20 engineering faculty members and 100-plus graduate students, the three-story structure is a model of efficiency and is on track to earn LEED Platinum status, the highest sustainability rating awarded by the US Green Building Association. Recycled materials accounted for 20 percent of the materials used in construction, and at least 75 percent of construction waste was specified for diversion from landfills.

"The building is designed to be really energy efficient, incorporating many new advances in technology and control," said Bowers, the Fred Kavli Chair in Nanotechnology, referring to active and passive features that enable Henley Hall to run with 40 percent less energy.

Igor Mezić, a UCSB professor of mechanical engineering who is director of the university's Center for Energy-Efficient Design and head of the IEE's Buildings and Design Solutions Group, contributed to the building's energy-saving smart features. For years, large buildings have been fitted with sensors to collect data, but no large-scale data analysis was done on it, so a lot of the data on air-conditioning, heating, and such were discarded. "In the past twenty years, however, the level of analysis once done by humans has been replaced by an automated algorithmic layer," said Mezić, whose algorithms will turn sensor data into substantial energy savings in Henley Hall.

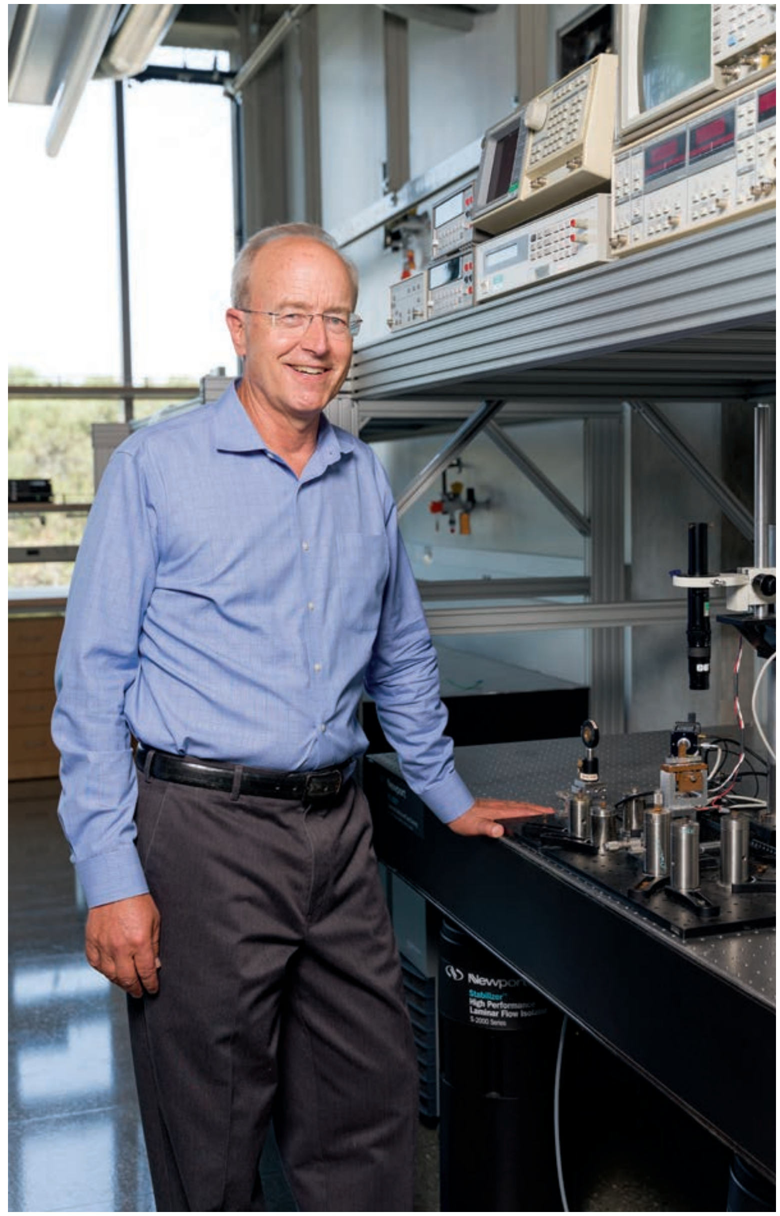
The building relies on natural ventilation and natural lighting. All lights are motion-activated and have sensor-controlled daylight dimming. Windows on the three-story central atrium have sensors and open or close automatically, depending on the weather. "It will be a guide for future buildings on campus," Bowers said.

The roof is supported by beams that have chilled water running through them to provide ambient cooling to the interior, a system that is much more efficient than conventional air-conditioning, which pushes a lot of air through, causing dust. Only the labs in the building rely on air-conditioning, because their temperature needs to be tightly controlled.

All the offices face north and are cooled naturally, and solar panels and a solar heat shield keep the south side of the building cool, aided by windows that incorporate the latest-design glass. "It used to be that to get this level of solar heat rejection, you'd need fairly dark glass, but the glass today is amazing; it's very clear but has little solar heat gain," Bowers explained.

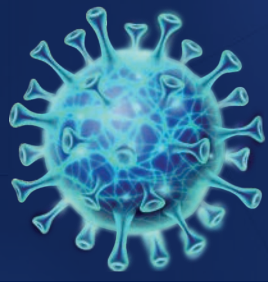
"Energy efficiency is key to solving climate change and making U.S. industry more efficient in energy use and expense," he added. "Henley Hall is essential to expanding UC Santa Barbara's contributions to energy efficiency. Shared laboratories make it possible to bring researchers together to collaborate on important problems."

Specifically, Bowers noted, Henley Hall provides the space for IEE to expand its research in such important directions as developing more-efficient servers, more-efficient data communication, novel architectures and novel cooling approaches, quantum computing, and more-efficient chemical processing. "And, of course," he said, "we will expand our solid-state lighting research at UC Santa Barbara."



Institute for Energy Efficiency Director John Bowers visits a Henley Hall lab, where he will be working soon.

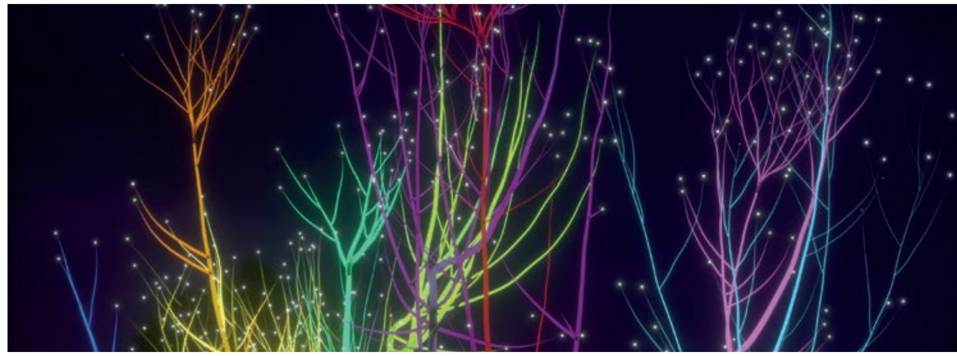
A formidable wet-lab array awaits the arrival of equipment in newly completed Henley Hall.



COVID CONTRIBUTIONS

The Pathway to UV Lights that Can Destroy Viruses

UCSB materials scientists work on semiconductors that could transform how we disinfect surfaces, personal protective equipment — even the air we breathe



The COVID-19 outbreak has brought into sharp focus the need to be able to sanitize surfaces, personal protective equipment needed by front-line health workers, and even the air we breathe in shared closed spaces, such as ships and airplanes.

UV lights — those emitting in the very short, ultraviolet, wavelengths — are a promising tool for this purpose. Already, some jails and prisons are using robots topped by a bank of UV lights to decontaminate cells and shared spaces, such as dining halls. UV light damages human skin and eyes, though, so the rooms are emptied before the robots go through, sanitizing everything in them.

For the past twenty years, the Solid State Lighting and Energy Electronics Center (SSLEEC) in the UC Santa Barbara College of Engineering has been a world leader in developing ever-more-powerful and energy-efficient solid-state LED lighting. For about fifteen years, smaller SSLEEC research efforts have been directed at developing LEDs emitting in the ultraviolet wavelengths of 200-280 nanometers (UVC), primarily with an eye on water purification in areas of the world lacking water-treatment infrastructure. UVC lights have been used for decades by municipal water plants, because they destroy the DNA of many microbes, rendering drinking water safe.

While the Sun sends ultraviolet light in the form of UVA and UVB, the best UV light for purifying air and water and for inactivating microbes — UVC — can be generated on Earth only via man-made processes. Until recently, UVC decontamination systems have been enabled not by LEDs, but by mercury-vapor lamps. Among them is the SteriPEN, a water-purification device used by backpackers. If the glass in the SteriPEN breaks, mercury is released, rendering the device useless.

"One big drawback to using mercury lamps for disinfection of enclosed spaces is that they require a lot of voltage to operate, which is difficult to achieve for a portable device should it need to run on battery backup during a power outage," says **Steve Denbaars,** SSLEEC co-director and the Mitsubishi Distinguished Professor. "But LEDs, which are small, non-toxic, run on little power, and are essentially shatter-proof, can go everywhere. You could even imagine having a UV LED on your cellphone to decontaminate it if someone else touches it."

When, in March, UCSB laboratories ramped down in response to the outbreak, exceptions were made for what was deemed essential research. SSLEEC's UV projects qualified and not only continued, but expanded. "Pre-COVID, we had one [PhD] student working on it; now we have five," Denbaars notes. "With COVID, we shifted people from the white-LED projects to the UV LED projects."

He calls COVID a tipping-point application for UVC LEDs, "because you can't decontaminate an entire room by spraying, and you can't decontaminate your food by spraying it with Clorox," he says. "You can't even decontaminate your mask with Clorox, or with alcohol. But you can decontaminate it with UV light. The other way to decontaminate masks is to use vapor hydrogen peroxide, but to do that you have to buy a special reactor, which is expensive, and that process allows you to use the mask only about three times."

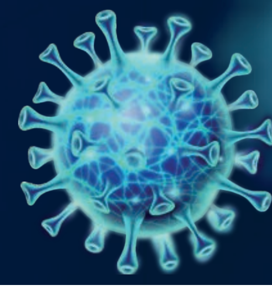
A preview of a study that was published in the September issue of the journal *Emerging Infectious Diseases* compared four methods for decontaminating N95 respirators: treating them with UV light, with heat (150 degrees Fahrenheit), with a 70-percent ethanol solution, and with vaporized hydrogen peroxide (VHP).

VHP and ethanol had the highest rate of inactivation of SARS-CoV-2, which causes COVID-19; however, after two rounds of usage, the VHP- and ethanol-treated masks showed marked drops in filtration performance. The heat-treated masks constantly underperformed compared to the UV-treated masks and did not function effectively after two decontaminations.

> "Government people are calling us now and asking what it will take to get UV LEDs to be really efficient."

Further, says **Chris Zollner,** who is completing his fourth year as a PhD student in the SSLEEC, "In this study, the researchers placed the mask far from the UV LED, resulting in a low 'dose' of UV radiation, so they needed a lot of time to get UV disinfection to work well. I suspect that, had they placed the LED closer to the mask, it would have been disinfected much more quickly."

At their current efficiency and power, UVC LEDs are able to decontaminate masks without damaging them, and as power and efficiency increase, Denbaars notes, he expects to see sanitization times come down to a few seconds of exposure.



Denbaars says that the COVID-19 pandemic has ignited the conversation around UV LED research funding: "Government people are calling us now and asking what it will take to get UV LEDs to be really efficient."

Currently, UVC LEDs are only about 3-percent efficient, making them most effective for low-power portable applications, while the LED light bulb you buy at the store is about 60-percent efficient. "We have a twenty-fold improvement we can do," says Denbaars, adding, "It's a complicated process in materials science."

The team, spearheaded by Denbaars, who uses metal organic chemical vapor deposition (MOCVD) to grow the semiconductor materials, as well as UCSB materials professors **James Speck,** who characterizes the new materials, and Nobel Laureate **Shuji Nakamura,** who designs the device, has also developed a new material, made by depositing a thin film of the semiconductor alloy aluminum gallium nitride (AlGaN) on a silicon substrate.

"Current UVC disinfection lamps, such as mercury vapor lamps, have fixed light emission of 254 nanometers," says Denbaars. "However, many bacteria, fungi, and viruses are killed more efficiently at different wavelengths. The AlGaN material system being developed at UCSB allows for greater flexibility in fine-tuning UVC light emission from an LED, which would make targeting specific microorganisms a real possibility. Aluminum gallium nitride is the only semiconductor that provides light of the correct wavelength, and UCSB is a world leader in developing it."

It is expensive and time-consuming to make a functioning UV LED on a sapphire substrate, so UCSB researchers have developed a new process: by replacing the more-often-used sapphire with silicon carbide, they can use much simpler traditional epitaxy methods to grow high-quality AlN and AlGaN materials.

Heating and air-conditioning systems, which recirculate air, are another big target for improved decontamination. Denbaars notes that state-of-the-art high-efficiency particulate (HEPA) filters are made to filter out particles down to three microns in size. Once captured by the filtration system, however, viruses can shrink as they dry out, possibly enabling them to pass through the filter and be recirculated into the airplane or operating room, where they may infect people. In environments lacking HEPA filters, rather than being captured, the viruses are simply redistributed.

With powerful, efficient UVC LEDs, Denbaars says, "You could pass air through a light tunnel to decontaminate it; you just need enough photons to hit enough of the air. It used to be that people thought it would be nice to have contamination devices on subways and ships and other enclosed spaces where people gather in large numbers. The coronavirus has made it priority one."

Long-term, Denbaars says, "The goal is to shift to certain shorter wavelengths of UV that are safe for skin and eyes, so that you could conduct safe decontamination even in the presence of people. You could leave the lights on all the time for applications like hospital operating tables, navy ships and submarines, airplanes, prisons, and so on. I think we're years, not decades, away from that."

Understanding a Pandemic's Disparate Impacts

By nearly every measure, the COVID-19 pandemic has taken a disproportionate toll on the disadvantaged. Thanks to funding from the Pahl Initiative on the Study of Critical Social Issues in the Division of Social Sciences, UC Santa Barbara economics professor **Heather Royer** is studying ways to address that disparity. The Pahl Initiative is a gift of alumni **Louise and Stephen Pahl** to support social science research on topics of pressing social importance.

"As a resident of Santa Barbara County, it is hard not to see the disparate impacts of this pandemic," Royer says."Social science research can help us in understanding the causes and consequences of the pandemic, and can assist in the county's recovery."

Charles Hale, SAGE Sara Miller McCune Dean of Social Sciences at UCSB, said of the research, "It will add to the growing list of ways that we can and must rebuild better after COVID."

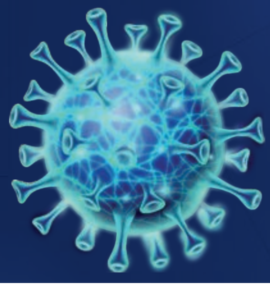
"Santa Barbara County is a microcosm of what's happening both in the state and nationwide," Royer says, "so, what we learn from studying this county can be informative to the local area and more broadly to California and the United States."

Hale also interviewed county organizations and residents to get a sense of their first-hand experiences with the COVID-19 pandemic and their suggestions for possible action going forward. "As a researcher, I can speculate what the drivers are," she explains, "but getting the insights of people 'on the ground' will lead to better-informed policy."

Aside from their COVID research, Royer and one of her collaborators, Mireille Jacobson, an associate professor of gerontology at USC, will investigate the role of the health-care safety net for the disadvantaged. In particular, they'll focus on how the expansion of federally qualified health centers (FQHCs), often referred to as neighborhood health clinics, has increased access to health care for the underserved.

"We will also study how this expansion interplays with hospitals — in particular, as new clinics emerge, do we see a drop in emergency room visits in an area?" Royer notes. "This system of FQHCs provides health care for one in three persons in poverty. The existence of these centers may be critical in the COVID-19 recovery as a provider of primary care for the poor."

Heather Royer



COVID CONTRIBUTIONS

Speeding Toward Faster Tests

As COVID-19 began sweeping the nation in March, Santa Barbara County's Public Health Department faced an acute shortage of reagents needed to conduct the most accepted CDC- and FDA-approved method of testing, called RT-qPCR. In response, a group of faculty members in the Department of Molecular, Cellular and Developmental Biology (MCDB) — professors **Diego Acosta-Alvear, Carolina Arias Gonzalez, Kenneth S. Kosik,** and **Max Wilson** — sprang into action.

First, they gave county public health officers enough reagents to process six hundred tests, but, then, with reagents limited and knowing that testing was an essential tool for fighting the spread of the virus, they began developing a new, faster test based on the CRISPR technology that has revolutionized genomics.

"By mid-March, we knew we had to respond somehow," says Arias Gonzalez.

"It spoke to our sense of social responsibility," adds Acosta-Alvear.

With their efforts deemed essential by the university, the team was allowed to continue working after the ramp-down of campus research, with several members of each professor's lab working in shifts, while adhering to strict social-distancing guidelines.

"We developed the CRISPR assay method so that it's versatile," says Arias Gonzalez. "It can work at high throughput, so you can use robots to set up the reactions and test a large quantity of samples, and you can use the specialized equipment we have here and the specialized personnel who are all well trained to use it."

But, she notes, "Not everybody has fancy equipment, robots, and PhD students and postdocs at their disposal," so, the team set out to optimize the test so that it would be easy to perform without sophisticated equipment. They call the result CREST, which stands for "Cas13-based, Rugged, Equitable, Scalable Testing." It can go anywhere, since it can be run with a cell phone app, a 9-volt battery, and a couple of simple pieces of equipment: a Thermocycler, which is smaller than a toaster, and a small cardboard fluorescence viewer.

> "The campus testing will allow us to detect single cases and test contacts before the virus undergoes exponential spread."

To use it, a sample is collected, processed, and put into the thermocycler, where any SARS-CoV-2 genetic material present is amplified. The material is then detected by the CRISPR enzyme Cas13, which can be programmed to detect SARS-CoV-2 genetic material. When the Cas13 encounters certain bits of SARS-CoV-2, it acts like a kind of molecular "scissors," cutting off the shroud from a bright fluorescent molecule that is visualized by shining a black light on the test tube. CREST allows a binary readout that is easy to interpret: positive samples fluoresce, while negatives remain dark.

The results were robust but relied on a commercial column-based method to extract the genetic material of the virus, which costs five dollars per sample and has limited availability because of the global shortage of testing reagents. To address that, Acosta-Alvear's lab developed a method to extract RNA that is cheap — only about twenty cents per reaction — user-friendly, and makes use of reagents that almost any lab in the world has. As part of the package, they also developed a handheld 3D-printed centrifuge, which effectively facilitates the isolation of nucleic acids from all microorganisms they have tested so far.

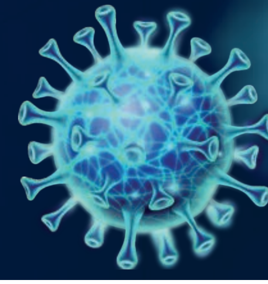
The researchers then worked with the UCSB Student Health Center, Cottage Hospital, Pacific Diagnostic Laboratories, and the county Public Health Department to test the assays in two trial runs. In the first, they collected about eight hundred samples from healthy, COVID-19-symptom-free UCSB student, faculty, and staff volunteers between May 28 and June 11. Every sample was tested twice, once with the CDC-approved RT-qPCR test, and once with the UCSB–developed CREST. The researchers' protocol required results to be available in twenty-four hours. The first trial yielded no positive results.

No testing was done during the break between spring and summer quarters, because the campus was largely empty. After the break, a second group of one thousand healthy volunteers was tested between June 26 and July 2. One positive showed up on the 26th, one on the 27th, and one every day, for nine positive tests. Eight were confirmed both with CREST and in a clinical lab, the latter serving as a way to double-check that the assays were robust and reliable.

The results, says Arias Gonzalez, "precisely reflected the community spike among asymptomatic people that occurred two to three weeks after Santa Barbara was declared open," she says, giving the researchers confidence in their assays. "Asymptomatic carriers can inadvertently transmit the virus to others, increasing the potential of covert outbreaks. Surveillance testing will allow us to detect those cases early and take preventive measures to protect our community. Had we been able to test in between the two cohorts, perhaps we could have picked up some cases."

"With further validation, the campus testing will allow us to detect single cases and test contacts before the virus undergoes exponential spread," sysd Ken Kosik, Harriman Professor of Neuroscience. "Think of this as putting out spot fires."

COVID CONTRIBUTIONS



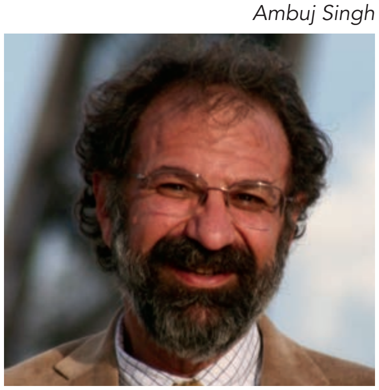
Spreading the Word to Spread the Knowledge

When COVID-19 hit last spring, those seeking a broader understanding of the pandemic and the virus that drives it were served well by a weekly seminar series UC Santa Barbara offered. "Issues, Approaches, and Consequences of the COVID-19 Crisis" brought together experts from UCSB and the Cottage Health System to examine diverse COVID-related topics.

The hour-long sessions convened Tuesdays via Zoom, with each week featuring a different speaker. Free and open to the public, the series was organized jointly by **Ambuj Singh,** a professor of computer science and of biomolecular science and engineering, and **Joseph Walther,** a professor of communication and director of the campus's **Center for Information Technology and Society** (CITS). While the live series ended June 30, recordings of the webinars can be found on the CITS website: **cits.ucsb.edu/spring2020.**

"There is a lot of fear and much that is unknown, and the only way you conquer that is with knowledge and information," says Singh, who also is director of the campus's Data Science Initiative. To that end, he and Walther have brought together an interdisciplinary group having expertise ranging from biology and medicine to public health and ethics to artificial intelligence and machine learning.

Ambuj Singh



Joseph Walther

Speakers from engineering and the sciences included Singh and **Yu-Xiang Wang,** an assistant professor of computer science, presenting on coping with the uncertainty of COVID-19 datasets; mechanical engineering professor **Francesco Bullo** discussing the reliability of various models used to predict the propagation of infectious diseases; and **Carolina Arias Gonzalez,** an assistant professor in molecular, cellular and developmental biology (see story on opposite page), who joined Lynn N. Fitzgibbons, a Cottage Health System infectious disease specialist, to discuss multiple facets of the novel coronavirus and COVID-19. Other talks covered political, social, and economic issues of the pandemic, and included speakers aligned with other research entities involved in the series, such as NOVIM, which was founded at the Kavli Institute for Theoretical Physics with the goal of making complex scientific topics accessible to non-scientists; the Center for Spatial Studies; and the Center for Responsible Machine Learning.

"Celebrities' and authorities' most important message to the public has been that we're all in this together," says Walther, the Mark and Susan Bertelsen Presidential Chair in Technology and Society. "It's the same for academics. The center's motto is that we're interested in problems too big for any one discipline to solve, and that's never been more true than in this case."

What better example of interdisciplinarity, Walther noted, than how social behaviors like distancing affect the impact of a biological threat?

Machine Learning and a Black Swan: COVID-19

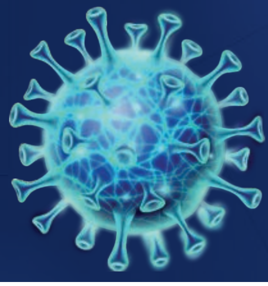
How would it spread? How fast and how far? Those were important questions as COVID-19 hit last March. That was when UC Santa Barbara mechanical engineer and applied mathematician **Igor Mezić** and a group of colleagues at his university alma mater in Croatia and at Aimdyn, Inc., in Santa Barbara began working a lot of very late nights. Their goal was an adaptive transition in which they would take an algorithm they had been developing for another purpose, with funding from the Defense Advanced Research Programs Agency (DARPA), and use it to try to predict the spread of the unfolding COVID-19 pandemic.

DARPA is developing artificial intelligence (AI) fundamentals, but the deep-learning and other machine-learning (ML) methods the agency has, Mezić says, "cannot be guaranteed to be correct in many military applications, and there are some applications where the AI has to be one hundred-percent reliable. DARPA keeps looking to fix that, and we were working on a new set of methods."

The group had been developing an ML algorithm that could make accurate predictions in what are known as "black swan" scenarios, so named because they are entirely new and unexpected and therefore have no previously established patterns. COVID-19 was a prime example of such an event and, thus, the perfect test for the algorithm.

"Our group was developing a methodology of prediction for DARPA that would be robust for a situation where somebody just throws a bunch of data at you, like a black swan," Mezić says.

The research, which is based on the Koopman Operator methodology Mezić has been using to develop machine-learning models that are quick to learn and can be readily adopted from one context to another without requiring reams of new data for "retraining," has been completed and the results written up in an article that has been submitted for journal publication. Because the article will be embargoed if it is accepted for publication, currently we can confirm only that, according to Mezić, the Koopman Operator–based AI shows considerable promise in its ability to predict the spread of the novel coronavirus and other "out of the blue" events based on very small data sets. More information on this topic will be forthcoming.



COVID CONTRIBUTIONS

Tweaking the Model

People have behaved differently during the COVID-19 outbreak, than epidemiologists would expect them to under normal circumstances, making it necessary to revamp standard models.

"Some of the early epidemiological models of COVID-19 relied on assumptions about human movement and connectivity that were totally unrealistic, given that most of the country had been shut down," said UC Santa Barbara disease ecologist **Andy MacDonald,** a researcher at the UC Santa Barbara Earth Research Institute.

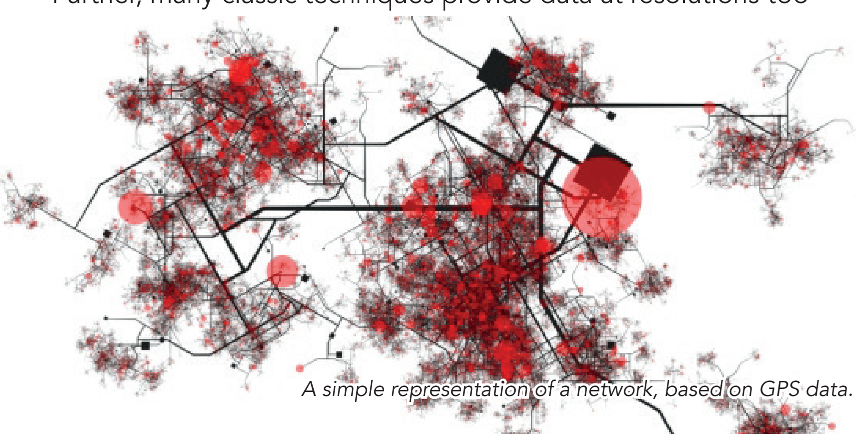
In June, MacDonald, UCSB postdoctoral researcher **Dan Sousa,** and colleagues at Columbia University and UC Berkeley received a one-year, $200,000 grant from the National Science Foundation to address this issue. The funding comes from NSF's Early-Concept Grants for Exploratory Research (EAGER), which supports proposals for high-risk, high-reward research. As MacDonald says, "The ideas may not pan out, but if they do, they have the potential to be transformative."

What he and his colleagues proposed was using satellite and GPS data to build better models. Classic epidemiological models use factors such as commuting and air travel to estimate the degree of connectivity among different population centers. But with people largely staying put as statewide stay-at-home orders were issued, those data sources didn't provide much useful information.

The team planned to use remote sensing to source more-appropriate data to feed into the models. For instance, rather than using commuter-travel data to estimate connectivity, they're looking at other elements, such as night-time lights, with brightness coinciding with the density of built infrastructure; gridded population density, indicating where people are living within those built areas; and mobile phone density, location, and movement, the last being useful in determining the level of social interaction. Such remotely sensed data is also consistent across the entire United States.

"All of these data sources will be brought together to create high-resolution spatial networks of population connectivity, as well as to estimate where people are likely to be, to interact, and to travel," MacDonald says.

Further, many classic techniques provide data at resolutions too



A simple representation of a network, based on GPS data.

Andy MacDonald

low to predict how the disease may spread at small scales, such as among neighborhoods, which can influence the likelihood of subsequent long-distance transmission. The new data sources will provide information at a variety of spatial scales, providing more detailed insights.

The higher resolution should also enable the team to better estimate transmission dynamics as events unfold. "The idea was that if we can use these new data sources to understand how people are interacting with each other, we might be able to better track and predict the extent and speed of transmission, say, from a hotspot that is opening up to a neighboring county that is still closed," MacDonald explains.

And while, as he says, "The human-behavior component of the COVID pandemic is really challenging," causing problems for models, he believes that the reason he and his colleagues got the funding was that their approach could be useful not only for COVID, but also for seasonal flu or for anything that propagates through a network.

"We've shown that by using this kind of data, we can build in a lot more realism than we could in the past," he explains. "Earth-observation data is getting so refined, both temporally and spatially, and if we build in some of these new data sources that are coming on line, then maybe we can do a much better job of modeling these sorts of [spatially propagating] processes than we could in the past."

A month and a half into the project, MacDonald said, "We are all adapting to changing times and changing scientific needs."

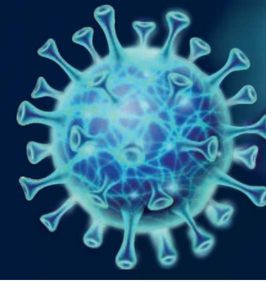
Powering up for PPE

As the nation faces its second shorage of personal protective equipment (PPE) during the post-Thanksgiving surge in COVID cases, replicating what occurred last spring, we remember well how UC Santa Barbara faculty and staff responded from the outset.

While students, faculty, and staff were sent home, **David Bothman,** manager of the Microfluidics Lab and the Innovation Workshop, both in the university's California NanoSystems Institute (CNSI), worked alone to design and 3D-print face shields to augment other protective equipment worn by health professionals. He also created an online portal where people on campus could sign up to help. The UCSB Engineering Machine Shop also contributed PPE, joining a number of scientists and engineers who put aside their own work to support the community through the COVID crisis.

In CNSI's well-equipped workshops — which include 3D printers, laser cutters, and a range of other tools — some three hundred faculty and student users from ninety different research groups and CNSI Incubator companies can build scientific instruments and prototypes of their inventions.

COVID CONTRIBUTIONS



Vial Business

A protective vial for medicine is nearly as important as the medicine itself.

With vaccines for the novel coronavirus becoming available, shipping vials of it safely around the world is a question of packaging. UCSB chemical engineer **Glenn Fredrickson** recently worked in an advisory capacity with the American drug company SiO2 to develop a new material coating for vials and syringes.

Fredrickson is a world expert on creating computer simulations of possible soft-material polymers and the monomers used to make them. The coating he helped design, he said in an article that ran in the *Santa Barbara News-Press*, "solves significant challenges in the commercialization of vaccines and biological drugs, which presently cannot be solved by glass or plastic vials. Bringing this advanced coating to market will enable pharmaceutical manufacturers to safely and more rapidly deploy their critical products."

The Mitsubishi Chemical Professor said that the new vials prevent glass particles from flaking off and entering the drug solution and can withstand extreme temperature changes, prevent breakage and thermal stresses, and prevent silicone oil from getting into the drug solution. "You want a package that can handle a major temperature change from room temperature to a really cold temperature," he said.

AI for Local Predictions

From the beginning of the pandemic, we have been barraged by COVID data. Often, local information has mattered to us most.

"We are all overwhelmed by the data, most of which is provided at national and state levels," said **Xifeng Yan,** a UC Santa Barbara computer science professor and Venkatesh Narayanamurti Chair. "Parents are more interested in what is happening in their school district and if it's safe for their kids to go to school in the fall."

Until now, however, few forecasting websites have provided reliable local information. Yan and fellow UCSB computer science faculty member, assistant professor **Yu-Xiang Wang,** the Eugene Aas Chair, have developed a novel forecasting model, inspired by artificial intelligence (AI) techniques, to provide timely information at a more localized level, which officials and anyone in the public can use to help make decisions related to protecting public health.

Their project, titled "Interventional COVID-19 Response Forecasting in Local Communities Using Neural Domain Adaption Models," received a nearly $200,000 Rapid Response Research (RAPID) grant from the National Science Foundation in late April.

"The challenges of making sense of messy data are precisely the type of problems we deal with every day as computer scientists working in AI and machine learning," says Wang. "We are compelled to lend our expertise to help communities make informed decisions."

The researchers developed an innovative forecasting algorithm based on a deep-learning model called Transformer. The model is driven by an "attention mechanism," which intuitively learns how to forecast by learning what time period in the past to look at and what data is the most important and relevant.

"If we are trying to forecast for a specific region, like Santa Barbara County, our algorithm compares the growth curves of COVID-19 cases across different regions over a period of time to determine the most-similar regions. It then weighs those regions to forecast cases in the target region," explained Yan.

In addition to COVID-19 data, the algorithm also draws information from the U.S. Census to factor in hyper-local details when calibrating the forecast for a local community.

"The census data is very informative because it implicitly captures the culture, lifestyle, demographics, and types of businesses in each local community," said Wang. "When you combine that with COVID-19 data available by region, it helps us transfer the knowledge learned from one region to another, which will be useful for communities that want data on the effectiveness of interventions in order to make informed decisions."

Yan and Wang plan to make their model and forecasts available to the public on a website and collect enough data to forecast nationwide. "We hope to forecast for every community in the country, because we believe that when people are well informed with local data, they will make good decisions," said Yan.

Men of AI action (from left): Xifeng Yan and Yu-Xiang Wang

THE LAB'S in the MAIL

Teamwork in the Electrical & Computer Engineering Department ensures that students in required classes have what they need to do lab work at home

UC Santa Barbara engineering students who are taking ECE 10A or 10C in this fall quarter probably do not fully grasp what it took to ensure that they can do hands-on lab work for the courses, which are being taught remotely.

Second-year electrical engineering majors at UCSB must normally take those two courses, plus a third, ECE10B; together they make up the Foundations of Analog and Digital Circuits & Systems requirement. Students learn the essentials of analog and digital circuits in 10A, are introduced to MOSFETs (metal–oxide–semiconductor field-effect transistors) in 10B, and learn the basics of transient analysis (a circuit's response over time) in 10C.

Each course includes a lab to provide hands-on experience in applying core knowledge. Last spring quarter, when the COVID pandemic closed campus labs — undergraduate labs will remain closed at least through fall quarter — the ECE 10 labs were run online, with simulations taking the place of hands-on work. When summer arrived, department faculty, including department vice-chair **Clint Schow** and assistant professor **Galan Moody,** came up with a plan for fall quarter that would afford students the critically important hands-on experience. "We concluded that online simulations weren't the way to go," says Moody.

"The students really need to work with the hardware to build an intuitive and conceptual understanding of the content in the lectures," Schow adds.

But that hardware is prohibitively expensive. The solution was to put together and mail to each student, wherever they might be, a package containing the parts needed to do the lab assignments at home. The main piece is an Arduino board, which costs only about $50, as opposed to an alternative that costs $500. Arduino is an open-source electronics platform based on easy-to-use hardware and software. The programmable board has a micro-controller that can read inputs, such as a light on a sensor or a finger on a button, and turn them into an output to perform some action, such as activating a motor or turning on an LED.

The task of ensuring that these mailed lab packages would work fell to four doctoral students who are TAs in the various ECE10 courses: **Nikita Buzov, I. T. Fufuengsin, Shabnam Larimian,** and **Kamyar Parto.** Their work involved "tweaking" the Arduino board to give it the required functionality, because, as Parto said, the cheaper instrument came with measurement limitations. "This is not necessarily a bad thing," he told students in a written message. "The definition of being an engineer is having the ability to adapt to come up with a smarter way."

Their "smarter way" involved accessing and tweaking a lower level of the Arduino's software, so that it could function as a generator. "Normal users are not supposed to do that with an Arduino board, but we did it, and it worked fine, says Parto. "We also modified some codes so that it can function as an oscilloscope. That's the key thing we did, and now we can do a lot of processes with a fifty-dollar device that would normally require a thousand-dollar device."

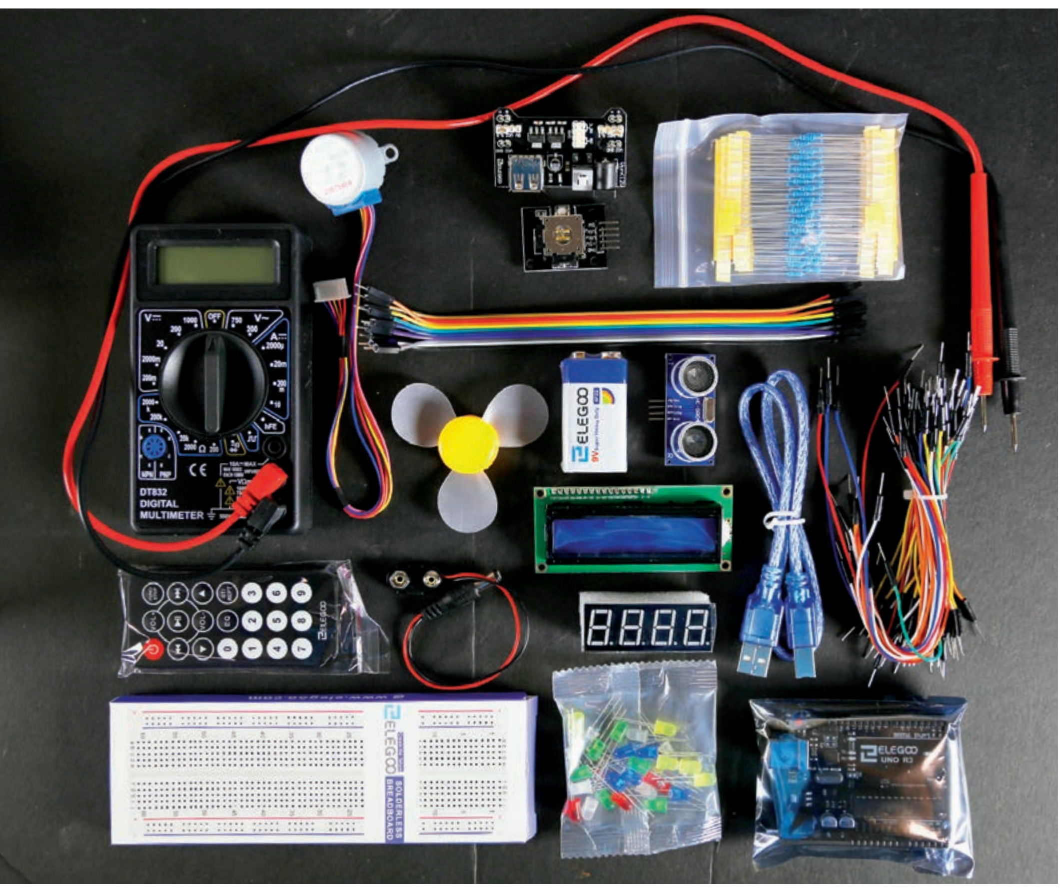
They tested the Arduino by using it to do all the labs in the course and then adjusting them as needed given the board's somewhat different abilities.

"I feel good that we now we have the actual physical lab so that the students can really touch the stuff and work with the physical parts. It will help them for the future," says Larimian. "I think, too, that at the end of this year, the students will be able to problem-solve and debug the circuits even better than the students before who were present in the class on campus. Doing the labs independently, they'll learn the material much better."

ECE shop director **Paul Grit** and his colleague **Chris Wimmel** assembled and mailed the kits, which included the Arduino board, a "breadboard" (a kind of blank canvas for building electronic circuits), a digital multimeter, LEDs, operational amplifiers, capacitors, inductors, and resistors.

"The graduate students are heroes for this," Moody says. "It would not have been possible without them."

Schow said that he is very pleased with the result, adding, "It's a great example of everyone not doing the easy thing but realizing what the right thing was to do and then pulling together to get it done as best we can under tight circumstances with limited resources."



Thanks to creativity, initiative, and teamwork, undergraduate electrical engineering students have what they need (above) to do their lab work at home.

FOCUS ON: **BioPACIFIC MIP**

A Major Grant for Bio-Based Plastics

National Science Foundation awards UCSB and UCLA $23.7 million to develop high-performance bio-based polymeric materials

Synthetic polymers — think plastic and its chemical cousins — are among the foundations of modern life. The ubiquity of such petroleum-based materials has everything to do with their combination of strength, flexibility, and chemical inertness, the last of which also makes them durable. Given the environmental impact of plastics, however, and the fact that petroleum deposits are finite, one grand challenge is to develop a new realm of sustainable bio-based, high-performance alternatives to petroleum-based polymers. Harnessing nature to make these materials will be a huge undertaking requiring a fundamental change in how polymers are made.

To support such an effort, the National Science Foundation (NSF) has named UC Santa Barbara and UC Los Angeles joint partners in the **BioPolymers, Automated Cellular Infrastructure, Flow, and Integrated Chemistry: Materials Innovation Platform** (BioPACIFIC MIP). The five-year, $23.7 million collaboration is part of the NSF Materials Innovation Platforms (MIP) Program and has a scientific methodology reflecting the broad goals of the Materials Genome Initiative, which was established with the aim of developing new materials "twice as fast at a fraction of the cost." BioPACIFIC MIP is one of two MIPs awarded this year.

The BioPACIFIC MIP leverages the facilities, expertise, and experience of UCSB and UCLA, partners since 2000 in the California NanoSystems Institute (CNSI), which has headquarters at both campuses. It will include faculty and affiliates — thirteen from UCSB and seven from UCLA, supported by seven scientific staff. BioPACIFIC MIP will impact a large number of students and researchers at UCSB, UCLA, and across the country in the fields of materials science, biology, chemistry, and engineering.

The project is aimed at developing bio-based plastics having properties superior to those of existing petroleum-based polymeric materials. It is envisioned as a closed-loop scientific system comprising every aspect of such research, from discovery of microorganisms that can be used as biological "factories" to generate building blocks for polymers, through simulation, design, building, testing, and learning, with feedback loops built into the system. Guest researchers will be welcomed to develop, characterize, and engineer new materials based on merging synthetic biology with materials synthesis.

"Nature has an expansive range of functional building blocks, and we now know that it's possible to synthesize them into better macro-materials, like polymers," says BioPACIFIC MIP director and principal investigator (PI) **Javier Read de Alaniz,** a UCSB professor of chemistry and associate director of the CNSI in the College of Engineering. "We will be extracting blocks from nature that you can't access in any other way and then using synthetic routes to combine them into materials having properties that no other material has."

"Our goal is to be the bridge between fundamental and applied research, driving collaboration with industry and establishing Southern California as an economic engine of biomaterials research and innovation," says materials professor **Craig Hawker,** co-PI on the BioPACIFIC MIP and director of the CNSI at UCSB. "It has been our goal for many years to take advantage of our connection with UCLA to land a transformative project such as this."

It is hoped that the BioPACIFIC MIP will support more than a thousand academic researchers and over two hundred companies annually and yield hundreds of peer-reviewed publications each year.

"I see this as a perfect partnership, because UCLA and UCSB have complementary characterization tools and complementary expertise, and when we put them together, we can make a user facility that will be unprecedented in the science it will enable and the services it will provide," said MIP co-director **Heather Maynard,** a UCLA chemistry and biochemistry professor and associate director of the CNSI there.

The collection of expertise at UCSB and UCLA will be coupled with an automated, high-throughput living bioreactor platform and robotic automation to rapidly prepare libraries of bio-based polymer materials. Integration of these platforms with computer modeling and machine learning, as well as user access to a robust facility infrastructure at UCSB and UCLA, will further the process of optimizing plastics derived from living organisms.

The BioPACIFIC MIP will be broken into four sections — In-House Research, External Users, Education, and Knowledge Sharing — while the scientific mission will be organized into four interconnected Elements, each described in one of the following sections.

Some of the UCSB and UCLA faculty and staff collaborators (back row, from left): Michelle O'Malley, Lube Lenaburg, Wendy Ibsen, Craig Hawker, Javier Read de Aleniz, Heather Maynard, Tobias Höllerer, M. Scott Shell, Adam Stieg; (front row, from left): Yi Tang, Arica Lubin, Ambuj Singh, Hosea Nelson, Tal Margalith, Rachel Segalman.

Finding the Bio Building Blocks

ELEMENT 1:
Synthesis Biology and Living Bioreactors

Synthesis biology lies at the heart of the BioPACIFIC MIP. Researchers in Element 1 will focus on identifying and developing promising biomolecule building blocks and new cell-based polymerization methods. They will explore and expand the chemical space of monomers accessible through synthetic biology and engineer cells to serve as production and polymerization "chassis" for bio-derived polymers.

The group's approach will be to engineer biocompatible polymerization tools in living organisms for the production of biopolymers from renewable feedstock. This will be done with a focus on altering how yeast, fungi, and bacteria use their internal mechanisms to generate building blocks. The engineered organisms can be added to a Materials Library and then screened to determine their potential value as starting systems for an array of new high-performance polymer biomaterials to be developed in Element 2.

"Biology makes a lot of cool little building blocks in the form of molecules, peptides, and proteins, and often, we look at the chemistry of those building blocks and don't know how useful they are," says UCSB chemical engineer **Michelle O'Malley,** who is part of the Element 1 team. "That is mostly because people who have the expertise to make them are often not the people who look at them through the lens of a materials scientist. This effort is bringing people together to make that translation."

"We envision the synthesis biology being fluid, so that people can use both places depending on their priorties," says **Heather Maynard**. "If someone is more interested in synthetic biology, looking at how microorganisms can make certain kind of molecules or monomers and how to characterize them in two and three dimensions, then they'll

An example of the kind of high-throughput system that will allow a substantial acceleration of time-consuming lab-experiment set-up processes.

mostly be at UCLA. If they have monomers already or want to use something from the library to make polymers, they'll be at UCSB."

O'Malley explains that she will be working to build a pipeline to identify organisms that have the potential to make chemically diverse building blocks. She and her Element 1 colleagues will then partner with materials scientists to determine "whether those building blocks are actually worth the time and effort to develop them, perhaps to make polymers, coatings, or maybe even drugs," she says.

At the heart of the Element 1 research will be a high-throughput living bioreactor platform system — that is, a reactor that can change and adapt in its task of producing products made from cells — developed to conduct automated experiments in synthetic biology. Normally, experimental work is exceedingly time consuming. But, as the first user-facility in the nation to link automation and high-throughput experimentation across both synthetic biology and material synthesis for rapid biomaterial discovery and development, BioPACIFIC MIP will reduce lab times dramatically, accelerating the design-build-test-learn (DBTL) cycle from yielding one sample per week to more than five hundred per week.

> "As the first user-friendly facility in the nation to link automation and high-throughput experimentation... BioPACIFIC MIP will reduce lab times dramatically."

Artist's concept illustration refers to the BioPACIFIC MIP goal of identifying biological building blocks that can be engineered and assembled to create high-performing polymers.

Fast Track to New Materials

ELEMENT 2:

Automation speeds the process dramatically

Artist's concept illustration: high-speed research ahead.

"We'll be exploiting BioPACIFIC in two ways," says **Craig Hawker,** co-PI of Element 2 at UCSB. "The first is to take advantage of bacteria and nature's other cellular factories to make existing materials much more efficiently. The second is to exploit nature's ability to prepare complex, multifunctional molecules and direct that machinery to new designer materials, materials that synthetic chemists cannot prepare using traditional techniques."

Using organisms to make new polymeric organisms, he explains, saves researchers from having to produce them under high pressure or at high temperature using toxic chemicals to drive reactions, as is required to make petroleum-based polymers.

"If you go to a major chemical plant, you'll see multiple highly complex systems for each step of the process," says Hawker, who is also the Alan and Ruth Heeger Professor of Interdisciplinary Studies and Clarke Professor. "But, in organisms, nature already takes care of all these separate processes within the same cell. We're trying to make use of that cellular machinery, so that instead of a large, energy-intensive chemical plant that makes, perhaps, a million pounds of a polymer, we'll have hundreds of billions of microbes making a similar, if not a better, polymer much more efficiently — at room temperature, with no toxic chemicals and with little, if any, waste."

Equally important, Hawker notes, is to maintain a careful perspective with regard to scale. "For certain applications, such as polyesters used in packaging, you may need millions of pounds," he says. "For some functionalized materials that may not be used in a bulk setting but as, say, a coating, worldwide production might be only a thousand pounds, so, you can tolerate a smaller yield because it adds such a high value. It's a real Goldilocks kind of calculus for materials design that we are keeping in mind from the get-go."

Like her colleagues in Element 2, **Rachel Segalman,** chair of the Chemical Engineering Department and Edward Noble Kramer Professor at UCSB, will likely find herself working closely with researchers in both Element 1 and Element 2. In her work, she examines how hierarchical polymer structure affects the thermodynamics of self-assembly and macroscopic properties. That fits in Element 1, but she also has significant expertise in producing bioinspired polymers via robotic synthesis, which leans toward Element 2.

Like Element 1, Element 2 will employ a high-throughput system to scale up processes. "We may do ten polymerizations at once in a flow system, so that you set up the system, and it directs the components to the ten different reaction systems, and you get your ten products," says BioPACIFIC MIP co-director and UCSB professor of chemistry and biochemistry **Javier Read de Alaniz,** adding, "We're automating how we do polymer synthesis."

"Right now, a student in my group can carry out about two reactions a day" says UCLA professor and BioPACIFIC MIP co-director **Heather Maynard,** whose expertise lies in the synthesis, characterization, and medical application of biopolymers and bioinspired materials. "With the rapid-throughput system, we'll be able to do fifty to one hundred experimental reactions per day. A student will be able to prepare the number of polymers in a week that had previously taken them more than half a year."

Further, robotic handling and automation of synthetic and purification steps are safer than traditional methods requiring each experiment to be set up by hand, and eliminate user-to-user variability. And, explains Maynard, who earned a master's degree at UCSB, "It allows people who may have an idea for a material but are not polymer chemists to become involved and use the facilities. And if a visiting researcher sees something in the library of monomers and thinks, *I could do something with that,* MIP staff scientists can steer them through the relevant processes."

Element 2 researchers will also be linked forward to Element 3 (computation) and back to Element 1. "We can perhaps figure out ways to use enzymes and proteins to polymerize some of those monomers and then bring these new polymers back to Element 1," says Maynard. "So, maybe we make two hundred polymers and then see which have the properties we want. The computational part will be really important as a feedback. We'll have both, which is why it's so exciting. Experimental science is informed trial and error. It is time-consuming to set up experiments and then await processes to occur that generate results. This allows a massive acceleration of the entire laboratory process."

> "With the rapid-throughput system, a student will be able to prepare the number of polymers in a week that had previously taken them more than half a year."

Training the Next-Generation Workforce

An important component of the MIP is to prepare the next generation of scientists and engineers in interdisciplinary biomaterials discovery and high-throughput experimentation, such as that being pioneered in the BioPACFIC MIP. A focus on outreach and fellowships will bring graduate students and postdoctoral scholars into BioPACIFIC MIP facilities to receive training and help drive investigations.

The project team will proactively engage budding researchers who represent California's diversity, with the goal of assembling a cohort in which half the fellows are women and underrepresented minorities. Fellows will have access to a cluster of educational offerings and mentorship opportunities.

One component, a weeklong "summer school" led by experts from industry, academia, and national laboratories, will provide guidance to fellows, facility users, undergraduate and graduate students, and postdoctoral fellows. The school will serve not only as a training ground, but also as a recruitment tool to attract a diverse cohort of users into the MIP.

Currently, a huge training gap exists between academia and industry in terms of training for such high-throughput automated science; industry has invested heavily in automation and big data and has, as a result, a critical need for university graduates who have this experience. The undertaking will involve a multi-pronged approach, but a key element will be to provide training on how to set up and analyze experiments that leverage automation and large data sets.

"A lot of industry would like more training in automation and related skills; they're very interested in it," says MIP co-director and UCLA professor of chemistry and biochemistry **Heather Maynard.** "But in traditional labs you don't get that component, so, this will be an additional tool for broadening their training. Imagine a company being able to hire someone out of university who arrived at work already knowing how to do this without months of training. That would be very valuable to a company."

The training will be coupled with programs to develop students' "soft" skills, such as communication and project management. Overall, the center will provide a clear connection between students' training and their career aspirations, empowering trainees from diverse backgrounds to become the next-generation workforce at the frontier of engineering and science.

Data Narrows the Design Space

ELEMENT 3:

Combining computer simulations and artificial intelligence to explore a vast universe of possibilities

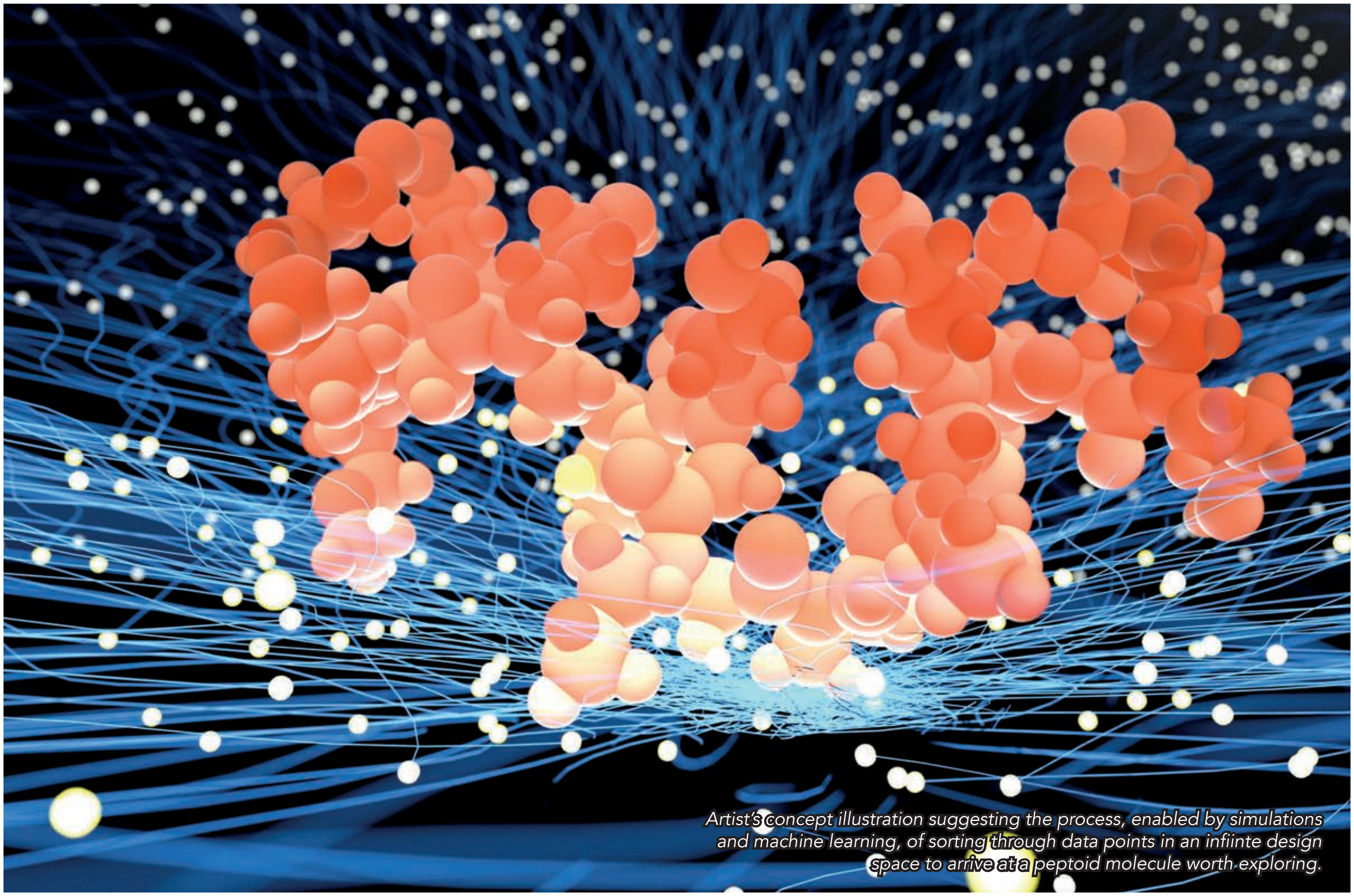
Processing and profiling the properties of new biomaterials — whether they are derived from microorganisms that produce complex building material blocks or are entirely synthetically produced bio-polymers — are time- and labor-intensive processes, and that is without exploring the nearly limitless design space enabled by rapid-throughput development of new bio-molecules. Element 3 researchers will use computational tools, including simulation and machine learning (ML), to characterize new monomers and polymers, improve existing ones, identify and specify desirable material properties, and suggest appropriate chemistries and processes to achieve desired form and function or to improve the effectiveness of the living bioreactors used to produce targeted bio-materials.

Two members of the UC Santa Barbara team — chemical engineering professors **Glenn Fredrickson** and **M. Scott Shell** — have expertise in creating simulations that will be valuable to the project. Fredrickson has developed field-theoretic computer simulation models that enable studies of structure and thermodynamics across a wide range of complex fluids and soft materials at large, supramolecular length and time scales. Shell develops molecular simulation methods for detailed, atomistic-resolution modeling of bio-based and synthetic soft materials, complex interfaces, and water-mediated and hydrophobic interactions that underly many material self-assembly processes. By combining these two approaches to predict properties from the atomistic to macroscopic scales, Fredrickson and Shell provide a powerful framework enabling the MIP to generate molecular insight and predictive materials modeling across scales.

"The high-level role of computational and simulation work as part of BioPACIFIC is to provide guidance to the experimental and synthetic groups as to what to make," Shell says. "Let's say you need a polymer that has this toughness, this refractivity, these kinds of mechanical properties. What should the ingredients be? What should the molecules look like? The idea is to use computations as intelligent ways of exploring the huge range of options and coming up with relationships that allow us to predict, for instance, what the properties will be if we make a particular kind of polymer."

Broadly accessible databases overlaid with machine-learning algorithms using both simulation and experimental data of structure-property relationships will be integrated to help close the design loop, optimize materials design, and provide feedback among explorations of the design space and desirable material properties.

"The challenge in this project is that the design space is huge," says UCSB computer science professor **Ambuj Singh,** who leads the ML effort. "The number of possible molecules is such that there is no



Artist's concept illustration suggesting the process, enabled by simulations and machine learning, of sorting through data points in an infiinte design space to arrive at a peptoid molecule worth exploring.

way to explore the entirety of the possible design space, so, one needs a strategy to probe the most meaningful subspaces. This probing can be based on your own data or on data you have from the public domain. So, the question is, how do you get this data and build the model of this space so that you can try to identify substances that are potentially fruitful and should be probed in order to design new materials?"

To do that, he continues, "You need to be able to probe, you need to be able to store the results of your probing, and you need to store the results of your reactions, so this design is not going to be a one-step process. It's going to be multistep reactions, and each reaction has certain conditions under which it happened. The multistep process makes it much more difficult to explore the design space."

"There are robust techniques that Ambuj and others are working on now that allow you to start organizing, interrelating, and interpreting rich data sets from materials that have interesting measured properties, from a spectrum of different experiments and simulations having slight variations," notes Shell, the Dr. John E. Myers Founder's Chair in Chemical Engineering. "Machine learning is very good at identifying the key factors that are important, as well as making predictive models that allow you to then say 'OK, now if I make this new system, what do I expect for this property?' It's a much more rapid way of exploring the space than can be done using brute-force, expansive simulations alone, since each individual simulation run requires a significant number of compute cycles.

"They're complementary approaches," he adds, "in the sense that our simulations provide a detailed molecular picture that gives a tremendous amount of physical insight into how to think about the interactions that drive the properties of the materials, which machine learning can then use to derive predictive structure-property relationships."

"The multistep process makes it much more difficult to explore the design space."

Eye on Application

ELEMENT 4:

Characterizing materials to describe potential and inform future directions

Researchers at the UCSB and UCLA facilities of the BioPACIFIC MIP will turn a sharp eye to DNA in their pursuit of novel new bio-based polymers.

Once new engineered microorganisms, monomers, and polymers are discovered, they need to be characterized to determine whether their chemical structure and resulting properties are as expected or as needed to inform further material development or refinement.

Element 4 researchers will overlap significantly with Elements 1 and 3 "to develop a predictive and mechanistic understanding of how composition influences structure and properties to improve the synthesis and formulation," says UCSB mechanical engineering professor and group lead **Megan Valentine,** an expert in the design, development, and implementation of customized tools for microscale characterization of biological and bio-inspired soft materials using rheology, mechanical testing, and imaging.

Element 4 researcher and UCSB chemistry professor **Songi Han** brings expertise in developing novel techniques in electron paramagnetic, nuclear magnetic resonance, and dynamic nuclear polarization that enable the study of biomolecular structure, dynamics, and interaction with unprecedented sensitivity, resolution, and information content.

"Element 1 folks will be developing processes for making molecules, many of which will be intended for making material," says chemical engineering associate professor **Matthew Helgeson,** a member of Element 4 who brings expertise in the structure and the dynamics of complex soft matter, including biomaterials, surfactants, polymers, and gels. "If someone wants to engineer a molecule or a protein to make something like artificial spider silk, what we envision coming out of that side of the center are literally hundreds of proteins in which ninety-nine percent of the sequence is the same, with small variations here and there to try to make a better material."

The question then, he says is, "How do you screen all those hundreds of proteins for the property that you want? Our expertise in my lab is characterizing the mechanical properties of materials."

Helgeson and his colleagues are developing a rapid-screening tool for microrheology, a process used to examine flow and plasticity characteristics at extremely small scales. UCSB will have a state-of-the-art x-ray scattering instrument for that work, providing an unparalleled fifty-fold increase in speed and sensitivity compared to existing non-synchrotron-based systems.

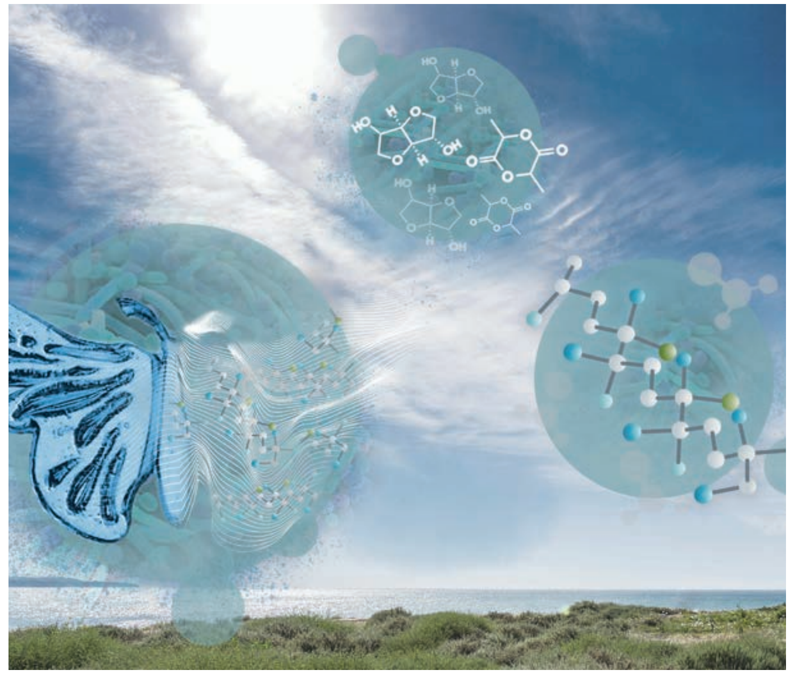
Another example of new technology is found at UCLA, where researchers are developing a new cryo-electron-microscopy technique called microcrystal-electron diffraction (MicroED). It will enable researchers to take the semi-crystalline form of a bio-derived natural product monomer and generate high-resolution data on its chemical structure within minutes, in contrast to the hours or even days needed to capture the same data using conventional techniques.

"Through BioPACIFIC, we will develop new tooling, new processes, and new materials to meet the needs of diverse applications, with the specific tasks of members evolving as the project progresses," says Valentine. "This adaptation and flexibility set this award apart: through BioPACIFIC, we will develop the infrastructure necessary to tackle many critical questions in biomaterials science, including new questions that weren't envisioned at the outset."

Finally, she notes, "Unlike many of our collaborative grants, which solely support on-campus efforts, BioPACIFIC will focus on building enabling tools and knowledge bases to bolster the biomaterials community across the nation and the world. This is exactly the kind of collaborative, cross-cutting research upon which I built my career, and I am excited to work with scientists and engineers at UCSB, UCLA, and across the nation to advance biomaterials innovation to meet important societal needs."

> "BioPACIFIC will focus on building enabling tools and knowledge bases to bolster the biomaterials community across the nation and the world."

Sharing the Knowledge



Recognizing the importance of collaboration in materials research and the key role of user facilities in allowing the community to access cutting-edge tools, theBioPACIFIC MIP management team, led by executive directors **Tal Margalith** at UCSB and **Adam Stieg** at UCLA, has engaged with a wide range of national centers-of-excellence to design a user facility that avoids reproducing existing infrastructure. This integration is also critical in identifying and implementing best practices in user support, education, and outreach.

While preparing their proposal to NSF, various team members made multi-person visits to the Caltech Center for Catalysis and Chemical Synthesis, the Illinois Biological Foundry for Advanced Biomanufacturing, and the Stanford Nanocenter and Molecular Foundry. Those forays, together with long-standing relationships with such international centers as the Materials Innovation Factory (University of Liverpool), the Center for Integrated Nanotechnologies (Sandia National Laboratories), and the Institute for Complex Molecular Systems (Eindhoven University of Technology) were instrumental in developing the extensively collaborative model that is the foundation of the BioPACIFIC MIP and that will enable it to take a leadership role in the global materials community. A strategic consequence of this network will be the fostering of a culture of truly international knowledge sharing.

TOMORROW'S TOMOGRAPHY

An instrument developed by Tresa Pollock and colleagues brings extensive new capabilities and tremendously accelerated work rates to an important area of materials science

Tomography — the science of creating three-dimensional images — is well known as a result of its important application in medical imaging. While "soft" tissues and organs can be imaged in a straightforward way using X-rays, advanced "hard" materials of the kind used in energy, aerospace, and nuclear applications are too dense for X-rays to penetrate.

UC Santa Barbara materials professor **Tresa Pollock** has worked to create a novel tomography system that enables 3D imaging of both hard and soft materials. The system, designated the "TriBeam," is the first to combine an extremely fast femtosecond laser beam (a femtosecond is 10^{-15} seconds), an ion beam, and an electron beam, making it possible to acquire, layer-by-layer, a unique set of information about materials chemistry and structure, which is then reconstructed into 3D data sets. The TriBeam is now being commercially manufactured by Thermo Fisher Scientific, the world's leading microscope manufacturer.

The integration of the femtosecond laser is the TriBeam's key innovation, as it makes possible slicing speeds that are about 15,000 times faster than can be achieved with an ion beam only. That dramatically enhanced slicing rate makes it possible to generate data sets that represent a much larger volume of a material in question, rendered with a level of detail that allows researchers to capture important physical details, which, in turn, enable them to make projections about such materials characteristics as strength, ductility, and fatigue life, all critical in high-stress aerospace applications and medical applications where a material may be put into the human body.

McLean Echlin, a lead research specialist in Pollock's lab, explains that each layer removed for tomography can be as thin as 0.25 microns and up to tens of microns, with most being around 1 micron, so that one thousand layers would be required to achieve a $1mm^3$ sample, which is, Echlin says, "really big for the resolution and types of data we acquire."

To be able to create a 3D computer rendering from so many digitized slices, Echlin adds, you need to be able to remove the layers from the material at a workably fast rate. Ion beams, until now the workhorse for this type of process, produce very accurate images, but only of tiny specimens. "And the process is too slow to be scaled up," he notes. "The TriBeam overcomes that limitation. It's like a night-and-day difference."

The idea to use this new class of laser for tomography came when Pollock was working with Gérard Mourou — who would receive the 2018 Nobel Prize for Physics — and colleagues in the Center for Ultrafast Optical Sciences at the University of Michigan. Mourou and his student Donna Strickland had earlier developed "chirped pulse amplification," an advance that enabled the development of ultrashort, ultra-intense femtosecond lasers, which were first applied in eye surgery.

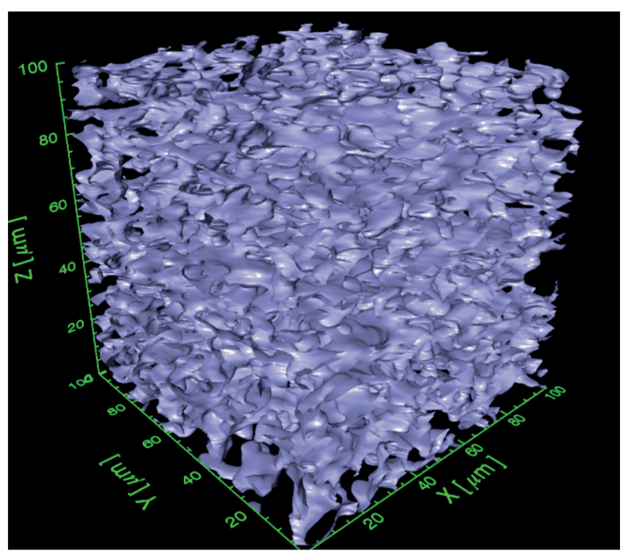
At Michigan, Pollock discovered that femtosecond lasers made it possible to remove very thin (less than 1/50th the diameter of a human hair) surface layers from a wide range of engineered materials, without damaging or melting them. She reasoned that, if automated, repeated layer-by-layer removal could be a feasible approach for generating high-resolution tomography data sets.

The actual research on the tomography platform came after Pollock, now the associate dean of the College of Engineering, arrived at UCSB in 2010. Here, she and her team, which has included Echlin and senior research scientist **Chris Torbet;** PhD students **Toby Francis, Will Lenthe,** and **Andrew Polonsky;** and postdoctoral researchers **Alessandro Mottura** and **Jean-Charles Stinville,** began working closely with Thermo Fisher Scientific to develop the technology.

Along the way, Pollock, the ALCOA Distinguished Professor, encountered plenty of people who doubted that such a system could be built, surprisingly, even after she had built it and was using it. "Early on, we presented some 3D data sets at a conference," she recalls, "and afterwards I was approached by a gentleman who told me that what we had done was impossible. He said he had tried it and it doesn't work."

But it did work, and it does work, so well that, on May 14, Thermo Fisher announced the release of the Thermo Scientific Helios 5 Laser PFIB system, a commercial version of the machine that Pollock built in a lab in UCSB's Elings Hall, with design improvements based on "lessons learned" from the prototype system.

The company describes the Helios 5 as "an advanced focused ion beam scanning electron microscope (FIB-SEM) with a fully integrated



3D reconstruction of a tungsten-copper composite, created from data captured with the TriBeam instrument. The copper (rendered) acts as an ablative coolant for the tungsten (transparent) during exposure to extreme heat.

femtosecond laser, which quickly characterizes millimeter-scale volumes of material in 3D with nanometer resolution." Because it emits extremely short pulses, which interact with material for a very short time, the femtosecond laser avoids producing the kind of thermal damage to the material that results from longer-pulse lasers.

As a result, the platform can be used for a wide spectrum of materials without requiring detailed setup studies to understand how to avoid damage. The in-situ TriBeam approach, all conducted within the microscope chamber, permits high-resolution imaging, as well as crystallographic and elemental analysis, without intermediate surface preparation or removal of the sample from the chamber.

In its release, Thermo Fisher wrote, "The Helios 5 combines the best-in-class Thermo Scientific Elstar SEM Column for ultra-high-resolution imaging and advanced analytical capabilities with a plasma FIB column for top performane in all operationg conditions, and a femtosecond laser that enables in-situ ablation [removal of material by vaporization] at removal rates not previously obtained by any commercially available product."

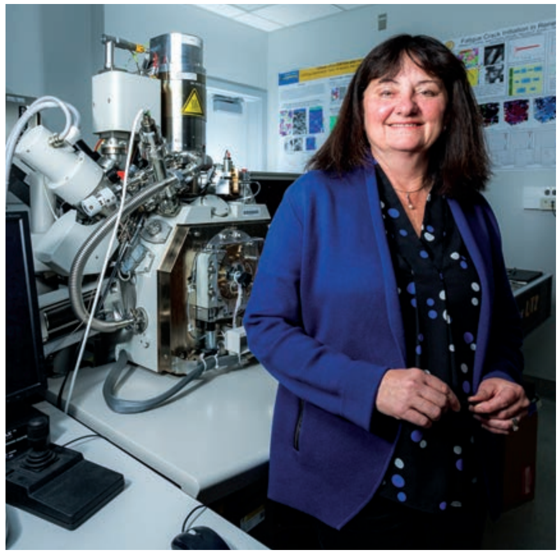
"Not only can researchers quickly and accurately image statistically relevant, site-specific, millimeter-size cross-sections at nanoscale resolution, but they can also set up large-volume 3D analyses to be completed automatically overnight, freeing up the microscope for other uses," according to Rosy Lee, vice president of materials science at Thermo Fisher. For many materials, a large cross-section of up to one square millimeter can be milled by the Helios 5 Laser PFIB in less than five minutes.

The first commercially available units were sent to the National Institute for Materials Science (NIMS) in Japan and to the University of Manchester in Manchester, England.

Dr. Tim Burnett, from the University of Manchester, said that the equipment would allow researchers "to reach deeply buried features and interfaces, as well as machine and extract multiple minute test specimens from targeted locations in times not previously achieved by our research team."

The Helios 5 is also able to expedite analysis of failures in materials while obtaining fast access to buried sub-surface layers often inaccessible with traditional FIB. This is particularly important in the semiconductor chip business, Pollock notes, where rapid failure analysis of 3D interconnects in integrated circuits is critical in the manufacturing environment.

"This new platform may well be a game changer in terms of the range of materials that can be characterized, the type of data sets that the equipment generates, and the speed with which it does the work," Pollock says. "The instrument is also well matched with the emergence of 3D printing processes" [another important part of Pollock's research]. For advanced approaches, such as electron beam melting, the TriBeam can provide a detailed view of the structure of the material at the scale of the melt pool, providing critical information on the physics of this extremely complicated manufacturing approach."



Tresa Pollock in Elings Hall with her original prototype of the TriBeam, now in commercial production.

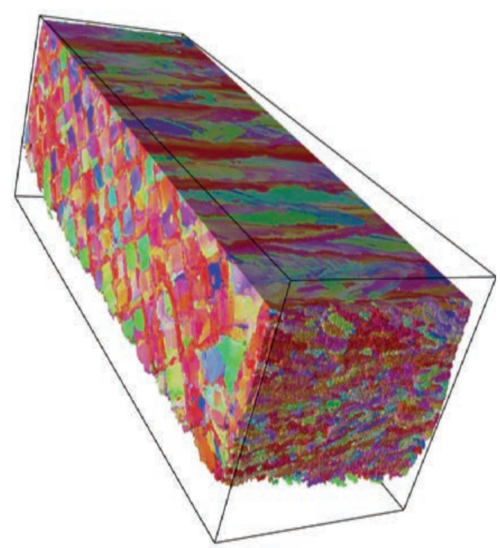
Many challenges arose as Pollock and her team developed the instrument. For instance, the laser had to be mechanically coupled with the microscope and the beam focused tightly to a specific region in the vacuum chamber. New high-precision stages were introduced to control sample motion. Further, since material layers were being ablated in-situ, a protective shield was designed to protect sensitive electron-beam-path microscope components. Software also had to be written to coordinate and control all the beams and analytical instruments in a fully automated way, and servers had to be installed to store the many terabytes of data being generated.

Fortunately, Pollock explains, her early supporters at the Office of Naval Research and the Air Force Materials Laboratory believed that her team would find solutions to those problems. And, indeed, her group has since produced 3D tomographic data sets on nickel, titanium, tantalum, cobalt, and steel alloys, as well as for organic and ceramic matrix composites, geological samples, superconducting wires, thermo-electrics, and 3D printed alloys.

Pollock's work began, because, as she writes on her website, "Developing high-fidelity material-property models often requires three-dimensional information on the distribution of phases, grains, or extrinsic defects. Concurrently, information on orientation and spatial distribution of elements may also be essential. Acquisition of this information in appropriate representative volume elements is a major challenge."

The need for this type of information has been at the core of many recent national materials initiatives. For example, in 2014, the Materials Genome Initiative (MGI) challenged the scientific and engineering communities to generate an infrastructure for developing new materials twice as fast and at a fraction of the cost by combining large data sets, new modeling approaches, and accelerated experimental approaches. Pollock delivered a lecture at the White House on the occasion of the five-year anniversary of the initiative. Her group has recently designed new cobalt-nickel alloys for 3D printing and used the TriBeam to understand how structure evolves during printing and how to control it in order to achieve extremely high-strength printed components that can operate at temperatures above 900˚C.

Described by colleagues as an especially creative and innovative scientist and materials engineer, Pollock, displays her characteristic humility when pressed on the importance of this particular advance, reluctantly admitting, "For me, it's a pretty big deal. It's nice to see this kind of result after working on something for so long. Just as rewarding is the opportunity to work with a large community of talented students and collaborators along the way. Science is a team sport."



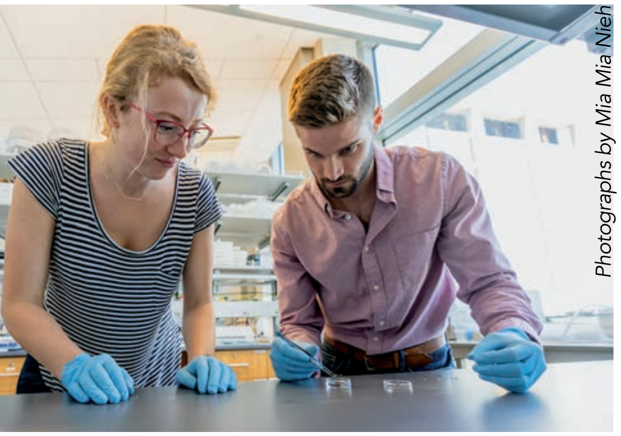
A 3D rendering of an additively manufactured (i.e. 3D-printed) cobalt-base superalloy, rendered from data captured with the TriBeam.

Faculty Q&A

BETH PRUITT

Deep Dive into Heart-Cell Dynamics

Since arriving at UC Santa Barbara from Stanford University in 2018, **Beth Pruitt,** professor in the Mechanical Engineering Department and the Biomolecular Science and Engineering Program, and director of the Center for BioEngineering, has taken a highly collaborative approach while pursuing an ambitious research agenda. Pruitt's lab specializes in designing and making micro-devices used to measure with high precision how cells, and especially those in human heart tissue, respond to changes in their environment. Pruitt was the driving force in establishing the stem cell "biobank" in UCSB's Center for Stem Cell Biology and Engineering, and was recently named a Fellow of the Biomedical Engineering Society. We caught up with her in August.



Photographs by Mia Mia Nieh

PhD students Kerry Lane (left) and Liam Dow at work in the BioEngineering lab.

Postdoctoral scholar Cheavar Blair fills a vial at a hood in Beth Pruitt's lab.

Convergence: *Can you shed some light on the importance of being named a Fellow of the Biomedical Engineering Society (BMES)?*

Beth Pruitt: This is one of the honors I'm proudest of, because BMES is *the* professional society for bioengineers. I was trained as a mechanical engineer, and I was elected a Fellow of the American Society of Mechanical Engineers in 2015. I was very proud of that honor, which was based largely on my group's contributions to microtechnology and measuring systems — tools we have made over the years to measure things that you couldn't measure any other way or couldn't measure as quantitatively as we set out to do. And while those tools have been directed largely at biology, our work was just starting to have an impact in understanding the role of mechanics in biology and the bioengineering of cellular interfaces and environments. Having BMES recognize our work as an important contribution to the field of bioengineering means a lot to me.

C: *One area of your research areas is mechanobiology. What is that exactly?*

BP: When I'm teaching my mechanobiology class, I tell students that they'll find different definitions in different journal papers. So, it's good to think about what the definition is. We start by distinguishing between mechanobiology and biomechanics, two very similar words. If I just want to know the difference between, say, Jell-O and brick, that's biomechanics. I care only about the mechanics of each: how it feels and resists loading, whether it's more like bone or brain. We can use good old mechanical-engineering principles to understand that.

Knowing these properties helps us to design and make a suitable environment or a device to interface with biology. We try to mimic a tissue or the surface of a tissue and then adhere cells to that. We're interested in how the cells' behavior changes depending on whether they are on a soft hydrogel or on a more traditional tissue culture material, like glass or hard plastic.

We know that the cells interface with and respond to their environment by appearing and acting differently, and that's broadly referred to as mechanobiology. We can't treat it like a static engineered material that has properties that I can measure and that don't change without my intervention. Living materials can remodel themselves to change the mechanical properties of the cells and surrounding matrix material. Living materials also have mechanical sensors and signaling processes to measure and respond to the environment. They can respond through short- and long-range processes, on short and long time scales, by growing or destroying cells or matrix, by changing shape or position, and by changing their cell type and their biomechanics. They are highly dynamic — the ultimate smart material.

Further, mechanotransduction is the process by which cells probe or "feel" their mechanical environment and transform that into these observable cell behaviors or responses by preferentially running different "programs" or biomolecular signaling cascades. And cells have a whole bunch of parallel mechanisms and checkpoints to make sure they do this right every time for reproduction and development to be so successful. A large part of what interests us in our lab right now is not just what happens during normal development and function, but also how it goes wrong in disease progression or injury. We want to know whether mechanical changes act in a feedback loop to mediate biological signaling.

C: *What do you hope comes about as a result of a deeper understanding of the biomechanics of heart-muscle cells?*
BP: We hope that by making finer-scale quantitative measurements of these various cell models, we can start to understand very intricate processes that occur on the molecular level — changing a molecular process on a cell and quantifying the impact it has at the cell level. If we can begin to replicate, for example, some of the hallmarks of heart disease in a human cell model, we can enable a lot of discovery without animals, because we can use these stem cells that were derived, for example, from human skin cells. Importantly, these heart muscle cells, derived from stem cells, are from a human background instead of a mouse genotype or a rat genotype. I always joke that the hearts of mice and men are different, but it's true: not only do they differ greatly in size, but a mouse heart beats about six hundred times a minute, and ours beats sixty. As a result, these two hearts have very different dynamics and mechanics, and very different underlying composition of the proteins that drive a heartbeat. These proteins are also associated with the majority of inherited heart disease mutations that have been documented. So, our goal is to study the role of these mutations in disease processes not only in human cell models but also in the right mechanical environments. In this way, we seek to enable better platforms to test disease mechanisms and potential therapies.


Heart land: Beth Pruitt in the lab with PhD student Orlando Chirikian.

"In this way, we seek to enable better platforms to test disease mechanisms and potential therapies."

C: *When you arrived at UCSB from Stanford, you became the driving force in establishing the cell bank and the Stem Cell Institute at UCSB. Why was that important — for you and your fellow researchers on campus?*
BP: We had been using three cell lines from the Allen Institute for Cell Science when my lab was at Stanford. These

cells are unique in that different proteins of interest have been labeled, so we can watch protein activity in living cells. They also cost six hundred dollars per vial, so we were really selective at first. We also knew that more lines that would be super-targeted to our research were going to be released soon, and we wanted to buy those, too.

Because these are human-derived cells, there are a lot of controls and protections surrounding their use. We were allowed to proliferate our one vial of cells to hundreds, but only for our own approved research. Gaining the approval to first obtain and then use these cells is a significant undertaking. Through our ongoing collaboration with the Allen Institute, we worked with them and the relevant entities at UC Santa Barbara not only to purchase all of their lines that were available at that time, but also to create a biobank agreement, which greatly increased the access to the cell lines for other labs on campus.

Having the cells available in a biobank eliminates more than half of the paperwork for other labs on campus that would like to use these stem cells. Each lab still needs review by an oversight committee that ensures ethical uses of the cells, but still, it's great to have that kind of "candy store" on campus and be able to say, "I'd really like to see a fluorescent tag on *that* protein." Best of all, when any of us makes improvements or additions to these banked lines, the biobank agreement allows us to "redeposit" and share them with any other lab on campus.

We ended up buying twenty of the lines and then banking multiple vials of them. If you culture the cells in the right way, you can make eighty or a hundred vials from one vial, plenty for my lab, for backup, and for other people who want to use them. This biobank is consistent with UCSB's culture of collaboration and makes it easier for a community of users to share experience, cell lines, and knowledge.

Postdoctoral scholar Anna Kim (left) and Erica Castillo, a Stanford doctoral candidate, image beating heart cells on a microscope in Beth Pruitt's lab at UCSB.

C: *Can you tell us about the graduate program in biological engineering that has been proposed at UCSB?*
BP: The proposal is for a new PhD degree program in biological engineering, and it has gone most of the way through the campus review process now. This interdisciplinary program will draw faculty from both the College of Engineering and the Division of Math, Life and Physical Sciences. The proposal is currently being reviewed by **Executive Vice Chancellor David Marshall** and **Chancellor Henry T. Yang** before moving on to the next stages of UC review. The campus review comments were generally quite positive and the main concerns centered on how to realize the longer-term growth goals of a new program launched during or on the heels of a pandemic. Notably, these same reviewing entities also recognized that campus does already have a strong base of resources in terms of faculty enthusiasm and commitments to teaching, training, and mentoring in the new program. Thus, we believe we can successfully launch the program now, even if faculty hiring and growth toward our goals of launching an undergraduate program may be delayed.

C: *Can you tell us about the process of ramping down and then reopening the lab in response to COVID?*
BP: We went back into the lab on June 15, and people have been making good progress ever since. I'm really impressed. It has highlighted a few places where we need to be more organized, but overall, I'm really proud of my lab for how they have handled this whole situation, how they have made the best use of their time when we were sheltering in place and couldn't enter the lab, and how quickly people got back to their research when they returned.

We've always had a collaborative lab, but this has really fostered a deeper collaboration. If you don't have permission to be in the lab as much as you want to, and someone is going to be there making devices, maybe they make them for their experiments but also for others to use. And someone who is doing the cell manipulation can prepare something for someone else. The pandemic has made us more dependent on each other, and that has really brought out the best in everyone.

We also had some undergrads who were supposed to do research with us this summer, but they're not allowed back in the lab yet, and we don't know when they will be, so we switched all their projects from what they *were* doing to doing video and image analysis. It was a skillset that none of them really had, but we we took a team approach to mentoring them. Each student had a grad-student mentor and would attend a session each week run by one of the mentors or a postdoc to learn about a different mode of analysis. So, they got exposed to all of the things you can do with image data. They became proficient over the summer and are now able to support those who can work in the lab. It's different, but it's working.

Solving the Mystery of Bubbling DNA

Exposure to enzymes causes a peculiar response in liquid droplets formed by DNA. A new study explains the mechanisms behind it.

Omar Saleh

"A watched pot never boils," goes the saying, but that was not the case for researchers from UC Santa Barbara, including materials professor **Omar Saleh,** and their partners at the Ludwig-Maximilians University (LMU), in Munich, Germany, when they watched a "pot" of liquids formed from DNA. Their findings appear in the *Proceedings of the National Academy of Sciences.*

Recent advances in cellular biology have enabled scientists to learn that the molecular components of living cells, such as DNA and proteins, can bind to each other and form liquid droplets that appear similar to oil droplets in shaken salad dressing. These cellular droplets interact with other components to carry out basic processes that are critical to life, yet little is known about the function of the droplets or how they interact with other cellular components. To gain insight into these fundamental processes, the researchers used modern methods of nanotechnology to engineer a model system — a liquid droplet formed from particles of DNA — and then watched those droplets as they interacted with a DNA-cleaving enzyme.

An artist's rendering depicts strands of DNA. Exposure to enzymes can cause droplets of DNA to bubble.

Surprisingly, they found that, in certain cases, adding the enzyme caused the DNA droplets to start bubbling suddenly, like boiling water. "The bizarre thing about the bubbling DNA is that we didn't heat the system; it's as if a pot of water started boiling even though you forgot to turn on the stove," says Saleh, co-leader of the project. However, the bubbling behavior didn't always occur; sometimes adding the enzyme would cause the droplets to shrink away smoothly, and it was unclear why one response or the other would occur.

To get to the bottom of the mystery, the team carried out a rigorous set of precision experiments to quantify the shrinking and bubbling behaviors. They found that there were two types of shrinking behavior, the first caused by enzymes cutting the DNA only on the droplet surface, and the second caused by enzymes penetrating inside the droplet. "This observation was critical to understanding the behavior, as it put into our heads the idea that the enzyme could start nibbling away at the droplets from the inside," notes co-leader Tim Liedl, professor at the LMU, where the experiments were conducted.

By comparing the droplet response to the DNA particle design, the team cracked the case: they found that bubbling and penetration-based shrinking occurred together, and happened only when the DNA particles were lightly bound together, whereas strongly bound DNA particles would keep the enzyme on the outside. Saleh notes, "It's like trying to walk through a crowd; if the crowd is holding hands tightly, you can't get through."

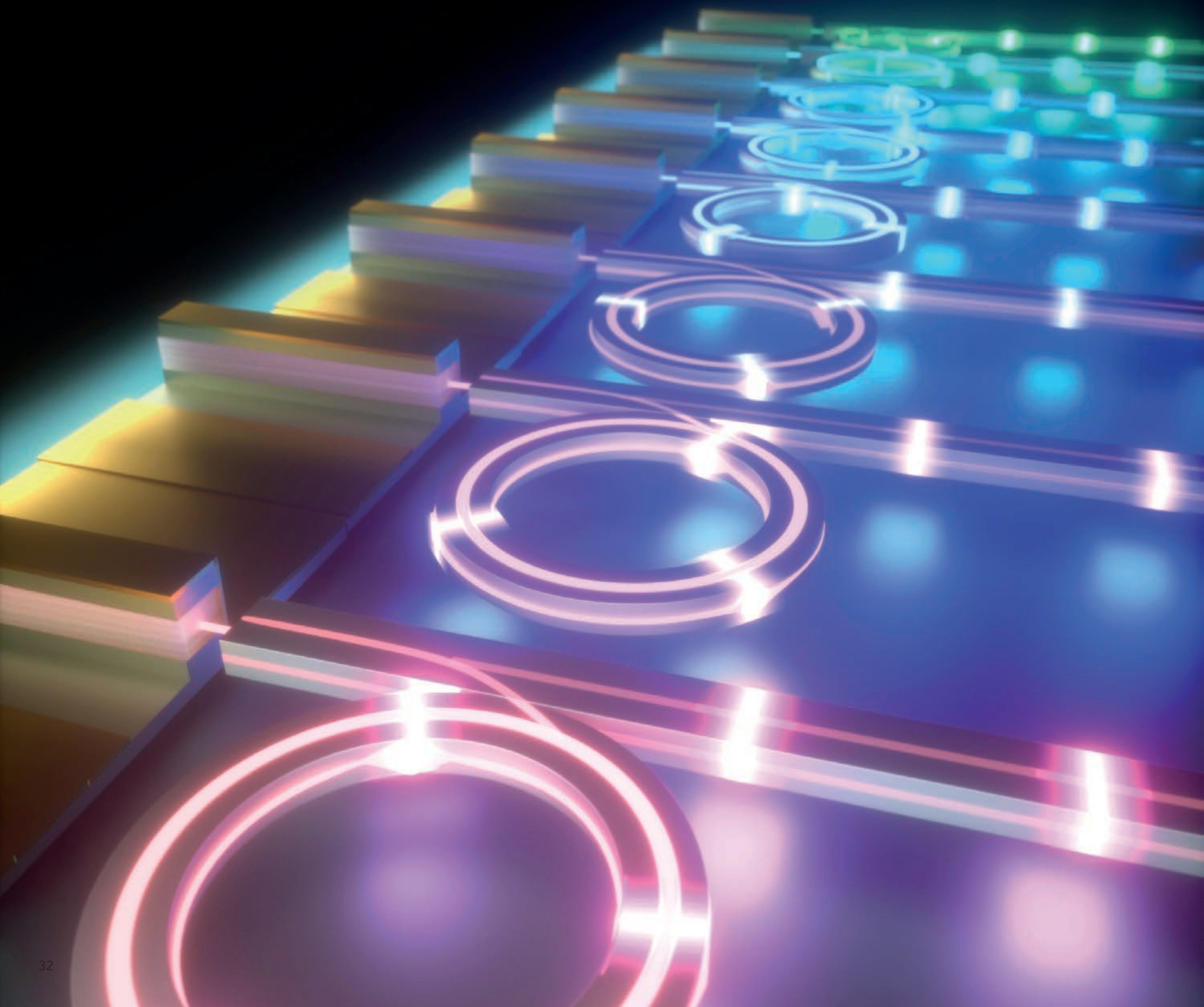
The bubbles, then, occur only in lightly bound systems, which allow the enzyme to get through the crowded DNA particles to the interior of the droplet and begin to eat away at it from the inside. The chemical fragments created by the enzyme lead to an osmotic effect, where water is drawn in from the outside, causing a swelling phenomenon that produces the bubbles. The bubbles grow, reach the droplet surface, and then release the fragments in a burp-like gaseous outburst. "It is quite striking to watch, as the bubbles swell and pop over and over," says Liedl.

The work demonstrates a complex relationship between the basic material properties of a biomolecular liquid and its interactions with external components. The team believes that the insight gained from studying the bubbling process will lead both to better models of living processes, and to enhanced abilities to engineer liquid droplets for use as synthetic bioreactors.

The research was enabled by an award to Saleh from the Alexander von Humboldt Foundation, which allowed him to visit Munich and work directly with Liedl on this project. "These types of international collaborations are extremely productive," says Saleh.

"Combing" Lasers for Better Technology

UC Santa Barbara researchers lead a project that could revolutionize the viability of photonic systems




John Bowers

"With integrated photonics, we can make an optical clock that could fit in a wristwatch, and it would be affordable."

While computer technology continues to progress rapidly, the growing power demands of data centers have created a bottleneck by pushing electrical input-output systems to their physical limits. Maintaining progress will require a significant shift in how computers are built.

In recent years, photonics — which refers to revolutionary systems in which light waves are used to transmit data faster than electronic systems can while also generating less heat — has come to the fore. It has provided a solution to the chip-to-chip bandwidth problem by enabling higher-bandwidth servers that can be farther apart and require less energy.

One element of the photonics revolution was advanced when **John Bowers,** the Fred Kavli Distinguished Professor in the Department of Electrical and Computer Engineering at UC Santa Barbara, along with UCSB colleagues and researchers at Intel, demonstrated a technology called the *silicon laser*. Fifteen years later, Intel now provides millions of silicon photonic transceivers to data centers around the world.

"The entire internet is now driven by photonics," says Bowers, who directs the College of Engineering's Institute for Energy Efficiency (see page 8) and led the collaborative research effort.

Now, Bowers has played a lead role in another important discovery in silicon photonics, the result, this time, of a collaboration involving UCSB, Caltech, and the Swiss Federal Institute of Technology Lausanne (EPFL). In their groundbreaking work, featured in *Nature,* the researchers managed to simplify and condense a complex optical system into a small package that significantly reduces the cost of production and can be integrated easily into traditional silico-chip production.

The explosion of data traffic in recent years has meant that each individual silicon photonic chip must handle data at an ever-increasing rate. The most efficient way to address this demand is by using multicolor laser light to transmit information. The more laser colors you have, the more information can be carried.

A laser typically generates only one color of light at a time, with the result, Bowers says, that "You might need fifty or more lasers in that chip for that purpose, each one generating a single color of light. But using fifty lasers has a number of drawbacks. It's expensive and also rather inefficient in terms of power use. What's more, the frequency of light that each laser produces can fluctuate slightly due to noise and heat. With multiple lasers, the frequencies can even drift into each other, much as early radio stations did."

A technology called "optical frequency combs" provides a promising solution to address this problem of laser drift. The comb is a collection of equally spaced frequencies of laser light. Plotting the frequencies reveals spikes and dips that resemble the teeth on a hair comb and the spaces between — hence the name.

Until now, generating an optical frequency comb required bulky, expensive equipment. But, by taking an integrated-photonics approach, Bowers's team was able to demonstrate the smallest comb generator in the world, which resolves all the problems previously associated with the technology. The structure is significantly smaller and cheaper than former versions, can be integrated into a small chip on silicon, and requires less power to operate.

The configuration of the system is rather simple, consisting of a commercially available feedback laser and a silicon nitride photonic chip. "What we have is a source that generates all these colors out of just one laser and one chip," Bowers says. "That's what's significant about this." It is a classic case of getting more from less.

The new technology is also much more convenient to operate. Previously, generating a stable comb had been a tricky endeavor. Researchers had to modulate the frequency and adjust power with extreme precision to produce a coherent comb state, called a *soliton,* and that process was not guaranteed to generate such a state every time. "The new approach makes the process as easy as switching on a room light," says co-author Kerry Vahala, a professor of applied physics and information science and technology at Caltech.

"What is remarkable about the result is the reproducibility with which frequency combs can be generated on demand," adds Tobias J. Kippenber, professor of physics at EPFL, who provided the low-loss silicon nitride photonic chips, a technology already commercialized via LIGENTEC. "This process used to require elaborate control."

In addition to addressing the demands of multicolor light sources in communication-related products, it also opens up new opportunities in multiple applications. One example is optical clocks, which provide the most accurate time standard in the world and have many uses, from navigation in daily life to measurements of physical constants.

"Optical clocks used to be large, heavy, and expensive, and there are only a few in the world," Bowers notes. "With integrated photonics, we can make an optical clock that could fit in a wristwatch, and it would be affordable. We should see more-compact, more-sensitive GPS receivers coming out of this approach.

"This is the key step to transferring the frequency-comb technology from the laboratory to the real world," Bowers concludes. "It will change photonics and change our daily lives."

The project was funded by the Defense Advanced Research Projects Agency (DARPA)'s Direct On-Chip Digital Optical Synthesizer (DODOS) program, which demonstrated optical synthesizers using photonic integrated circuits.

Why COVID is NOT Driving a Robot Revolution

Immature technologies and risk aversion block robotic dominance…for now.

Ever since COVID drove everyone into their homes in spring, Americans have been on an online buying jag. As a result, many fulfillment and distribution businesses have experienced dramatic increases in demand. With social-distancing rules in place at warehouses, some expected a sudden shift to robots, which would handle products and block transmission of the virus in the bargain.

That didn't happen, say UC Santa Barbara technology management assistant professor **Matt Beane** and his Stanford University colleague **Erik Brynjolfsson** in a paper published in the *MIT Sloan Review.* In ongoing research funded partially by NSF, the two have so far sampled more than twenty companies of varying sizes around the country in terms of their adaptation of AI-enabled robots specifically and automation more generally.

"This piece is about what happens to investments in automation during COVID," Beane says. "Generally, it's bad news for any firm that uses the word *robot* to describe what they're selling. A few firms sell robotic automation, physical robots that automate things, but many of those are a solution looking for a problem."

Beane says that the pandemic has driven companies to adopt what he has called *plug-and-play automation,* which "refers to anything that can be purchased easily, arrive at your facility quickly, has a small physical footprint, and is *modular* — meaning that I can easily hook it up to other forms of automation — and *repurposeable*, so that I can pretty quickly switch it from sorting one type of thing to another."

As an example, one company they studied uses industrial pumps to fill containers with a variety of liquids. When the pandemic started, they instantly lost sixty percent of their business. When they received multiple requests to bottle hand sanitizer, they scrambled to acquire six more pumps and started packaging it, along with a different sanitizer for surfaces, and a lubricant used in the medical field. The pumps have no artificial intelligence and no robotic elements.

"They had the pumps and the filling equipment," Beane says. "The demand for lubricant dropped off quickly, but demand for the other products grew, so they had to be able to disconnect the pump from one product line and swap it over in an hour or two to a new piece of filling equipment for a different product."

The problem even with that solution, Beane says, is that companies that could integrate plug-and-play elements into their systems probably did so before the pandemic and now will snap up remaining plug-and-play units to meet increased demand, leaving nothing for would-be new adapters. If a firm wasn't already using plug-and-play technology, they will face an uphill battle to acquire it now.

Even when companies could integrate a robotics system to sort some type of good, many do not, Beane notes. "They say, 'We could go four times faster than this with a robot, but the rest of the facility can't get us products fast enough to do that, so there's no sense in us going faster.' They could go faster only if the organization completely changed five processes upstream, but that takes years of business re-process engineering."

A more common path for many companies right now is to hire more people in the short term, even if it means spending more money and being a bit less efficient, because they are wary of investing in new technology during such an uncertain time.

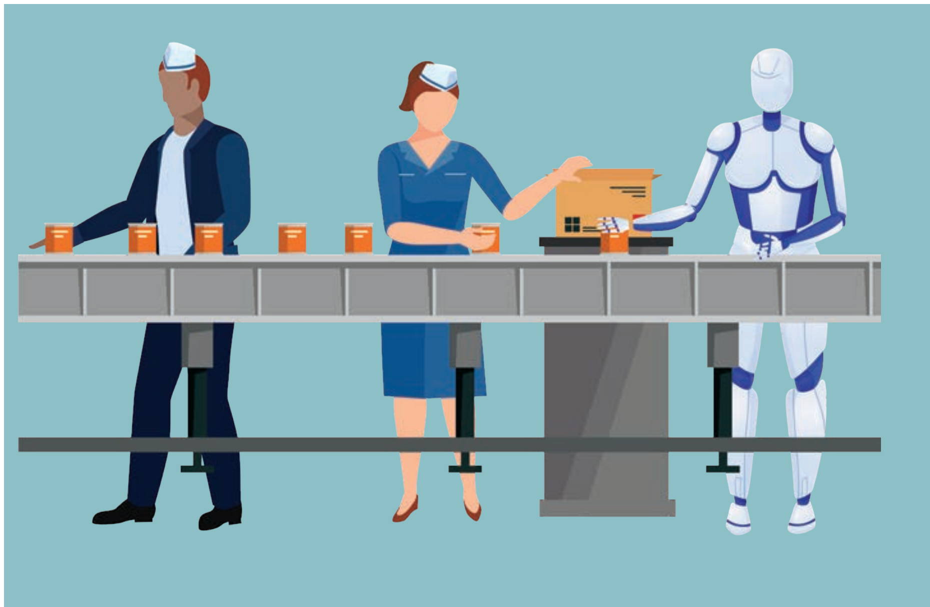
In fact, even before the pandemic, investment in robots was small, and resulting job losses were few.

"The robots-replacing-people thesis is misleading because the people doing the analysis don't agree on what a robot actually is," Beane says."If we define a robot as something that has a five- to seven-axis arm that does some manipulation task — picking something up from an uncertain position and putting it into a container — then, no way. The only robots that are adding repeatable value and therefore possibly leading to job loss are in extraordinary repeatable, long-lived production processes like in aerospace or automotive manufacturing or electronic systems assembly.

"But nobody would refer to those as robots because they don't have visible arms," he continues. "If what we mean by a robot is one of these roughly human-scaled arms that does some manipulation tasks, then the level of investment in robotics amounts to something less than a rounding error. Erik and his colleagues' very recent study, using Census data, shows that only 1.3 percent of firms are investing in any kind of robotics system, and almost all of that is invested in these proven systems. The kinds of robots that people think of as robots — not one of them is doing an uncertain task at 99.96-percent accuracy so that a business can get a good, predictable return — at least, not yet."

Beane and Brynjolfsson's research program includes only firms that are attempting to make AI-enabled robotic systems that can handle a changing list of less-structured, less-predictable tasks while making money doing it. "Every single firm in our sample we selected because they are developing absolutely bleeding-edge robotic technology," Beane says. "Some of them will be successful, and those technologies will be successful at scale, but that will be years from now. All of them right now are venture capital–sanctioned experiments."

To watch a CNBC interview with Beane and Brynjolfsson, go to: https://cnb.cx/3kOXg6w



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Henley Hall, the new home of the Institute for Energy Efficiency, opened on time in September, bristling with green features and providing eighteen new labs for cutting-edge research related to energy efficiency and sustainabilty.