Spring 2023

Caltech magazine

LAUNCH PARTY

How Caltech propels student entrepreneurship

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Left: The Initiative for Caltech Students will enhance campus life in a variety of ways, such as providing resources for student-run clubs like OASIS, which recently hosted a campus Holi celebration (at left). Holi is a Hindu holiday also known as the Festival of Colors. For more on the Initiative, see page 28.

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Feature: **Piecing the puzzles together**

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Spring 2023 Volume LXXXVI, Number 1

Caltech
magazine

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Caltech magazine ISSN 2475-9570 (print)/ ISSN 2475-9589 (online) is published at Caltech, 1200 East California Boulevard, Pasadena, CA 91125.

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This issue includes FSC-certified paper, and is printed by Lane Press, South Burlington, Vermont.

Above: Student teams compete in the 38th annual ME72 Engineering Design Competition on March 9, 2023.

Letters

A Teacher's Power

It was with delight that I read about the naming of the Lee F. Browne Dining Hall earlier this year. Mr. Browne was my chemistry teacher at Blair High School, Pasadena, prior to his joining the staff at Caltech. I attribute my winning of the 1968 American Chemical Society High School Chemistry Contest to Mr. Browne's expert teaching, sparkly personality, and love of chemistry. Although I elected not to attend Caltech and not to major in chemistry, I will never forget the contribution this wonderful man made to my life!

—Stephen Riffenburgh, MD
SOUTH PASADENA, CA

Reflecting on "Reflections of '72"

I definitely believe that anyone who wishes to do engineering and sciences should not be limited by what society tells them what they can or cannot do. There should be no quota for any race, but rather encouragement for [people] traditionally not seen as "smart" to pursue an education

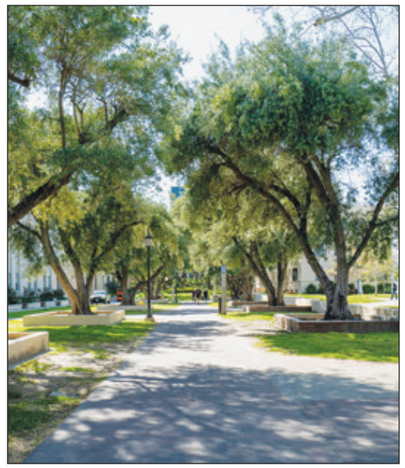
@JacsonJanele on Twitter

A Mentor Remembered

Many thanks for the latest edition of the magazine. I enjoyed reading many stories, especially the In Memoriam pieces. I especially appreciated the tribute to Leon Silver, whom I remember from my undergraduate days in the early 1960s. Lee was born in Monticello, New York, not far from where we now have a summer cottage. Although I was principally interested in geophysics, I profited from the excellent courses that Lee taught and appreciated the interest he took in me, which continued throughout my career in mineral physics at Columbia, the Australian National University, and, for the past half century, at Stony Brook University.

—Bob Liebermann (BS '64)
SETAUKET, NY

The snowy San Gabriel Mountains as seen from Caltech Hall Library on March 1, 2023.



Leafed Out?

Interesting details in the article about trees (Fall 2022, "Caltech in Five Trees," page 8). But what happened to the olive trees that gave their name to the Olive Walk?

—Martin Goldsmith (MS '52, PhD '55)
SEAL BEACH, CA

Editor's note:
Fear not! The 20 olive trees *(Olea europaea)* along the Olive Walk have not gone anywhere!

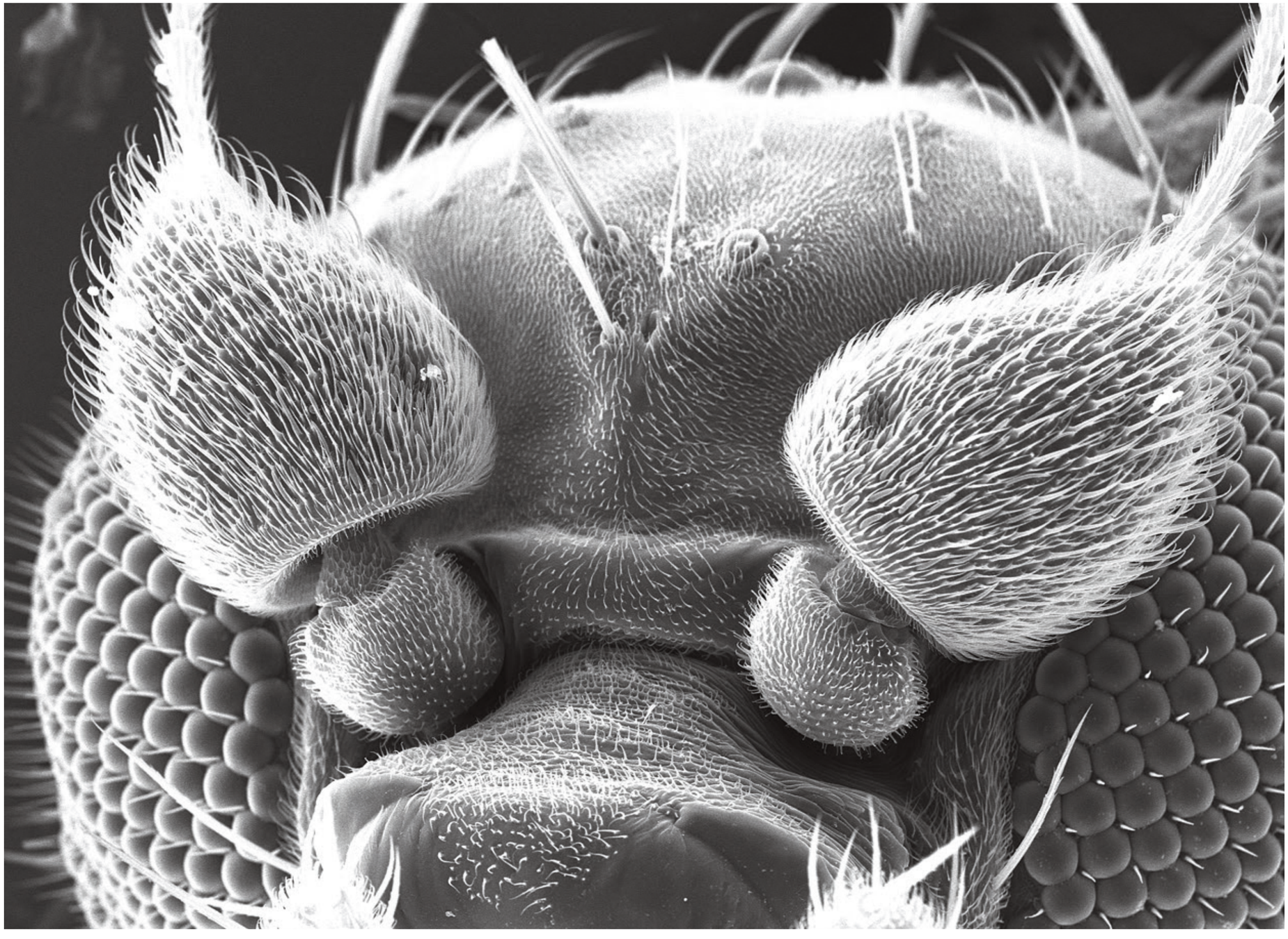
Winter in Antarctica

In your article about Zhongwen Zhan (*Caltech* magazine online, March 2023), you state that the Antarctic winter "is too inhospitable for human scientists to hang around."

In fact, people from the U.S. Antarctic Program (both scientists and support staff) do spend winters in Antarctica, both at McMurdo Station (a few hundred) and at the South Pole (about 50). Some of those people are even affiliated with Caltech! For example, Professor Jamie Bock's group in PMA operates telescopes at Amundsen-Scott South Pole Station through the Antarctic winter. The Antarctic summer season is used for telescope upgrades and repairs while science data are collected during the Antarctic winter, and the team generally includes at least one scientist/ engineer to ensure that the telescope remains operational through the winter.

—Asad Aboobaker
JPL Systems Engineer
ALTADENA, CA

Editor's note:
Read about Professor of Geophysics Zhongwhen Zhan's recent research trip to the South Pole:



A scanning electron microscopy (SEM) image of a female *Conicera tibialis*'s antennae.

SoCaltech

- Illustrating the biological world
- Carver Mead's big honor
- Meet me at Browne: The dining hall's new name; and more

On the Fly

If lab animals were celebrities, *Drosophila melanogaster*—the common fruit fly—would be a household name. For decades, Caltech researchers have developed genetic tools that allow them to use these flies, among the most common animal research subjects in the world, to answer questions such as how emotions are encoded in the brain and how a fly's microbiome influences its ability to walk.

But some different flies with lesser-known names are making an appearance in the laboratory of Elizabeth Hong (BS '02), assistant professor of neuroscience and Chen Scholar. These include *Termitophilomyia*, which live as a parasite in termite nests; and *Conicera* (shown at left), colloquially known as coffin flies due to their affinity for dead animals. In Hong's lab, research scientist Ezgi Kunttas, in collaboration with Brian Brown, entomology curator at the Natural History Museum of Los Angeles County, studies the evolution of a diverse group known as phorid flies—looking specifically at the evolution of their noses.

Olfaction, or the sense of smell, was one of the first sensory systems to evolve in animals, because it is a necessary tool to sniff out food, avoid predators, and find a mate. The Hong Lab primarily uses fruit flies to study how this primal sense is wired into the fly brain and, by extension, our own. A fly's "nose" consists of its two antennae, which are coated with thin hairs called sensilla that hold the insect's olfactory neurons. Odors diffuse into tiny pores on the sensilla and bind onto corresponding receptors on the olfactory neurons, which send signals down the hairs and into the brain. Though humans do not have antennae, an analogous process

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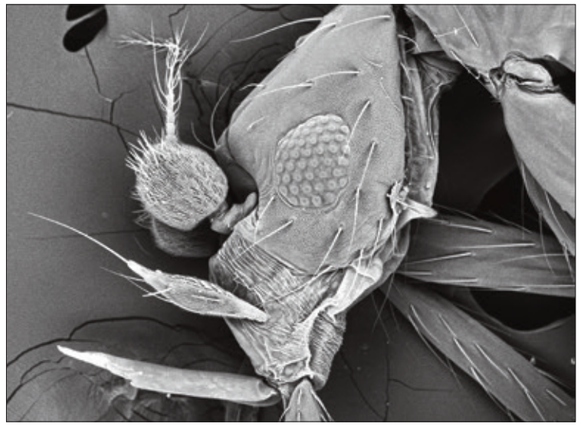
On the Fly

continued from page 5

happens in our noses when we lean in to catch a whiff of a delicious dish or recoil from the stench of rotten eggs.

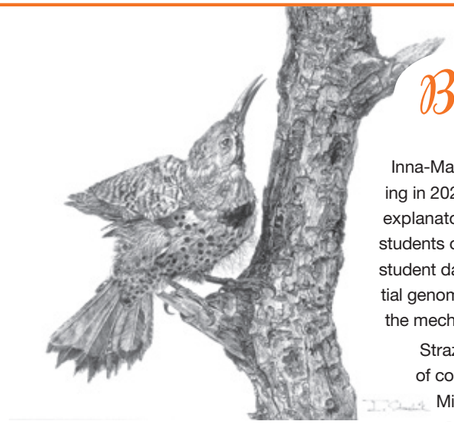
Kunttas uses scanning electron microscopy to take detailed, magnified photos of the antennae of exotic flies to understand how their diversity across different species may relate to the evolution of niche lifestyles: parasitic, scavenger, or herbivorous, for example. Tiny *Conicera*, which measures only 1 millimeter long, feeds on dead animals. But because it is outcompeted by larger carrion feeders such as blowflies, *Conicera* finds sources of food underground that bigger flies cannot access. Such comparative analyses help illustrate the selective pressures that shape antennal form and function to optimize the detection of chemical signals that promote each species' survival.

"Fruit flies are interested in the sweet aroma of fermented fruits, which is very different than the decaying organic matter that coffin flies are drawn to," Kunttas says. "Understanding the differences in how odors are processed in the brains of insects that care about very different types of odors provides insight into the broader problem of how complex chemical information can be efficiently coded and read out."

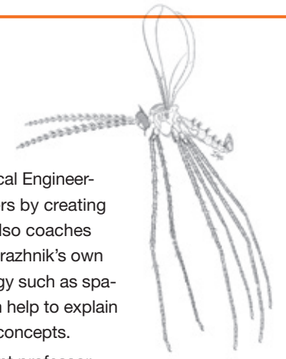


A scanning electron microscopy (SEM) image of a female *Termitophilomyia* head, highlighting the antennae and reduced eyes.

ENGINEERING AN AUDIENCE

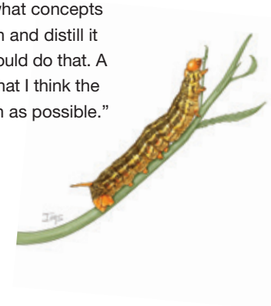


Beautiful Biology



Inna-Marie Strazhnik, who joined the Division of Biology and Biological Engineering in 2020 as a visual communications specialist, assists researchers by creating explanatory illustrations to accompany their scientific papers. She also coaches students on visual communication (the bird at left is a drawing from Strazhnik's own student days). Her work typically focuses on topics in molecular biology such as spatial genomics and computational workflows, and the illustrations often help to explain the mechanics of molecular interactions or to break down high-level concepts.

Strazhnik works closely with the labs of Matt Thomson, assistant professor of computational biology and Heritage Medical Research Institute Investigator; Mitchell Guttman, professor of biology; and Long Cai, professor of biology and biological engineering. "Every single illustration presents its own little challenge," Strazhnik says. "First, you have to understand what the main point is, and what concepts you'll have to put in. You kind of know immediately how you can take all that information and distill it into just those key points. Then you also get this clear picture in your head of how you should do that. A really elegant visual tells a much bigger story in just a few simplified graphics. So that's what I think the puzzle is: trying to figure out how to do the most with as little real estate in an illustration as possible."



Short Stories, Big Ideas

A new short-story collection is bringing the imaginations of Caltech and JPL graduate students, postdocs, alumni, faculty, and staff to life. Released in March 2023, *Inner Space & Outer Thoughts: Speculative Fiction from Caltech and JPL Authors* was spearheaded and edited by members of TechLit, Caltech's creative writing club. The anthology features original stories in themes across science, technology, space, and time. The idea for the project came about in 2020 during the COVID-19 pandemic, says Rachael Kuintzle, a biochemistry and molecular biophysics grad student who founded TechLit and served as the book's editor in chief.

"A lot of people weren't able to spend as much time on their research—they had more time to write," Kuintzle says. "So we thought, why don't we take advantage of this time and put out a call for submissions? We got some great pieces, and then, over the next year, our editors worked intensively back and forth with the authors to develop their stories."

Notable contributors include award-winning speculative fiction authors and Caltech alumni David Brin (BS '73), S.B. Divya (BS '96), and Larry Niven (EX '60).

"The authors took their expertise and came up with these beautiful creative stories, sometimes grounded in their own work, sometimes grounded in an area of science that they've always been curious about but never got to explore professionally," Kuintzle says.

Read more about the anthology and order your own copy: **magazine.caltech.edu/innerspace**

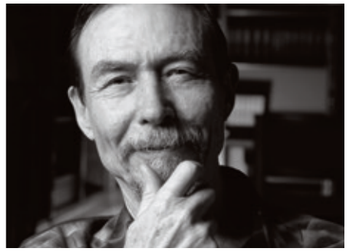
Dining Hall *Distinction*

The Caltech community gathered in November to formally dedicate the Lee F. Browne Dining Hall, Caltech's central dining facility. The dining hall was renamed in fall 2021 in honor of the late Lee Franke Browne, a former Caltech employee and lecturer who joined Caltech in 1968 and served for two decades as director of secondary school relations and special student programs before retiring as a lecturer in education, emeritus. Browne, who died in 2010, dedicated his life and career to efforts that expanded students' access to STEM. He also advanced human rights through his involvement with community organizations such as the National Association for the Advancement of Colored People (NAACP), and others. Speaking for the extended Browne family, Adriene Tri, the youngest of Browne's four children, described her father as "a man of strength and dedication, whose commitment to our education was paramount."

Read more about the event:

Chip Memory

Carver Mead (BS '56, MS '57, PhD '60), *recipient of the 2022 Kyoto Prize in Advanced Technology, on teaching Caltech students how to build integrated circuits in the early 1970s:*



"I redefined what semiconductor devices were. They're just more complicated than you thought. … What I taught them was exactly what I had learned in the last three years figuring out how to design my own chip: that you can get a conceptual picture of each of the process steps and what it does in terms of the structure of the geometry, what that does in terms of the electrical circuit diagram, and what that does in terms of logic. If you have those conceptual pictures in your head, you can hold the whole process in your head. One person can do this whole thing. I had done it; the students are smarter than I am, so they'll certainly be able to do it, and they were."

Mead delivered these remarks in his Kyoto Prize commemorative lecture from November 2022. Learn more about his invention of VLSI (very large-scale integration), the cornerstone of modern computing:

A Light in the Shadow

Astronomers using W. M. Keck Observatory on Maunakea in Hawai'i have discovered that aurorae at visible wavelengths appear on all four major moons of Jupiter: Io, Europa, Ganymede, and Callisto. A team led by Caltech and Boston University observed the moons in Jupiter's shadow so their faint aurorae, caused by the gas giant's strong magnetic field, could be spotted without competition from sunlight reflected off their surfaces.

"These observations are tricky because, in Jupiter's shadow, the moons are nearly invisible," says Katherine de Kleer, assistant professor of planetary science and astronomy and Hufstedler Family Scholar. "The light emitted by their faint aurorae is the only confirmation that we've even pointed the telescope at the right place." De Kleer was lead author of one of two research papers describing the discovery published in the *Planetary Science Journal* in February. She was also one of the Caltech researchers and alumni photographed by Christopher Michel, artist in residence at the National Academy of Sciences, for his *New Heroes* series, which celebrates the scientists and engineers working on solutions to society's biggest challenges.

View more ***New Heroes*** portraits:

Nitika Yadlapalli (fifth-year graduate student)

#SoCaltech *is an occasional series celebrating the diverse individuals who give Caltech its spirit of excellence, ambition, and ingenuity. Know someone we should profile? Send nominations to* ***magazine@caltech.edu.***

For more #SoCaltech, go to magazine.caltech.edu/post/category/SoCaltech

Nitika Yadlapalli (MS '21) works in the lab of Vikram Ravi, assistant professor of astronomy, studying millimeter-range electromagnetic-spectrum emissions from high-energy astrophysical sources. She has spent a lot of time at the Owens Valley Radio Observatory (OVRO) working first with the Deep Synoptic Array (DSA), and now with the Stokes Polarimetric Radio Interferometer for Time-domain Experiments (SPRITE). Sometimes, she says, the wildlife gets too close for comfort.

"Early in my second year, a couple of us went to OVRO to work on tests for the first DSA dish. Vikram [Ravi] had decided we were going to observe a bright radio source that would pass through the north–south meridian at 10 p.m. The DSA dishes are pointed north and only move in elevation, meaning you can't spin them to point east or west. And because this was the first dish online, we didn't have computer control or any computer monitoring of where the dish was pointed. The only way to point it was to strap a digital level onto one of the axes, then flip a switch at the bottom. I was responsible for pressing the button on the data recorder. Vikram was on a ladder, reporting the digital-level reading, like, 'We're at 60 degrees! Sixty-five degrees!' Finally, everyone said, 'OK, we're on the source! Hit the button!' The thing is, it's the middle of the night, I'm sitting there with this giant glowing box, all these bugs are flying around me, and this really big scorpion runs past my feet. I screamed. Vikram is going, 'Hit the button!' And I'm yelling, 'No, there's a scorpion!' I pressed it, but I was scared. Everything worked out though, and I still loved the whole experience enough to keep coming back to OVRO and work on instrumentation for the rest of my thesis."

Origins

The Personal Computer

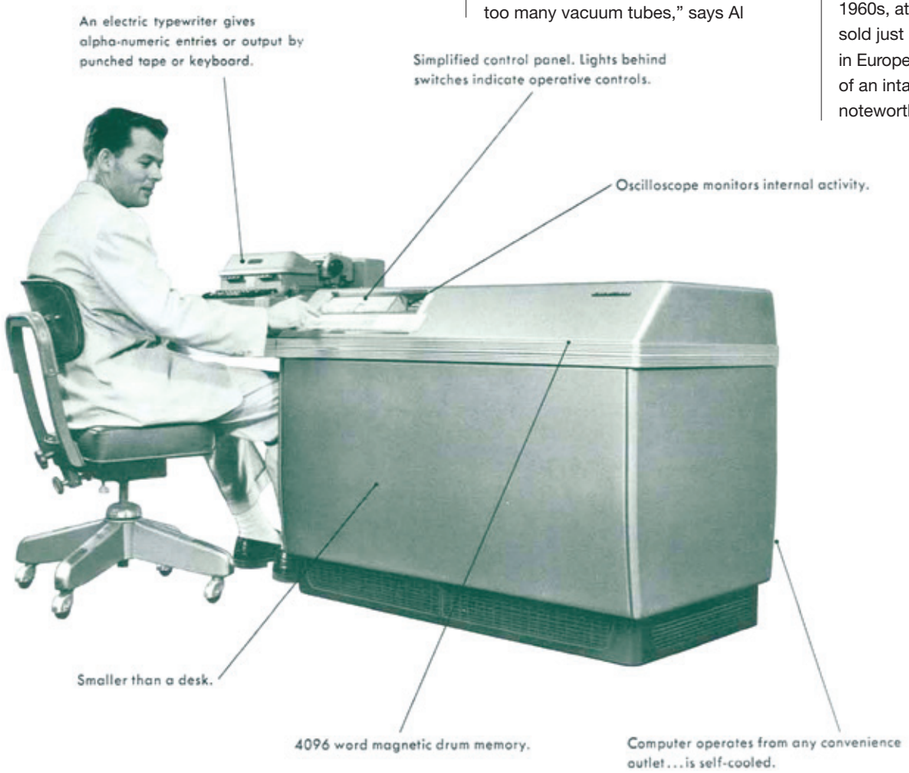
A nearly 70-year-old 800-pound machine found in a German basement last November turned out to be, according to the website Ars Technica, an innovation that changed the course of computer history. And it has its roots at Caltech.

Known as a Librascope General Precision-30 (LGP-30), the machine was designed by Caltech researcher Stanley Frankel in 1954. Frankel, who had performed calculations for the Manhattan Project using the first electronic computer, ENIAC, was recruited by Caltech in the early 1950s to head the Institute's new digital computing unit. The LGP-30, which Frankel described as a "simple general purpose computer," was considered small at the time though it weighed as much as a grizzly bear. It was called MINAC before a Glendale-based company called Librascope licensed the design and hired Frankel and Caltech graduate student James Cass (BS '50, MS '53) to create a production-ready product.

The result was the first personal computer: a desk-sized single-user machine that plugged into a wall socket. It contained 113 vacuum tubes for logic circuitry, and its primary memory device was a magnetic drum—a metal cylinder that measured 6.5 inches in diameter and 7 inches long. Data was entered and received through an attached Flexowriter, which was a typewriter that used punched paper tape.

"Much of the computer hardware before the LGP-30 used far too many vacuum tubes," says Al Barr, professor of computer science at Caltech. "Vacuum tubes used a great deal of electrical power, produced a lot of heat, and were fairly unreliable since they frequently burned out like incandescent light bulbs. The LGP-30 used a goodly amount of solid-state diode logic to reduce the number of vacuum tubes, increasing its reliability and decreasing its power use. The hardware design was one of the stepping stones that opened the door to the modern computer revolution."

The LGP-30, which could be used for a variety of mathematical and applied engineering computations, was released in 1956 at a reported cost of $47,000 (around $500,000 today). Although more than 500 units were sold through the 1960s, at a time when most designs sold just a handful, only 45 were sold in Europe. This makes the discovery of an intact LGP-30 all the more noteworthy.



A graphic from the original LGP-30 brochure published in 1956.

Rocking Out

In 2020, Caltech graduate students launched the Caltech GPS Outreach GO-Outdoors Program, which connects students, postdocs, and faculty members in the Division of Geological and Planetary Sciences with local K–12 teachers. The program aims to increase exposure and access to geosciences fields through curated lesson plans, classroom visits, and, most importantly, field trips (about eight per year), during which elementary, middle, and high school students have the opportunity to see what they are learning about up close.

The more than three dozen Caltech members of GO-Outdoors also provide teachers and administrators with additional educational resources for their classrooms. In its more than two years, the GO-Outdoors program has reached nearly 250 students across eight Pasadena-area schools and is continuing to grow.

"The outdoor experience for the kids enabled them to visually see and get a deeper conceptual understanding of real-life applications in their own backyard," says Yolanda Muñoz, a teacher at Sierra Madre Elementary School. Muñoz's third- and fourth-grade students learned about landslides and debris flow through a field trip to Bailey Canyon Wilderness Park in Sierra Madre to look at debris catchments. This built on an earlier class visit in which Caltech volunteers taught the students how to construct their own miniature debris flows with water and sand. The children then performed tests to see how much water it took to knock over plastic dinosaurs.

Last year, students from Pasadena Unified, Alhambra Unified, and San Gabriel Unified school districts participated in a field trip to the San Gabriel Mountains, where they developed a real-world understanding of seismic faults. "It was amazing," says Maia Dimas, a Pasadena Unified high school student, who notes the field trip enriched her understanding of geology and seismology. "I loved walking around and trying to find faults, discussing how the faults worked, and how seismologists map out faults and geography."

Shaelyn Silverman (MS '21), a graduate student in geobiology and GO-Outdoors co-founder, says the program is tailored to meet the expressed needs of the teachers. "Our activities always draw upon evidence-based strategies for effective student learning," she explains. "During outreach trips, I always feel incredibly energized from the students' excitement for engaging in science and being in the outdoors."

The Caltech team also purposefully structured GO-Outdoors so it can continue in perpetuity, says Claire Bucholz, a Caltech assistant professor of geology and GO-Outdoors advisor. "It took some very conscientious efforts on their part to design the leadership roles and mentoring structure so that, even with the cycle of graduate students joining and leaving Caltech, there will always be a core group who can lead the endeavor," she says.

Caltech research technician and GO-Outdoors volunteer Katie Ann Huy says the program means a lot to her since she came from an underrepresented background where access to science education was scarce. "Joining GO-Outdoors has given me the opportunity to give back to communities like those I was brought up in and find belonging within the division," she says. "I believe GO-Outdoors and outreach groups like it can allow underrepresented students to feel supported in their identity and their desire to give back to their communities."

Juliet Ryan-Davis (MS '20), a graduate student in geology and GO-Outdoors co-founder, says she is grateful that programs like this one are valued by the Institute community. "The fact that Caltech supports this program just reinforces what I strongly believe: that science and society are inseparable no matter what."

—Sabrina Pirzada

Sea *Change*

Why two Caltech-related companies are taking the battle against climate change to the ocean.

By Lori Dajose (BS '15)

Even a January storm in Los Angeles could not dampen the spirits of the four-person team that makes up Calcarea, a carbon-sequestration start-up co-founded by Caltech geochemist Jess Adkins. But they did get wet—very wet.

On January 9, amid a torrential downpour, the group stood in a parking lot at USC donning hard hats and yellow vests as semitrucks delivered the components of a chemical reactor that could one day clean up excess carbon dioxide in Earth's atmosphere by capturing emissions from transoceanic shipping. The heavy rain turned into an afterthought for Adkins and colleagues Melissa Gutierrez (BS '19), Pierre Forin, and Troy Gunderson, whose excitement was palpable. "As long as there's no lightning," Adkins noted.

Carbon capture and storage efforts have long been centered on Earth's atmosphere, with companies scrubbing carbon dioxide from the air and storing it underground. While effective, the process is energy intensive and, thus, expensive. Calcarea and another new Caltech-affiliated start-up, Captura, are two of a handful of companies taking a different approach by switching their focus to the oceans.

Oceanic carbon removal is beneficial for the ocean biosphere, where increased carbon dioxide levels have destroyed swaths of marine ecosystems through ocean acidification, and also enhances the ocean's natural capacity to draw down carbon dioxide from the atmosphere through equilibrium processes. While Captura plans to remove carbon from the ocean directly, Calcarea's team aims to clean the flue gas directly from cargo ships to safely and permanently store carbon dioxide in the ocean by mimicking Earth's natural processes to make carbon dioxide react with limestone to produce bicarbonate ions.

Following a demonstration of an initial prototype in the lab, Calcarea's scaled-up reactor was manufactured in Houston. And so, on that rainy day in January, the team gathered to assemble and test it in an unassuming open-air parking lot at the edge of the USC campus. Though the team scheduled the delivery months before any storms were forecast for that day, the group was still determined to finish the job. After a lull in activity, Gunderson, an oceanographer, strode up and broke some bad news—the last truck of the day, carrying the cradle for the reactor itself, had broken down. Adkins smiled and shook his head. "Of course it did," he said.

Calcarea team members **Jess Adkins, Pierre Forin,** and **Melissa Gutierrez** (BS '19) await delivery of their prototype in the rain.

The CHALLENGE Ahead

Adkins, the CEO, had never led a start-up until Calcarea, but he felt compelled to take the leap because of the pressing urgency of human-made climate change and its consequences. Over the past 200 years, humans have figured out how to get plentiful efficient energy through burning hydrocarbons like oil and gas, enabling rapidly accelerated societal transformation. But the consequences of this progress—a warming, changing climate—have been costly to our planet and to people around the world, particularly those in vulnerable communities, such as developing nations.

Human activity has, in total, emitted 400 gigatons of carbon dioxide. About one-third of that has settled in the atmosphere, where it traps heat and causes global warming. Another third is taken up by the surface biosphere: soil, rocks, and plants that use carbon dioxide for photosynthesis. The final third, meanwhile, soaks into the ocean.

To have a chance of avoiding catastrophic damage to human health and the planet, the Intergovernmental Panel on Climate Change (IPCC) has determined that we must prevent the planet from warming by more than 1.5 degrees Celsius. According to the IPCC's models, this can only be accomplished by both switching to renewable energy and initiating carbon capture and storage practices to clean up the mess of emissions polluting the planet. This dual approach is required because even if fossil fuel use were eliminated tomorrow, the 400 gigatons of carbon dioxide already released must still be dealt with. According to the IPCC, that means removing 2 gigatons per year.

"It's no longer sufficient to only decarbonize the economy by switching to renewables," Adkins says. "We could have done it if we started earlier, but we didn't, and now we have to take carbon dioxide out of the atmosphere, and we also have to decarbonize the economy."

This urgent existential crisis, along with newly available funding for carbon capture and removal, has motivated researchers around the world to pursue daring new ideas: some in parking lots and garages, and others in their own homes. Captura, the other new company spun out of Caltech that is aiming to decarbonize the oceans, tested its first prototypes in the backyard pool of co-founder Harry Atwater, the chair of Caltech's Division of Engineering and Applied Science.

"My son had just graduated from college and was looking for a biochemistry project," Atwater says. "We had just received funding to develop early prototypes of our technology, so I told him, 'Hey, why don't we take a couple of months and just have some fun with this? We'll set it up in the backyard swimming pool.'" Since its backyard origins, Captura has won millions of dollars in funding and prizes to make its technology a reality.

DECARBONIZING Shipping

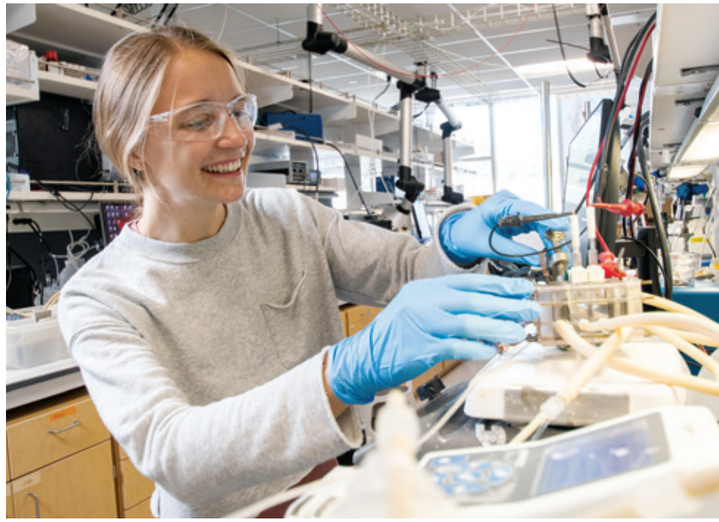
The primary target of Calcarea's cleanup effort is the shipping industry. While cars and homes can often easily be powered by clean wind- and solar-generated electricity, there are no efficient sources of renewable energy for the cargo ships that power our global economy. Cargo ships account for 3 percent, or 1 gigaton, of global carbon emissions per year. Focusing efforts to capture carbon from this sector, therefore, could put us within reach of removing the 2 gigatons per year the IPCC models require.

The Calcarea technology was inspired by natural processes already occurring on Earth. Over long periods of time, carbon dioxide gas in the oceans reacts with limestone ($CaCO_3$) shells on the seafloor in a process called carbonate compensation. The reaction transforms carbon dioxide and produces calcium ions and bicarbonate. In this way, nature equilibrates its carbon dioxide levels naturally. If humans were to disappear from Earth tomorrow, atmospheric carbon dioxide levels would ultimately settle back down to approximately 280 parts per million from our current level of 421 per million, though it would take tens of thousands of years to do so.

For almost a decade before starting Calcarea, researchers in the Adkins Lab worked to understand the kinetics of limestone weathering with the belief that accelerating this process could boost the planet's natural carbon sequestration processes. While they did discover an enzyme that could catalyze the process in the lab, they also realized that at high-enough concentrations of carbon dioxide (5 percent), the weathering reaction would happen much more quickly. The flue gas from cargo ships turns out to meet that bar, and ships can easily carry the limestone necessary to drive the reaction, even without the catalyst.

Adkins began to assemble a team and arrange a sabbatical from Caltech to focus on making accelerated limestone weathering into a viable carbon capture technology that could be sold to large shipping companies to install on their ships. He recruited engineer Forin, who was working in the green shipping industry in Norway, and former Caltech undergraduate Gutierrez. The three of them then spun off Calcarea with fellow co-founder, USC professor and biogeochemist Will Berelson.

"A big aspect of my work is on environmental justice," says Gutierrez, who conducted research in Adkins' s lab throughout her undergraduate years at Caltech. "We want to make sure that Calcarea is building relationships with local communities—like the people who live near the ports where we are setting up our prototypes—and environmental policy groups to ensure their involvement and buy-in with what we're doing."



Caltech graduate student **Éowyn Lucas** (MS '19), a member of the Captura team, develops materials that capture carbon dioxide directly from ocean water.

The team designed a chemical reactor that could bubble the exhaust gas from cargo ships into a tank full of limestone and flowing seawater, scrubbing the carbon dioxide from the ship's emissions and producing saltwater in its place. Calcarea's technology should be able to scrub up to 75 percent of carbon dioxide from a given cargo ship's emissions.

"During COVID, working alone in the back of my garage, I got into my own head asking what's the most important thing that I could work on right now," Adkins recalls. "Don't get me wrong—questions about glacial cycles and corals and the sulfur cycle still get me out of bed in the morning. But none of them are as important as sequestering carbon dioxide at scale. We're either going to try to solve the problem or we're not."

An ELECTROCHEMICAL Equation

As an electrochemist, Captura's Harry Atwater is approaching the problem of carbon capture from a different angle. The company uses an electrochemical process to filter seawater and remove carbon dioxide gas. Though the Captura lab benches are far from the ocean, crystalline salt patterns left by seawater from experiments can be seen all over the company's workspace in Pasadena,

The start-up environment, says Melissa Gutierrez (BS '19), requires creativity, flexibility, and a lot of teamwork. "We have a dynamic where you're allowed to not know all the answers—and then we figure them out together."

leaving a physical reminder of the company's eventual goal: to deploy its technology at sea.

When carbon dioxide is absorbed into the ocean, it undergoes chemical reactions with water to change from a dissolved gas into ionic salts, a process that occurs due to seawater's pH level of 8.1. Once this transformation happens, it becomes harder to remove carbon from the water. It is much easier to pull out its gaseous form.

The basis of the Captura system is to transform the carbon in seawater, which is in the form of salts, back into carbon dioxide gas and then sequester the gas. This is done by temporarily lowering the pH of a given volume of seawater. The seawater's pH is dropped from 8.1 to 4, which forces carbon to take the form of carbon dioxide. The gas is then stripped out of the water, and the team restores the pH back to a slightly more basic level of 8.2 before releasing the water back into the ocean.

Modulating pH is a critical component of the Captura system, and it hinges upon a bipolar membrane, which is a technology that splits seawater (H_2O) into acidifying protons (H+) and "base-ifying" hydroxyls (OH-). Chengxiang "CX" Xiang, a research professor at Caltech and Atwater's longtime collaborator, had studied how to develop bipolar membranes for decades. He and Atwater founded Captura in 2021, each putting their own money into the project on the belief that it would work. So far, their investment has paid off. With Xiang as chief technology officer and Atwater as chief science officer, Captura recently closed a $12 million Series A financing round, coming on the heels of a $1 million award in 2022 from the XPRIZE Carbon Removal competition.

Further development of the bipolar membrane was tasked to graduate student Éowyn Lucas. While working on her PhD, Lucas created a bipolar membrane that is more efficient and powerful than any other currently in development. She will join the Captura team full time after her graduation from Caltech later this year.

"I was able to create these membranes in the lab, and now I get to work on scaling them up and implementing them to solve a really important, real-world problem," she says. "I considered other possible routes after my PhD, but I just had to see this work through. I'm excited but nervous—I've never not been in school."

Fact:

Carbon dioxide gas extracted from the oceans can be safely pumped deep into the earth, where it is stored and does not contribute to global warming.

The major cost of scaling such a technology is the input of energy to run the process. Captura's plan is to install its systems at desalinization plants to share their energy infrastructure and, once the company grows in capacity, build standalone Captura platforms. Currently, a small prototype is operating at Caltech's Kerckhoff Marine Laboratory in Newport Beach, where it removes 1 ton of carbon dioxide from seawater per year. The team is currently building a kiloton system that will be the size of a 40-foot container, with the aim of constructing a system that can sequester 1 million tons of carbon dioxide each year.

"Leaders of industry have recognized that in order to maintain their customer base, they need to commit to total decarbonization of their operations in the coming decades. That is a really transformative change."

-Harry Atwater, Captura co-founder

Both Captura and Calcarea are performing quality control on their technologies and trying to determine all the ways things could go wrong as they scale up their prototypes. In addition to the technological challenges, the ocean is a complex, interconnected biogeochemical ecosystem, and many scientists have been wary of manipulating the environment with the targeted objective of offsetting the effects of climate change out of concern for its potential unforeseen side effects. Open questions for the two teams are how their systems scale up from the lab bench to the ocean, and how the ocean surface ecosystem might be perturbed by the byproducts of the Calcarea and Captura systems.

Adkins believes the potential good far outweighs the bad, however. "We're *already* perturbing the planet by dumping carbon emissions into the biosphere, and we're seeing the effects of that right now," he says. "Accelerated limestone weathering is simply mimicking what the environment already does to balance its carbon budget."

The GREEN Economy

For entrepreneurs trying to save the planet, there are billions of dollars in government funding for projects such as these, and industry is also recognizing the importance of fighting climate change. The Inflation Reduction Act passed by the federal government in 2022 allocates $370 billion for myriad sustainability-related projects, such as decarbonizing public transit, making manufacturing cleaner, and funding climate justice projects for underserved communities.

"Carbon removal is a technology that involves significant deployment of capital and energy at scale," Atwater says. "In 30 or 40 years, a huge amount of infrastructure in the world is going to be devoted to removing carbon dioxide. Governments have been leading the way on policy but, lately, leaders of industry have recognized that in order to maintain their customer base, they need to commit to total decarbonization of their operations in the coming decades. That is a really transformative change."

Many private companies acknowledge the need to combat climate change through carbon removal and curbing their own emissions. For example, Microsoft has pledged to sequester the same amount of carbon as it has emitted since its founding in 1975. With these ambitious goals, there is a need for partnerships between industrial polluters and carbon removal companies such as Captura and Calcarea.

Both the government and private sectors are funding and facilitating these partnerships, giving these early start-ups access to a revenue stream and path to profitability. Captura, for example, recently received a pledge of $500,000 from the private carbon market Frontier, which acts as a broker between Fortune 500 companies that are trying to decarbonize and the companies that will help them to do so. Simultaneously, the U.S. government has updated a former tax credit program called 45Q to provide direct payments to companies in exchange for each ton of carbon dioxide sequestered.

A major benefit of both Captura and Calcarea's proposed carbon capture solutions is that they are cost-effective. While the current leaders in atmospheric carbon capture can sequester carbon dioxide for about $1,000 per ton, Calcarea can do so for $76 per ton, while Captura aims to do so for $65 per ton.

"Ultimately, what we're trying to do only works when there's an economic balance sheet," Adkins says. "Environmental laws and government policies can really make a big difference in planetary health."

FRIENDLY Competition

In addition to the timeliness of the problem, the infusion of new funding sources is driving many researchers to enter the carbon capture business. There are now new efforts underway to grow kelp and algae, to shift ocean circulation, and to enhance the ocean's alkalinity. The Caltech teams say they welcome this competition and creativity.

"We need a diversity of tactics to take on the immense challenge that is climate change," Lucas says. "We're all trying to get grant money and attract the best scientists, but we're also all cheering each other on."

Adkins adds that the problem is too important not to have as many people working on it as possible. "My approach is informed by where I come from as a scientist studying oceanography and paleoclimates. Harry's comes from his electrochemistry background. There's a lot of carbon to sequester, so it's all hands on deck. Rain or shine."

Environmental laws and regulations have successfully reduced the emissions that created acid rain and depleted the ozone layer.

Jess Adkins is the Smits Family Professor of Geochemistry and Global Environmental Science. He serves as CEO of Calcarea.

Harry Atwater is the Otis Booth Leadership Chair of Caltech's Division of Engineering and Applied Science, Howard Hughes Professor of Applied Physics and Materials Science, and director of the Liquid Sunlight Alliance. Atwater is the co-founder of Captura and serves as chief science officer.

From left to right: Captura's **Cory Atwater, CX Xiang, Ibadillah Digdaya,** and **Harry Atwater** standing in front of the company's pilot system in Newport Beach.

OUT OF THIN AIR

How a Caltech PhD student and two Institute colleagues turned a carbon capture idea into a start-up that aims to help power plants clean up their toxic fumes.

By Omar Shamout

Climbing a single mountain is a monumental accomplishment. The founders of the carbon capture start-up C-Quester Inc. hope to scale six towering peaks—if only symbolically. The company's metaphorical mountaintops are its scale-up systems, which aim to capture carbon dioxide primarily from the smokestacks of power plants (and potentially from other large point-source emitters like fertilizer-, steel-, or cement-production plants), and to store it safely before it enters the atmosphere. That is why they have named each successive prototype phase after a significant peak. After working on phase A (Annapurna), they are in an advanced stage of phase B (Baldy), a prototype built in the lab that can remove 1 ton of carbon dioxide per year. Concurrently, they are building phase C, Centennial, at the company's new headquarters in a warehouse northeast of Los Angeles, which is designed to remove 100 tons of carbon dioxide per year. Next to come is Denali (1,000 tons), which would be directly connected and retrofitted to a power plant in central California. After that is Everest (100,000 tons) at a commercial demo plant, and Fuji (400,000 tons) at a commercial plant for large point-source emitters.

From left to right: C-Quester co-founders **Alan Gu** (MS, PhD '22), **Léopold Dobelle,** and **Clément Cid** (MS '14, PhD '18).

"We spotted a technology that we thought could work really well in the field," says Léopold Dobelle, one of C-Quester's founders, who is also a staff scientist in the lab of Michael Hoffmann, Caltech's John S. and Sherry Chen Professor of Environmental Science. "We are ready to scale it up; we're just looking for more funding."

C-Quester, founded last year by Dobelle and his colleagues Clément Cid (MS '14, PhD '18) and Alan Gu (MS, PhD '22), hopes its gas–solid chemical reactor systems will help slow climate change by neutralizing the carbon footprint caused by flue-gas emissions. But even if the founders manage to reach the top of Fuji in prototype, the problem would be far from fixed.

For some perspective on the enormous challenge of cutting carbon emissions, consider that about 40 million tons of carbon dioxide are already being captured from power and industrial facilities each year. But the International Energy Association estimates that number needs to increase 100 times over to meet the United Nations' energy-related sustainable development goals, meaning the world would need to sequester 4 billion tons annually.

And removing carbon is only the first challenge. "Carbon dioxide is a waste, so how do you handle the waste?" says Cid, the company's CEO, who received his PhD in environmental science and engineering. "We're working to help the client with a turnkey solution for capture, compression, transport, and storage."

Gu, C-Quester's chief technology officer, who received his PhD in chemical engineering, came up with the idea that became C-Quester in 2020 while working in Hoffmann's lab as a graduate student with Cid, the former lab manager, and Dobelle. "I thought maybe I could come up with a carbon-capture solution that is cheaper than all of the existing solutions," Gu says. "What came to mind was, why not use carbonate—bicarbonate chemistry, which has been known for a long time but not done for carbon capture?"

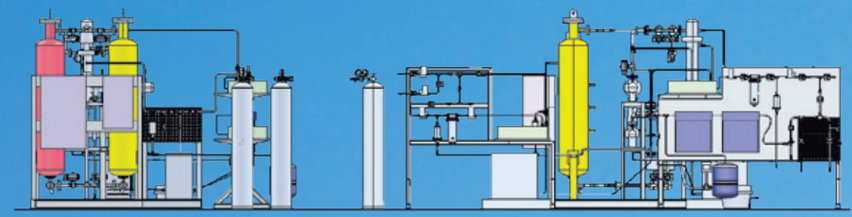
Gu won the 2022 Demetriades-Tsafka-Kokkalis Prize in entrepreneurship from Caltech for this research. The process, Cid explains, is similar to a natural form of carbon sequestration in oceans known as limestone weathering, in which compounds in calcium carbonate (found in shells on the ocean floor), seawater, and carbon dioxide break down and turn into dissolved bicarbonate ions. "What we are doing is making that breakdown happen in the gas phase and turning the bicarbonate into a solid," Cid says, noting C-Quester licenses the intellectual property from Caltech to perform the process commercially. "The real key in the invention is not the chemistry but driving the thermodynamics—forcing the reaction in one direction or the other while making sure to maximize the lifetime of the chemical sorbent."

Gu adds that, compared with other reactors, C-Quester's prototype uses a different type of material to absorb the carbon dioxide, an innovation that serves an economic function. "We have essentially a much larger surface area per volume, so the chemistry can happen in a much smaller reactor," he says. "That's another way for us to cut down the cost and have a patentable technology."

To build the initial protype, the C-Quester team obtained opportune funding in 2022 from two Caltech sources: the Resnick Sustainability Institute (RSI) and the SanPietro Global Warming Mid-Stage Innovation Fund, which supports decarbonization projects. Stephanie Yanchinski, the Resnick Institute's director of entrepreneurial programs, also helped C-Quester find initial partners to test its reactor, and the company is now collaborating with an industrial partner to scale up its capture system. Caltech also placed Luana Dos Santos, who was part of the Institute's WAVE Fellows research program for students interested in pursuing a PhD, with the team last summer. In addition to Hoffmann, the company is being advised by Melany Hunt, Caltech's Dotty and Dick Hayman Professor of Mechanical Engineering; and Julie Schoenfeld, Caltech's entrepreneur in residence focused on physical sciences, who provided feedback on their investor presentation and general messaging.

"Every time I meet with the C-Quester team, they have advanced the ball," Schoenfeld says. "They have educated themselves; they have taken the feedback, and they have learned from it. They've made substantial progress."

Schoenfeld adds that the market for green-tech firms such as C-Quester is enormous given the scale of the problem. "There are those who say that in order to really get to a meaningful amount of change in the amount of carbon in the air you need something like 100,000 start-ups," she explains. "There's an awful lot of money, and there is a tremendous need to solve the climate problem through innovation."



A schematic of C-Quester's phase C, or "Centennial," gas–solid chemical reactor.

RSI also helped facilitate the company's participation in the National Science Foundation's ZAP and BOOM entrepreneurship programs in 2022. In addition to providing an infusion of grant funding, the programs match company founders with mentors who teach them about customer discovery, how to craft a business plan, and more. C-Quester is now also part of NSF's national Innovation Corps (I-Corps) program, which has allowed Gu, Cid, and Dobelle to meet other start-up founders and a network of investors, alumni, mentors, and potential customers.

Gu says Caltech also provided many resources, including funding, to help him get the business off the ground while he was still a student.

"The Resnick Institute was very supportive in guiding me through what happens in this entrepreneurial world and in helping me gain the general knowledge that I didn't have," Gu says. "And having funding that you don't have to go through too many hoops to get is really helpful. Even though it doesn't seem like a lot of money, it can really change the world."

READY TO LAUNCH

Caltech students are using new programs, internships, and funding sources to turn their entrepreneurial dreams into reality.

BY ANDREW MOSEMAN

Eight Steps to Launching a Start-up While at Caltech

1. Come up with an idea.

When someone suffers a stroke, it is a race against time to save as much of their brain as possible. A patient's fate is based on how long it takes to transport them to the hospital, scan their brain, analyze the results, and, finally, provide a diagnosis and treatment. "During all this time, the brain is dying. The person's outcomes are directly proportional to how much time you can save in diagnosing and treating them," says Shane Shahrestani (MS '19, PhD '21), a student in the Caltech-USC MD/PhD program.

When he enrolled as a graduate student in medical engineering at Caltech, Shahrestani hoped to find a faster diagnostic solution for stroke patients. For his thesis, he developed a portable device that first responders could carry and use to discover blood-flow blockages in the brain, allowing them to begin treating a stroke before a patient gets to the hospital for a full MRI or CT scan. That idea turned into Pasadena-based start-up StrokeDx, co-founded by Shahrestani, where he continues to refine his invention while finishing medical school.

Shahrestani credits the culture of Caltech, and specifically the Andrew and Peggy Cherng Department of Medical Engineering, for helping him become a student entrepreneur. The department, he says, exposed him to an interdisciplinary group of researchers with expertise in developing medical devices, while its curriculum gave him the practical tools he needed to launch a start-up in the biomedical sphere.

"All the professors in the medical-engineering department have a lot of experience developing intellectual property," he says. "You're learning engineering, but you're also learning medicine, and you're learning the regulatory framework. You're learning what the FDA looks for in devices. You're learning how to get the right patents."

So You Want to Start a Business?

2. Talk to your principal investigator and OTTCP about how the idea could become a business.

As Shahrestani and StrokeDx demonstrate, student entrepreneurship is thriving at Caltech. And there are opportunities in this realm at both the undergraduate and graduate levels, says Julie Schoenfeld, one of the Institute's two entrepreneurs in residence (EIRs) at Caltech's Office of Technology Transfer and Corporate Partnerships (OTTCP). Schoenfeld represents the physical sciences, while Jay Chiang is the EIR in life sciences. "My job is to help people figure out how to take what they're doing in the lab to the next level and bring it out into the marketplace," Schoenfeld says.

OTTCP hosts an array of services and resources to support entrepreneurship at the Institute and to promote science and engineering knowledge created by Institute researchers, in part by developing partnerships with industry through the creation of new ventures. For example, the Caltech Seed Fund operated by OTTCP not only provides funding to help promising Caltech-affiliated start-ups get off the ground, but also connects business-minded undergraduates with internships at these new companies.

Meanwhile, the Institute's newly formed co-investment agreement with private venture capital fund Wilson Hill Ventures helps to launch new start-up companies that spring from labs on campus and at JPL, which Caltech manages for NASA. The Institute has a new innovation center near campus that provides space for nascent start-ups, like StrokeDx.

Case Cortese, OTTCP's director for innovation, new ventures, and entrepreneurship, says the office can answer a host of questions from nascent entrepreneurs. OTTCP, she adds, manages the intellectual property, handles the process of drafting and filing the patent, negotiates licenses with a start-up, and works with the EIRs to mentor the start-up teams. "If we have a student who is looking to start a company, we will listen to what their story is, what kind of help they are looking for, what they need," Cortese says. "And then we will source that help for them."

3. Work with OTTCP to protect the IP, primarily via patents.

Support may come from programs such as the Rothenberg Innovation Initiative (RI2), which provides support for Caltech's signature brand of high-risk, high-reward ideas. The Institute's new Initiative for Caltech Students will work to increase support for entrepreneurship as well. (See "Best in Class," page 28.)

Schoenfeld says Caltech can connect with students to deploy these services in three basic ways. The first avenue is through patentable ideas and other kinds of intellectual property submitted to OTTCP. When Schoenfeld is alerted to something promising by the licensing team, she reaches out to the creators directly. The second way is much simpler: "People just call in and they say, 'Look, I'd like to start a company. Can you help me out with this?'" Lastly, she proactively seeks out students who may have untapped ideas in market sectors in which abundant investment dollars are available, such as sustainability.

Making the Pitch

"Ever since I was an undergrad," says Andrew Singletary (PhD '22), co-founder of a new company called 3Laws Robotics, "my friends and I, including the now co-founder of the company, talked about doing a start-up, and we always had tons and tons of ideas."

Singletary worked on his graduate research on robotics safety systems in the lab of Aaron Ames, Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems. Singletary says he never thought the work he published during his graduate career could be the basis of a new company—until Schoenfeld approached him about the possibility. Then Singletary reached out to Thomas Gurriet (PhD '20). "It started off like, 'Hey, OTTCP has been reaching out to me. Why don't we talk to them and see if it's realistic and possible?'" Singletary says.

4. Outline a business plan and identify your competitors and market.

Once Singletary and Gurriet started to learn more, they raced to get 3Laws Robotics, which designs nonlinear control systems that ensure the safety of real-world robots, off the ground. With Singletary's graduation looming, Schoenfeld helped them pitch the idea to venture capitalists in the spring of 2022 and launch the company by summer, a breakneck pace for starting a new business.

Connecting with potential investors is an important part of the process for those trying to make the leap from student to entrepreneur. And, says StrokeDx's Shahrestani, that process is often also a lesson in the power of persistence. In Shahrestani's case, shortly after Schoenfeld showed him how to craft a compelling presentation to pitch his start-up, known as a pitch deck, the COVID-19 pandemic hit and led to an economic downturn that spooked many investors. "You don't realize how much goes into a start-up until you're actually doing it," he says. "My co-founder [Alexander Ballatori] and I probably did 300 or 400 pitches over the span of a year."

Though fifth-year graduate student Mackenzie Strehle is nearing the end of her PhD journey in the lab of Mitchell Guttman, professor of biology and biological engineering, the long trek to becoming a successful start-up founder is still mostly in front of her. Strehle got her first entrepreneurial experience in 2021 when she applied to OTTCP for an internship at Caltech start-up Tychon Technologies, headed by two Caltech faculty members: Mikhail Shapiro, professor of chemical engineering and medical engineering and a Howard Hughes Medical Institute Investigator; and Azita Emami, Andrew and Peggy Cherng Professor of Electrical Engineering and Medical Engineering and director of the Center for Sensing to Intelligence.

When she began to consider launching her own company one day, Strehle found inspiration and direction from the mentorship of Helen McBride, formerly Caltech's EIR for life sciences.

"Helen was really transformative for me in thinking about how I might actually make my own start-up and pursue this path later," Strehle says. "That led to me talking a little bit more with Mitch Guttman about potentially starting a company based on some of the work that we do in the lab."

That work focuses on small-molecule drug therapies that target RNA. Although most modern drugs target particular proteins, a vanishingly small percentage of the human genome actually encodes for proteins, Strehle notes. Techniques to target RNA instead would open up a host of new medicinal avenues.

"There's this unexplored and unmet need for designing therapeutics in this biological space that not a lot of people have really done right now," she says. "In our lab, we are really good at mapping where RNAs exist in the cell, and also how they behave and interact with other molecules. We can do this in a high-throughput sequencing-based method that distinguishes us from other labs. We're hoping we can leverage this technology to figure out how we can identify small molecules that might actually act on RNA."

5. Write a pitch deck with help from OTTCP to sell your idea.

Undergraduate **Brian Nguyen** (left) with entrepreneur-in-residence **Julie Schoenfeld**.

Learning the Ropes

Thanks in part to the hands-on education Caltech undergraduates receive, the Institute's culture of entrepreneurship is fostered among them much as it is with graduate students. Before she ever arrived on campus, Joy Shi, a third-year computer science undergraduate from Rockville, Maryland, had already launched a nonprofit called Integirls, which offers math competitions and problem-solving contests for high school girls and nonbinary students. Then, at Caltech, she got a crash course in what it takes to run a start-up.

After Shi's first year, she became a part of the Caltech Seed Fund's first class of interns and found herself working at a Caltech-affiliated start-up under the guidance of Maria Spiropulu, the Institute's Shang-Yi Ch'en Professor of Physics. Despite having nearly no previous background in quantum science, Shi became immersed in high-end research.

"I knew just a little bit from articles on it and watching YouTube videos," she says. "But as a freshman, I was immediately interacting with and working with people who are literally at the forefront of this field."

During the internship, Shi learned the ropes of project management while also reading up on leading-edge research in quantum networking and computing. She helped company leaders revamp a pitch deck as they sought additional investment for the start-up.

Brian Nguyen, a fourth-year undergraduate at Caltech studying electrical engineering, also got an early start in seeing the world from an entrepreneurial point of view. "In my first year, I wanted to understand how the medical system works, so I shadowed the neurosurgery team at NYU Langone Health," he says. "There, I saw how inefficient tools and processes limited a talented team from achieving its full potential. This experience sparked a desire to build tools to improve health care at scale."

Nguyen fulfilled that desire when, after his third year at Caltech, he landed a Seed Fund internship to work for StrokeDx. While Shahrestani and Ballatori came from a primarily medical background, Nguyen says his engineering-focused outlook led him to insights that helped bolster the company and its mission.

"Engineering is the science of creation," he says. "As an engineering student, you study math and physics to ensure you don't waste time building something that violates a fundamental law in the universe. In practice, once those rules are satisfied, you have to learn how to make trade-offs. You have to question your constraints and systematically test where your ideas fail. Now apply that framework to business. How do you use technology to eliminate the biggest risks to your company? At a start-up, you cannot afford to be slow and wrong. Over the summer, I created a lightweight data-logging module that monitors our sensor's performance. This allowed my team to rapidly test improvements to our device. Ultimately, this translates to building a better product in a fraction of the time and cost."

6. Pitch idea to potential investors, including Caltech funding sources.

7. Find a location for your start-up and do the legal paperwork to incorporate it.

Next Steps

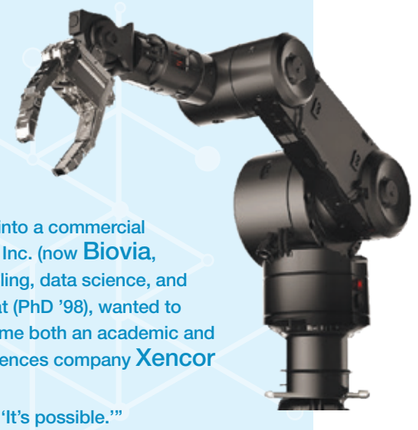
For Singletary, the launch of 3Laws Robotics was a triumph—but only the first of what he hopes will be many. He says that while he knew the technology was proven, in the first six months of the company's life he had to learn how to talk less and listen more—to hear what potential clients needed and then explain how 3Laws Robotics technologies could meet those needs. "The big idea with start-ups is that if you develop in a vacuum only what you think you need to develop, you're going to develop the wrong thing," Singletary says. "You have to develop alongside your customers."

The big leap for most students-turned-entrepreneurs is not the science and engineering but the art of running a business, says Schoenfeld. Strehle, a self-described "bread-and-butter academic," has begun to look far and wide for advice and wisdom about becoming a CEO, including seeking out members of the Caltech community who have previously made the jump. She also took advantage of the Institute's online Coursera courses. She took classes in such salient topics as start-up valuation methods and industrial biotechnology.

Shahrestani is now living twin lives, establishing StrokeDx while finishing medical school; he will graduate in 2023 and has plans to become a practicing neurosurgeon. "We're writing grants; we're pitching to people; we're writing new intellectual property; we're working with our engineering teams and building out these new devices," he says. "So far, it's been a lot of fun. It's super busy, but at the end of the day, this is exactly what I'm interested in, and I don't want to be doing anything else."

8. Launch your company.

Entrepreneurial Caltech Alumni Buoy Pasadena's Start-Up Scene



When Steve Mayo (PhD '87), now the Bren Professor of Biology and Chemistry and Merkin Institute Professor, joined the Caltech faculty in 1992, he already had experience in translating his laboratory research into a commercial company. While a student in the 1980s, he created Molecular Systems Inc. (now **Biovia**, which creates software products to aid researchers in molecular modeling, data science, and other fields). So, when one of his first graduate students, Bassil Dahiyat (PhD '98), wanted to create a start-up based on his work in protein engineering, Mayo became both an academic and entrepreneurial mentor. With Mayo's help, Dahiyat launched the life sciences company **Xencor** and became its president and CEO.

"It was very daunting," Dahiyat says. "What Steve did is just to say, 'It's possible.'"

A quarter-century later, Xencor is one of the anchors of what has become an innovation ecosystem in Pasadena, developing therapeutic antibody and cytokine treatments for cancers and autoimmune disorders. The advantages of living in Southern California have always helped Dahiyat attract people with life sciences expertise to the area. And now that Xencor is one of several established biotech firms in town, the positive effects of being part of an innovative community have begun to snowball.

While Silicon Valley is known for innovations in software and computing and "Silicon Beach" on the west side of Los Angeles focuses on digital content and film, the ecosystem centered around Pasadena has become a hub for start-ups in what Andy Wilson, executive director of the Alliance for SoCal Innovation, calls "frontier technologies." These include solar energy, telescopes, batteries, and artificial intelligence.

After Michael Amori (MS '07) completed his master's degree, the sunshine and quality of life kept him in town. "Honestly, I just loved Caltech, and I also just loved the climate in Pasadena," he says. "I thought it was a great place to raise a family." His closeness to campus also provided the spark for **Virtualitics**, an AI-driven data visualization start-up headquartered on Lake Avenue that he co-founded with Ciro Donalek, a computational staff scientist at Caltech's Center for Data-Driven Discovery (CD3). The two met through George Djorgovski, professor of astronomy and data science and director of the CD3, whom Amori met at a Caltech alumni event.

The minds behind **Miso Robotics**, a start-up with a host of Caltech connections, design and test the company's robotic fry cooks and other kitchen-based robots in the heart of Pasadena. When co-founder and chief research officer Ryan Sinnet (BS '07) helped start Miso in 2016 along with partners including the company's vice president of hardware engineering Rob Anderson (BS '16), the founders chose Pasadena due to its proximity to the robotics research at Caltech, which has its locus in the Center for Autonomous Systems and Technologies. The firm has also teamed up with **3Laws Robotics**, co-founded by Andrew Singletary (PhD '22), to safely manage and optimize the motion of its cooking robots. Today, Miso routinely hires new employees and interns from the Institute because of its robotics focus.

"What does it take to build a start-up in a new space or even just a competitive business? I think it takes the best people and the right people who have to have a certain skill set," Sinnet says. "And Silicon Valley being kind of saturated, a lot of people are interested in these opportunities here."

BEST IN CLASS

BY JULIA EHLERT

From left to right: Caltech students **Cristian Ponce, Chi Cap, Xinhong Chen, Jieyu Zheng,** and **Aditee Prabhutendolkar.**

Caltech's initiative FOR STUDENTS

What does it take for the most ambitious and innovative young minds to push the limits of possibility? **Curiosity. Perseverance. Ingenuity.** And an unparalleled student experience.

The Institute's newly launched Initiative for Caltech Students fundraising campaign will raise $250 million toward five critical priorities that will allow Caltech to continue to provide a richly diverse, immersive, and inclusive student experience. With support from philanthropic partners—alumni, parents, trustees, foundations, corporations, and community members—Caltech can ensure that students maintain access to a robust research, education, and co-curricular ecosystem that is close-knit, collaborative, and has made the Institute a destination of choice for the future leaders in science, technology, and society for decades.

"My wish is that students will think of Caltech as the place where they can fulfill their dreams. The place where they discover passions they can explore and develop throughout their lifetimes," says Caltech president Thomas F. Rosenbaum, holder of the Sonja and William Davidow Presidential Chair and professor of physics. "We help our students become well-rounded human beings to contribute significantly to their chosen careers and to society: critical thinkers and problem solvers who rely on their training in science, engineering, the humanities, and social sciences, and leverage their appreciation of the arts, theater, sports, and community service. The Initiative for Caltech Students is going to support and enhance those opportunities, for the students of today and for those to come."

What the Initiative Supports

One of the most critical functions of this campaign is to enable innovative and driven STEM students from around the world to access a world-class Caltech education, no matter their financial circumstances. **Undergraduate scholarships** have always allowed the most qualified, hard-working students to attend Caltech and devote themselves to learning. More than half of Caltech undergraduates receive need-based financial assistance. To make Caltech more accessible to all who are accepted and wish to attend, the initiative aspires to raise enough funding—through additional scholarships and other means—to ***reduce or eliminate the need for student loans.***

"When I was in high school, there was always a question of, 'Even if I do get into college, will I be able to afford it?' Learning about the QuestBridge Scholarship was such an eye-opening discovery because I realized if I worked hard, I would be able to go to Caltech and not have to worry about money. It was a huge stress relief for myself and my family. Thanks to my scholarship, I get to do really cool science, really cool research, and meet all these amazing people. I'm extremely grateful for this opportunity because if this didn't exist, I would not be in college."

—*Chi Cap, second-year undergraduate student, 2022–23 Robert Gardner Family Scholar, and QuestBridge Scholar. The QuestBridge National College Match program connects low-income, high-achieving students with partner schools like Caltech, which agree to provide full scholarships, including expenses, for matched students.*

Graduate fellowships enable Caltech to attract and retain the most talented students from across the world. The campaign aims to further Caltech's goal to ***provide an endowed fellowship for every graduate student during their first two years.*** Such support would allow students the academic agility to explore a variety of intellectual interests before selecting an area of concentration for their doctoral research. Because these fellowships would not tether graduate students to advisors, laboratories, or federal grants, students will be free to partner with the research groups of their choice and, if desired, create interdisciplinary problem-solving collaborations to pursue.

"As scientists, we're basically kids playing in the sandbox at the frontier of human knowledge. Caltech gives us the freedom and trust to explore new ideas and enrich ourselves as people in every aspect of our lives. That is really what chasing passion means—finding new inspiration and continuing to refuel your interests. For me, that's what the Caltech experience means."

—*Ben Thyer, graduate student*

Career advising services provide the tools to transform a student's educational experiences and interests into a successful career pathway—whether in academia, industry, or public service. The Initiative for Caltech Students will ***bolster the Career Advising and Experiential Learning (CAEL) program,*** which gives students equitable access to resources, training, and connections, including access to the Institute's worldwide network of 25,000 alumni, so they can achieve their career aspirations.

"Caltech's network is beyond impressive, and it's really impacted my experience. It's amazing how open so many people are to mentor or help others around them."

—*Cristian Ponce, second-year undergraduate student*

The co-curricular experiences students have at Caltech, through their residential houses, their participation in athletics or the more than 100 student-led campus clubs, and through organizations like the Caltech Center for Inclusion and Diversity, help students find balance and belonging in the Institute's rigorous academic environment. The Initiative's goal is to ***enrich these co-curricular programs, services, and organizations*** that foster community and enable personal fulfillment.

"Most international students don't get to go home or see our families for a long time. It can be very challenging and isolating. But having an organization like the Caltech C [the Caltech Chinese Association] provides a sense of community, a place to share our culture, and a feeling of home here at Caltech."

—*Xinhong Chen, graduate student and former president of the Caltech C*

The **health and wellness resources** that Caltech Student Wellness Services (SWS) provides help students find balance, manage stress, learn time management, and build connections throughout the Institute community. SWS also trains students to be peer health advocates and has developed strategic partnerships with the Office of Residential Experience, the Caltech Center for Inclusion and Diversity, International Student Programs, and the CARE Team to provide more robust programs that are integrated into students' everyday lives. ***Enhancing these resources*** will ensure that students get the most out of their Caltech experience.

"The student advocate roles are so important at Caltech. It can be intimidating for a student to talk to a stranger about something deeply personal, like a Title IX issue or mental health struggles. They feel better about going to someone they know and trust first. And then we can help them feel comfortable seeking help at a higher level when it's necessary and support them in connecting with those resources."

—*Aditee Prabhutendolkar, third-year undergraduate student, peer advocate, health advocate, Title IX representative, and Blacker House president*

"My first year at Caltech was all online—I was working from home and didn't know anyone. It was really tough. But when I was able to come to campus, participate in the swim team, and live in Page House, it had such a tremendous impact. I got to see people again; I was working better; I was learning more. This part of the community, it really helps your academic life. It means a lot."

—*Rahul Chawlani, third-year undergraduate student, 2022–23 Robert and Phyllis Henigson Scholar, and Page House social director*

"Being in a house and in the Black Students Union, it gives me a sense of belonging, and even more so, a sense of home. With the house system, you belong to a little home. With an identity-affiliated group like the Black Students Union, you get a little home as well. That's the biggest thing these spaces have provided me with—I don't feel like I'm some 'admitted student number 101'; I'm Ramona in Blacker House or Ramona from the BSU."

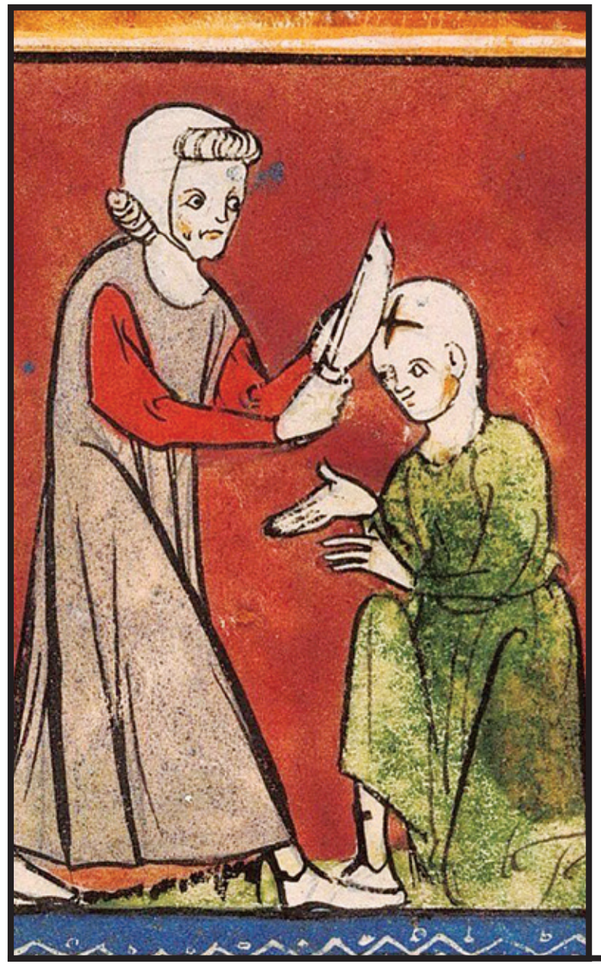
—*Ramona Murugu, second-year undergraduate student and co-founder of the Black Students Union*

"Through the Caltech Women in Biology and Biological Engineering (WiBBE) club, I was connected with a really great mentor [Sisi Chen]—she is the most amazing person I've ever met. She taught me that when you feel burned out, the best way to get out of it is to contribute to the community. Giving back is the best way to enrich yourself. I really took that advice to heart, and now I'm incorporating more opportunities to give back to the community into my daily life."

—*Jieyu Zheng, graduate student*

Paying the Blood Price

How ordinary life in the early Middle Ages was a lot like The Godfather.



By Emily Velasco

If a hypothetical 30th-century historian wanted to learn about your 21st-century life, they would have a harder time than they would trying to learn about Ronald Reagan or Pope Francis, but that does not mean they would be totally out of luck. Even an average person leaves behind quite a paper trail.

This is exactly how Caltech's Warren Brown, professor of history, learns about the lives of ordinary people in early medieval Europe—that period between the fall of Rome and the year 1000 that is often (though not quite accurately) called the Dark Ages. In his new book, *Beyond the Monastery Walls: Lay Men and Women in Early Medieval Legal Formularies*, Brown pieces together the contours of those people's lives through the legal documents they left behind.

Among other things, the documents show that violence was a much more regular feature of their lives than it is for us. "We live today in a society where the state has a monopoly on the use of force," he says. "If I were to come over and punch you, that would be illegal. But at a time and place when the state is much weaker than it is now, people had a fundamental right to use force on their own behalf to take vengeance or to defend themselves."

Though violent acts could be expected, they were not unregulated. A person could only kill or harm another for what the community thought was just cause. Violence had to take place within a legal framework, and there was always a cost.

"If you killed somebody, you would have to pay for them. It's called the blood price," Brown says. "If I killed your brother, I may have thought I had a good reason, but you and your family are very angry with me, and you're going to come after me unless I agree to pay you a certain amount of money to settle the debt. These amounts of money are specified in law. So, I'll pay you the money, and you'll write me a receipt that says you got it and that I'm free from any trouble about the matter. We only know about these receipts because they show up in the formularies."

Brown also says patronage and nepotism were not just rampant, but an acceptable and necessary means for those without power to gain access to those who did. If you were a peasant with a problem that needed solving, you might appeal directly to your king, whether by getting someone to send a letter for you or by walking 60 miles to make your request in person at the king's court. More often, however, you would appeal to your local lord, bishop, or abbot, who might have a relative who knew someone at court who could get the king's ear.

"If you knew or were related to somebody who had power, or you knew somebody who was related to somebody who had power, you went to that person and you begged and pleaded, and that person would intervene on your behalf. It's how you get things done," Brown says. "And it happened at all levels of society. I've got a whole collection of letters written by a local lord in the 820s, where you can see him writing the most prosaic letters like, 'So and so came to me and said he really would like to buy your pigs. Would you be willing to sell him your pigs?' People were appealing up the chutes and ladders of power in a way that we today, I think, would look on with suspicion."

If this sounds a bit like a mafia movie, with people asking favors of the don and others engaging in violent acts to settle their differences, you're not far off.

"It's a little caricatured, but you can get pretty close to understanding the early Middle Ages by watching *The Godfather*," Brown says. "The mafia also channels power along the lines of kinship, patronage, and protection, and it has rules regulating violence among its members. The difference is that it operates outside of the dominant system of law and order—and preys on it for profit. In early medieval Europe, it's just simply how things worked."

Moon Gazing

NASA's Lunar Trailblazer mission marks a new chapter in Caltech's enduring exploration of Earth's closest celestial companion.

By Ker Than

One of the most incredible discoveries about the Moon in recent times was made when no one was expecting it. In 2009, NASA's Moon Mineralogy Mapper (M^3) instrument on India's Chandrayaan-1 mission was mapping the composition of geological features on the lunar surface when it detected something surprising: reflected light from the near-polar regions of the Moon, carrying a possible spectral signature of water.

The water signal M^3 observed was present even in lunar regions exposed to sunlight, where temperatures can climb well above boiling. The improbable discovery—confirmed by two other spacecraft, Cassini and Deep Impact—challenged the prevailing wisdom of the time that the Moon was a mostly dry, dusty, and rocky world. Instead, it suggested water (H_2O) or hydroxide (OH-) could be continuously forming and sublimating on the lunar surface through a geochemical reaction with the solar wind. It pointed to a possible water cycle on airless bodies, building upon an earlier 2008 discovery by NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) of water ice in permanently shadowed regions of the Moon.

In the years since, the debate over how water ice got to the Moon has focused on two possibilities: one scenario involves comets and "wet asteroids" crashing into the Moon, while the other entails ancient volcanic eruptions disgorging water vapor from the Moon's interior and depositing frost on its surface.

Scientists will soon have another chance to investigate the mystery of the Moon's water thanks to NASA's Lunar Trailblazer spacecraft, which is scheduled to begin operation later this year. Bethany Ehlmann, professor of planetary science at Caltech, serves as principal investigator of the mission, which is managed by the Jet Propulsion Laboratory (JPL).

Lunar Trailblazer is one of five missions of NASA's Small Innovative Missions for Planetary Exploration (SIMPLEx) program, which holds competitions to select high-risk, low-budget small spacecraft to perform focused explorations of other planets, moons, and asteroids. Its task will be to understand the form, abundance, and distribution of water on the Moon, as well as the lunar water cycle. Lunar Trailblazer could also aid future human exploration of the solar system by identifying "operationally useful" deposits of water on the Moon. The diminutive spacecraft—weighing about 450 pounds and measuring only 11.5 feet wide with its solar panels fully deployed—will launch as a "rideshare," or secondary payload, on the lunar lander mission IM-2 by Intuitive Machines in late 2023.

"Lunar Trailblazer is among the first of a new class of small satellites that will do important planetary science at a much lower price point with a high science value per dollar," says Ehlmann, who is also associate director of Caltech's Keck Institute for Space Studies.

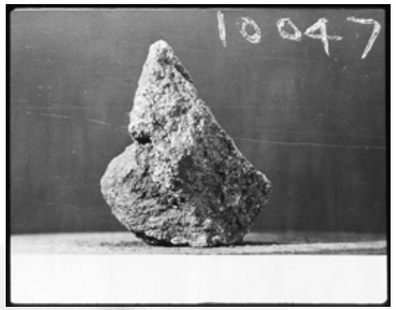
*Left:
Bethany Ehlmann

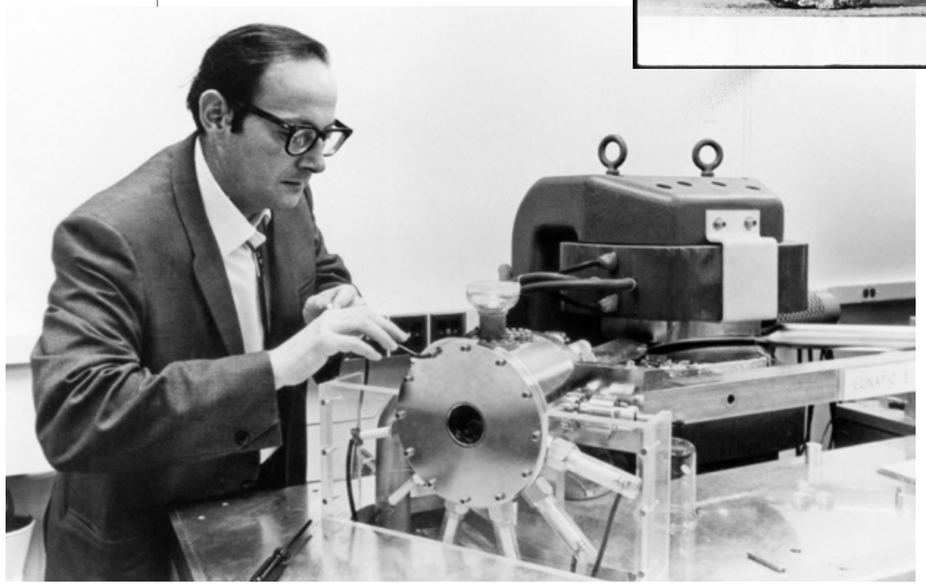
Lunar Trailblazer will carry two instruments: the High-resolution Volatiles and Minerals Moon Mapper (HVM^3), built by JPL, and the Lunar Thermal Mapper (LTM), built by the University of Oxford and contributed by the UK Space Agency. When used in conjunction, the instruments will provide scientists with five key pieces of information about the Moon's water: in addition to its form, distribution, and quantity, they will measure temperature and examine the mineralogical composition of the lunar rocks and regolith (loose deposits of dust and other materials). Lunar Trailblazer will map just 2 percent of the Moon's surface during its primary mission, but what it lacks in total coverage it will make up for in the quality of its data.

"Ours will be the highest spatial resolution mapping dataset to date for the lunar surface's water content, temperature, and composition," Ehlmann says. "Missions that have gone before us have produced global or near-global maps of the Moon, so we know where the most interesting spots are, and Lunar Trailblazer is following up and targeting them at many factors higher resolution."

The HVM^3 instrument that will fly aboard Lunar Trailblazer resembles an instrument flown aboard the Mars Reconnaissance Orbiter called the Compact Reconnaissance Imaging Spectrometer for Mars, or CRISM, which Ehlmann used as a graduate student to map the surface of Mars and which also influenced the design of the M^3 instrument that first found water on the Moon's sunlit surface. "Lunar Trailblazer is a mission where we're using some of the same instrumental techniques that I 'grew up' with scientifically on Mars," Ehlmann says.

HVM^3 was also influenced by previous attempts to miniaturize spectrometers for inclusion on Mars rovers, which are much more mass-constrained than orbiters. "We were not successful in getting picked to be put onboard Mars 2020, but that instrument development is what made us confident that we could do the orbiting imaging spectrometer at the right power and mass and size for Lunar Trailblazer," Ehlmann says. "Not only is our instrument smaller, it also has higher capability than its predecessors at the Moon. We managed to miniaturize it while making it better." If Lunar Trailblazer succeeds, it could make it more likely that some version of its miniaturized spectrometer could one day find its way to Mars, Ehlmann says, because "the spectrometers we once proposed for landed missions will now have flight experience. We'll be in a better position next time around when we suggest using this technique from the ground."





Left: **Gerald Wasserburg,** the late John D. MacArthur Professor of Geology and Geophysics, Emeritus, with the Lunatic I mass spectrometer in 1969. **Above:** A moon rock analyzed by the Lunatic I.

Lunar Trailblazer is also able to detect other icy volatiles, which are compounds that tend to vaporize easily, such as organics, carbon dioxide, ammonia, or hydrogen sulfide ice, which the Moon might have. The chemical makeup of these ices—whether they contain more sulfur or nitrogen, for example—could provide clues about the origin of the Moon's water via comets or volcanism. "My hope is that not only are we going to detect water, but that Trailblazer will also detect small amounts of these other ices," Ehlmann says. "That would be a bonus finding."

The benefits that flow from Lunar Trailblazer could extend even beyond the Moon. "I suspect we'll learn quite a bit about ice spectroscopic signatures, which will benefit the study of Mars but also contribute to the understanding of water cycles on other airless bodies in our solar system such as Mercury and asteroids," Ehlmann says. "Lunar Trailblazer will really demonstrate the power of small satellites to answer important questions in planetary science."

A Storied History

Lunar Trailblazer is just the latest in a long, rich history of lunar missions involving Caltech and JPL, which Caltech manages for NASA. The Surveyor and Ranger missions in the 1960s that helped NASA gather data about the Moon in preparation for the manned Apollo missions were managed by JPL. Caltech geologists and geophysicists, among the first to analyze material hauled back from the Moon, helped train Apollo astronauts; more on that below. The first scientist-astronaut to walk on the Moon—and one of the last people to step off it—was Caltech graduate and Apollo 17 crew member Harrison "Jack" Schmitt (BS '57). And former Caltech postdoc Jessica Watkins is a member of Artemis, a team of 18 astronauts who will help pave the way for NASA's next lunar missions, which will include sending humans back to the Moon.

Caltech scientists have also been integral to investigating many fundamental questions about the Moon, including its origins, age, history, and evolution, in addition to the presence and quantity of water. In 1961, Caltech scientists proposed the existence of cold traps—shadowy patches that captured and protected water deposited on the lunar surface. It would be almost 40 years before NASA's Lunar Prospector spacecraft confirmed their hypothesis. Through the 1960s and '70s, Caltech geochemists made many of the first scientific discoveries to come from the Apollo program, including the first precise understanding of the ages and histories of the rocks on the lunar surface. Caltech's David Stevenson helped fill in crucial details in the late 1980s about how the Moon might have been born from a cataclysmic impact between Earth and a Mars-sized object.

Above: Former Caltech postdoc **Jessica Watkins** is a member of NASA's Artemis mission team, which will usher in a new era of lunar research.

"What we and other people realized is that in order to get into a situation where you could make the Moon, you needed a large impact," says Stevenson, the Marvin L. Goldberger Professor of Planetary Science, Emeritus. It is thought that an ancient collision created an orbiting debris disk around Earth that coalesced into the Moon. "We argued at the time that the formation of the Moon after a giant impact was determined by the rate at which energy is lost from the Earth-Moon system by radiation. And that's something on the order of hundreds to a thousand years. So, we're talking about a very fast process."

Ehlmann says she is excited to participate in and extend Caltech's long arc of lunar exploration. "Caltech is one of those institutions that was there from the beginning, and I'm very happy to continue that tradition of discovery of the Moon and also pave the way for the next generation of explorers," she says.

'Just put them in the bag!'

Like millions of others at the time, Dimitri Papanastassiou (BS '65, PhD '70) watched in rapt attention as the Apollo astronauts traipsed, skipped, and trundled across the gray lunar surface. He paid particularly close attention when astronauts on the later Apollo missions picked up samples from the Moon. "I kept thinking, don't keep

looking at the samples. Just put them in the bag!" Papanastassiou says.

His vested interest stemmed from the knowledge (and hope) that some of the lunar samples collected by the Apollo astronauts would wind up at Caltech for study. "They were spending too much time discussing what they were seeing and debating whether to take this rock or the other one," Papanastassiou says. "Pick up both!" he says he wanted to tell them. "You have the capability; you don't have to decide!"

By the time Neil Armstrong made his famous small step on the Moon in the summer of 1969, Papanastassiou had already been a graduate student at Caltech for several years. Most of that time he spent working feverishly with Gerald Wasserburg, the late John D. MacArthur Professor of Geology and Geophysics, Emeritus, to construct a high-precision mass spectrometer designed specifically for interrogating Moon samples. The instrument, which separates ionized atoms according to their mass, was dubbed Lunatic I.

Wasserburg and five other Caltech faculty members—geologist Leon Silver (PhD '55), geochemist Samuel Epstein, geologist and planetary scientist Arden Albee, geologist Hugh Taylor Jr. (BS '54, PhD '59), and Donald Burnett, Caltech professor of nuclear geochemistry, emeritus—were among the 100 or so scientists selected by NASA to analyze the Apollo astronauts' lunar haul. Geochemist Clair Patterson also played a crucial role in developing the clean-room technologies that allowed Caltech scientists to extract and process trace amounts of materials from the lunar samples without fear of contamination.

Lunatic I was the first fully digital instrument of its kind, and its precision was 30 times better than any that came before. Lunatic I—now held in the collections of the National Museum of American History—was a decisive factor in NASA's decision to entrust Moon samples to Caltech for study, according to Burnett. "We were fully expecting that we would be approved to do this because we knew we had the best ways of doing it. We had been planning since 1966 on. We were ready, and it was all based on the Lunatic I mass spectrometer," he says.

But the Caltech scientists' confidence was tempered by the knowledge that all the preparation in the world would not matter if the lunar samples failed to make it to Earth in good condition. "If we were delivered a sample, we could do all this analysis on it," Burnett says. "But whether the samples got back safely and were not ruined in the process of reentry and recovery—that was far from obvious. We were terrified."

Fortunately, the Apollo astronauts delivered, ultimately carting home more than 800 pounds of lunar rocks and soil. With Lunatic I's unrivaled precision, Wasserburg and his colleagues determined that the igneous samples returned by the Apollo missions defined an extended range of volcanic activity between 3 billion to 3.9 billion years ago. Lunatic I also played a key role in discovering the first evidence of the "late heavy bombardment," a period roughly 4 billion years ago when the bodies of the inner solar system were pummeled by asteroids and comets.

> "Lunar Trailblazer will really demonstrate the power of small satellites to answer important questions in planetary science."
>
> –Bethany Ehlmann
>
> Lunar Trailblazer mission principal investigator

"The Apollo program started off for political reasons. It was not done for science. It was done to show that we could beat the Soviets," Burnett says. "But what's left standing now is the science that has come out of the lunar samples. That is the true legacy of the Apollo missions."

The Caltech scientists contributed to the Apollo program in other ways too. Wasserburg belonged to a select cadre of senior scientists known as the "Four Horsemen" who advised NASA throughout the Apollo missions. Silver, the late W. M. Keck Foundation Professor for Resource Geology, Emeritus, instructed the crews of the Apollo 13, 15, 16, and 17 missions in geology. Silver often took his astronaut students to the Orocopia Mountains in the desert southeast of Indio, California, where he would teach them how to assess, analyze, and record their surroundings like a geologist.

Caltech faculty were crucial to the success of the Apollo program, says Asif Siddiqi, a space historian at Fordham University and a former Eleanor Searle Visiting Professor of History at Caltech and The Huntington Library, Art Museum, and Botanical Gardens. "You can't really tell the story of Apollo without them," he says.

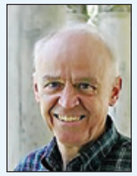
With Lunar Trailblazer, Siddiqi adds, Caltech is once again at the forefront of lunar research. "Caltech has already staked its claim on the history of lunar science. Lunar Trailblazer has the potential to really add fundamentally to our knowledge of the Moon," he says. "It's one of the most exciting missions to the Moon that I can think of right now."

They Put an "M" on the Moon

NASA scientists capitalize "Moon" and "Sun" when referring to Earth's Moon and Sun but not when referring to other such objects.

In Memoriam

Read more about their lives at **magazine.caltech.edu/post/in-memoriam**



Marc-Aurele Nicolet (1929–2022)

Marc-Aurele Nicolet, professor of electrical engineering and applied physics, emeritus, passed away on December 6, 2022, at age 93. His research focused on solid-state device technology and thin-film processes. Specifically, he studied the reactions of thin films with semiconductors (as well as ways to suppress these reactions) and analyzed thin-film materials using backscattering spectrometry and X-ray rocking curves—a way of analyzing single-crystal films. Nicolet became an associate professor in 1965, and he earned tenure in 1973. He retired in 1998.

Jason B. Saleeby (1948–2023)

Jason B. Saleeby, professor of geology, emeritus, passed away on January 16, 2023, at age 74. Saleeby, who worked at Caltech for 37 years, performed tectonic and geochronological studies of orogenic terranes of western North America, emphasizing the paleogeographic development of the Pacific Basin and its margins—specifically, the North American Cordillera, the mountain chain system that stretches along the Pacific Coast. A champion of getting into the field, he combined his hands-on approach to geology with lab-based expertise in geophysics, petrology, geochronology, and thermochronology to provide analysis from the continental scale down to the microscale.

Nelson Rising (1941–2023)

Nelson Rising, chairman emeritus of Rising Realty Partners, former member of the Caltech Board of Trustees, and life member of the Caltech community, passed away on February 9, 2023, at age 81. He shaped the landscape of Los Angeles and San Francisco, among other California cities, and played an influential role in state politics. Named to the Board in 2006, Rising became a senior trustee in 2013. He chaired the Buildings and Grounds Committee and was a member of the Executive and Investment committees. Rising founded Rising Realty Partners, an environmentally conscious real estate investment and operating company, with his son and current CEO, Christopher Rising, and partner, Scott McMullin.

Richard M. Rosenberg (1930–2023)

Richard M. Rosenberg, retired chairman and CEO of Bank of America, member of the Caltech Board of Trustees, and life member of the Caltech community, passed away on March 3, 2023, at age 92. Rosenberg was first appointed to the Board in 1989. During his tenure as chairman and CEO of Bank of America, Rosenberg strengthened the firm's retail franchise and corporate operations. The company became the second-largest bank in the United States, achieving record earnings, stock price, and dividend levels, and establishing itself as a leader in community reinvestment programs. He retired in 1996.

Gaylord E. "Nick" Nichols (1932-2023)

Nick Nichols, an administrator and honorary alumnus who worked at Caltech for 53 years, passed away on January 14, 2023, at age 90. Nichols joined JPL in 1957. He worked on projects including the Ranger, Mariner, and Surveyor unmanned missions and served as manager of planning and business operations for energy and technology applications, manager of external affairs, and special assistant to the director. In 1983, Nichols was appointed director of the IRC, which offered executive education courses and management training for business leaders in the technology and science sectors. Soon after, Nichols founded the Caltech/MIT Enterprise Forum, renamed the Caltech Entrepreneurs Forum in 2013.

Endnotes

In this issue, we talk with Caltech students who are exploring entrepreneurship through new programs, internships, and funding sources.

What would 20-year-old you have created if given the opportunity?

I certainly would have done a start-up. As a student, I learned about entrepreneurship through the Caltech Entrepreneurship Club but never had a chance to try it for myself. Warren Buffett came to campus in late 1997 when I was a senior. He spoke at Beckman Auditorium and, as the president of the E Club, I had the opportunity to meet him and have dinner with him prior to the event. This event was one of the most unique experiences I enjoyed as part of the E Club. A program where you could start up a business with fellow students would have been a great way to explore entrepreneurship as a 20-year-old.

Michael Michrowski (BS ’98)
LOS ANGELES, CA

I would have written my first musical or opera 20-plus years before starting to write both in my 40s, with a paid and mentored path toward workshopping both in L.A. Of course, had I seized that sort of opportunity in my 20s, that would have required realizing that I was supposed to be a musician far sooner than I actually did.

Cheryl Morganson (BS ’02)
CHAMPAIGN, IL

I blundered into that opportunity when I was 20. I was chosen to be the business manager of the *California Tech*. I had enjoyed writing for the *Tech*, but the immediate incentive of being business manager was earning commissions for selling advertising. I learned a lot about things like balancing books, meeting deadlines, and publishing. A few years later, I got a job at a laser-industry magazine. A few years later, I started freelancing, and my business skills helped tremendously.

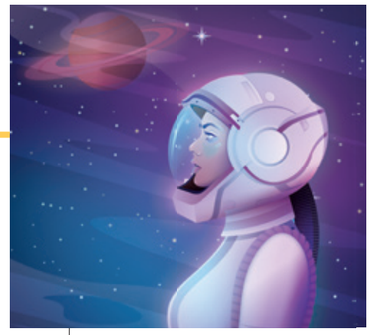
Jeff Hecht (BS ’69)
NEWTON, MA

This is an easy one—the civilian scientist astronaut corps, which would of course let in women.

Pam Wiedenbeck (MS ’74)
ALTADENA, CA

I *was* given this opportunity at Caltech when the development office sent me and my two roommates to meet a Santa Monica-based benefactor who ended up giving us $2,000 to start our digital music company Con Brio. The result was the development of several revolutionary early all-digital music instruments, including the ADS 200 instrument [shown below]. My early Con Brio years led me to found and grow M-Audio, a music industry leader from 1990 to 2010.

Timothy Ryan (BS ’78)
PARIS, FRANCE



At the time (1979), I wanted to create tiny 100-mile-per-gallon cars to save people money and not use up the planet. It turned out that most people want bigger cars, which resulted in trucks being used as cars to circumvent the MPG standards applied to cars (the SUV phenomenon).

John Whitehead (BS ’81)
DAVIS, CA

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Do Gas Stoves Affect Your Health?

"Besides people—and their pets—the major indoor pollutants come from burning stuff," says Paul Wennberg, Caltech's R. Stanton Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering, and a Resnick Sustainability Institute investigator. "When you're cooking, you are effectively adding a lot of things to the indoor air. Because homes are poorly ventilated, you end up building up significant amounts of contaminants, including nitrogen dioxide. Electric stoves will generally not generate nitrogen dioxide. Other things will produce nitrogen dioxide as well, such as burning candles."