Fall 2022

BREAKTHROUGHS

Berkeley Rausser
College of Natural Resources

Tapping the Powers of Biology

Can the bioeconomy bring renewable, carbon-negative products to a global scale?

Berkeley Rausser
College of Natural Resources

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LETTER FROM THE DEAN

As the need for energy independence, food security, and environmental sustainability grows more urgent by the day, it is apparent that there are no silver-bullet solutions. We must utilize all the tools we have to address these pressing issues and the other grand challenges of our time.

Our proverbial toolbox includes a growing set of solutions-oriented approaches that fall under a broad category called the bioeconomy. The term refers to the part of the economy that is based on products, services, and processes derived from renewable biological resources, such as plants and microorganisms.

Rausser College of Natural Resources is advancing the bioeconomy in many arenas. Our scientists are conducting research that supports a foundational understanding of microbes and biological processes that can sequester carbon or clean up ecosystems. Others are developing products and founding science-based startups that will transform the way we manufacture goods, grow food, treat diseases, and more. Our economists and policy experts are studying how to bring innovations from the lab to market, and other faculty are assessing the social and environmental impacts of new systems and approaches.

In this issue devoted to the bioeconomy, we explore the potential of biology-driven products and services as a way to foster sustainability at a global scale. We hope the stories here will inspire you about what the future may bring, and offer some optimism about the type of world we can create together.

I welcome your feedback at dackerly@berkeley.edu

David D. Ackerly

BREAKTHROUGHS

FALL 2022 / **CONTENT**

BUILDING THE BIOECONOMY

ONLINE
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Anastasiia Sapon (Martinez-Gomez); Mathew Burciaga (Hendrickson); Wildfire Courtesy Berkeley Forests.

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A boost for federal climate action

President Joe Biden signed the Inflation Reduction Act (IRA) into law in mid-August, ending a year and a half of negotiations with congressional holdouts skeptical of the Biden administration's proposed scope and spending.

Included in the $737-billion legislative package is $369 billion in new government spending on clean energy and climate mitigation over the next decade. From rebates on electric cars to incentives to retire coal-fired power stations, funds are set aside to help individual consumers, energy producers, and manufacturers adopt or develop renewable technology to cut their emissions.

"This bill includes the largest and most consequential climate and energy package ever to make it out of the U.S. Senate," said **Meredith Fowlie**, a professor in the Department of Agricultural and Resource Economics. Recent economic analysis by multiple organizations suggests these investments may help the U.S. cut carbon emissions nearly 40 percent below 2005 levels by 2030.

Incentives to help consumers buy new and used electric cars or install electric heating, ventilation, and air conditioning (HVAC) systems in their homes are funded through the bill, as are provisions to lower the cost of heat pumps, electric water heaters, and other building electrification improvements.

Environmental Science, Policy, and Management professor **Jonas Meckling**, whose recent publication in *Science* examines how and why countries lead or lag in energy transitions, said the incentives offered by the IRA represent a major shift in U.S. climate policy. "Rather than imposing regulatory 'sticks'—which were at the center of previous attempts at U.S. national climate policy—the IRA offers 'carrots' to incentivize businesses and households," he said.

In another recent study, published in *Nature Energy*, Meckling and his co-authors show how new forms of international cooperation and intensifying competition with China are main drivers for major economies to boost investments in clean energy research, development, and demonstration (RD&D). While the IRA emphasizes deployment of existing technologies rather than RD&D, last year's Infrastructure Investment and Jobs Act did expand funding for energy innovation, said Meckling.

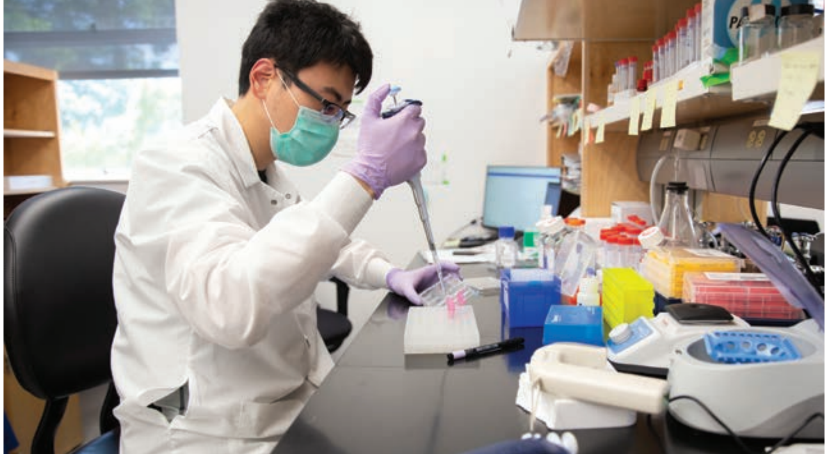
Forty percent of all money used by the IRA will be spent on environmental justice grant programs, which will help improve public health, reduce pollution, and revitalize marginalized communities by increasing access to affordable clean energy.

Speaking to the BBC World Service, Energy and Resources Group professor **Dan Kammen**—who currently serves as senior advisor for energy innovation at the United States Agency for International Development (USAID)—characterized it as a "key point" of the act.

"This is the first time the federal government has spent significantly on social, racial, and gender-based environmental justice, which is a great first step," he said.

— *Mathew Burciaga*

Julie Gipple



Brittany Hosea-Small

A new inhaled COVID-19 therapeutic

Scientists in the Department of Nutritional Sciences and Toxicology (NST) have created a new COVID-19 therapeutic that could one day make treating SARS-CoV-2 infections as easy as using a nasal spray for allergies.

The therapeutic uses short snippets of synthetic DNA to gum up the genetic machinery that allows SARS-CoV-2 to replicate within the body.

In a study published in the journal *Nature Communications* in August, the team shows that these short snippets, called antisense oligonucleotides (ASOs), are highly effective at preventing the virus from replicating in human cells. When administered in the nose, these ASOs are also effective at preventing and treating COVID-19 infection in mice and hamsters.

"Vaccines are making a huge difference, but vaccines are not universal, and there is still a tremendous need for other approaches," said **Anders Näär**, an NST professor of metabolic biology and senior author of the paper. "A nasal spray that is cheaply available everywhere and that could prevent someone from getting infected or prevent serious disease could be immensely helpful."

Because the ASO treatment targets a portion of the viral genome that is highly conserved among different variants, it is effective against all SARS-CoV-2 "variants of concern" in human cells and in animal models. It is also chemically stable and relatively inexpensive to produce at large scale, making it ideal for treating COVID-19 infections in areas of the world that do not have access to electricity or refrigeration.

If the treatment proves to be safe and effective in humans, the ASO technology could be readily modified to target other RNA viruses. The research team is already searching for a way to use this to disrupt influenza viruses, which also have pandemic potential. — *Kara Manke*

Watch NST graduate student Justin Lee explain how the new treatment works in a presentation that won the spring 2022 UC Grad Slam. The annual competition challenges graduate students from each campus to make their research accessible and entertaining.

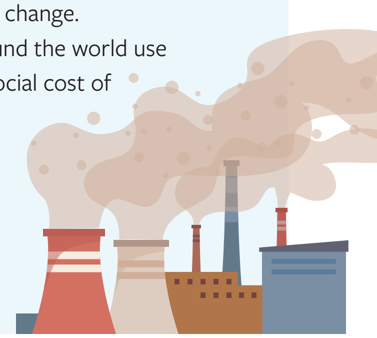
A tripled social cost of carbon

A new study led by researchers at Rausser College and nonprofit research institution Resources for the Future estimates that the social cost of carbon—a key metric for evaluating the future cost of climate change—is more than three times the value currently used by the U.S. government.

The study, published September 1 in the journal *Nature*, finds that each additional ton of carbon dioxide emitted into the atmosphere costs society approximately $185 per ton, which is 3.6 times the federal estimate of $51 per ton. A higher social cost of carbon indicates that reducing greenhouse gas emissions is likely to reap greater social and economic benefits than previously believed, and it could be used to justify more stringent climate policies.

"The social cost of carbon is the vehicle by which the work of thousands and thousands of climate scientists is incorporated into the regulatory process," said study senior author **David Anthoff**, an associate professor in the Energy and Resources Group. "Our team applied the latest socioeconomic projections, climate models, and risk evaluation methods to create an estimate that better reflects the true costs of climate change."

Policies that limit the amount of carbon dioxide released into the atmosphere are often costly in the short-term, but ultimately benefit society by reducing the devastating impacts of climate change. Governments around the world use estimates of the social cost of carbon and other greenhouse gases to weigh the costs and benefits of these policies. — *Kara Manke*



Breaking Language Barriers

MACHINE TRANSLATION COULD MAKE ENGLISH-ONLY SCIENCE ACCESSIBLE TO ALL

There's a well-known and long-standing issue in science: with English as the dominant language, non-native speakers can face major obstacles communicating their science or comprehending the work of others in scientific publications.

Machine learning has dramatically increased translation accuracy in recent years, but while tourists may be able to communicate sufficiently using Google Translate, even the best online services provide woefully inadequate translations of technical, scientific writing.

A UC Berkeley class taught by **Rebecca Tarvin**, an assistant professor of integrative biology, is tackling the issue head on. While participating in a translation working group hosted by Berkeley's Museum of Vertebrate Zoology, Tarvin and colleagues envisioned the course—called Breaking Language Barriers in Evolution and Ecology—as an "opportunity to teach students skills in translation literacy, as well as encourage students to be activists in this realm of structural change," said Tarvin.

Together with **Emma Steigerwald**, a graduate student in environmental science, policy, and management who chaired the working group, as well as integrative biology graduate students **Débora Brandt** and **Valeria Ramírez Castañeda**, Tarvin and colleagues from Canada, Israel, and Hungary collaborated on a scientific paper they hope will motivate scientists to translate their own research. The paper, which evaluates the advantages and limitations of machine translation tools, was published in the journal *BioScience* in August, with accompanying translations into Spanish, French, Portuguese, and Hungarian.

"Language can be a barrier, as well as a fantastic tool, to bring people together," emphasized Steigerwald, who is first author of the paper. "It's a barrier that we can surmount using this new technology."

The authors also assert that writing scientific papers in plain English—something nonscientists have encouraged for a long time—benefits both English and non-English speakers. In addition to being easier for anyone to read, Steigerwald said, plain language is easier for machine learning tools to accurately translate. "This is kind of future-proofing your writing, so that if someone wants to translate it into a million languages, they'll have a much easier time when it's written in that way," she said.

— *Adapted from an article by Robert Sanders*

The Ticker

Scott Stephens, a professor of fire science, was appointed to a new federal Wildland Fire Mitigation and Management Commission formed by the Departments of Agriculture, the Interior, and Homeland Security through the Federal Emergency Management Agency.

Christopher Schell, an assistant professor in the Department of Environmental Science, Policy, and Management (ESPM), was named a fellow of the California Academy of Sciences.

Dennis Baldocchi, a professor of biometeorology, was named one of the 2022 awardees of the Prince Sultan Bin Abdulaziz International Prize for Water.

Expanding UC's research forests

A new research forest in Shasta County has increased UC Berkeley's forest research station lands to nearly 10,000 acres. Transferred in September by Pacific Gas and Electric Company in collaboration with the Shasta Land Trust, the 3,244 acres will be stewarded by Berkeley Forests, the center that manages a network of UC Berkeley forests for research and outreach objectives.

The property will be Berkeley Forests' first in the Cascade Mountain range, creating opportunities for novel research in forest types and ecosystems not currently part of UC's network.

Overseen by Research Stations Manager **Ariel Roughton**, key focus areas for the forest include research on the effects of climate change in forested ecosystems and expanded experimentation with management techniques to mitigate climate impacts. Berkeley Forests also plans to partner with community members and local landowners. "Through this research forest we can contribute to all pillars of our mission—research, education, service, and diversity—in a way that has far-reaching impact while also serving local stakeholders," said Berkeley Forests Co-Director **Rob York**.

David Ackerly (forest); Rob York (river)

An advanced degree in dietetics

The Department of Nutritional Sciences and Toxicology has launched a new Master of Nutritional Sciences and Dietetics (MNSD) program to provide students with the training needed to become a registered dietitian nutritionist.

The 21-month program provides the required coursework and supervised practice hours for registered dietitian nutritionist credentialing examination eligibility and exposes students to leaders in the fields of clinical dietetics, research, food, education, policy, and public health. Applications for the inaugural cohort, which will arrive on campus in fall 2023, are now open.

Learn more at nutrition.berkeley.edu.

UC Berkeley and Novartis extended a research collaboration that focuses on developing technologies for the discovery of next-generation therapeutics. The effort is led by **Daniel Nomura**, a professor in the Department of Nutritional Sciences and Toxicology.

Forestry Camp reunion weekend returned this summer after a two-year hiatus, welcoming 170 alumni.

ESPM professor **Paolo D'Odorico** received the 2023 Hydrological Services Medal from the American Meteorological Society.

Rausser College of Natural Resources and Haas School of Business launched a **summer minor in sustainable business and policy.**

BUILDING THE BIOECONOMY

Tapping the Superpowers of Biology

Can the bioeconomy bring renewable, carbon-negative products to a global scale? BY ANN BRODY GUY

When the world needs a new superhero, instead of looking to bulked-up hulks like Thor and Aquaman, Hollywood might do better to go small. Microbe-small. Plants and microorganisms have always been at the heart of the planet's healthy functioning, but in recent years, advances in bioscience have supercharged them.

Today, biology is the engine of a rapidly expanding economic sector collectively known as the bioeconomy. Bioeconomy products, processes, and services typically share a focus on using renewable biological resources to solve the world's biggest, most pressing problems: producing sustainable energy and medicine, ending hunger, minimizing waste, and mitigating climate change. Superhero stuff.

In real life, that can look like mushroom packaging, microbes that break down garbage, plant-based meats, drought-resistant and carbon-storing food crops, and new biofuels to support the transition away from fossil fuels.

Definitions across countries, agencies, or institutions can vary. Does the bioeconomy include pharmaceuticals? Exclude traditional agriculture? However it's defined, the term is now integral to the global economy, serving as an umbrella category for a quickly-expanding segment of the U.S. economy. "Safeguarding the Bioeconomy," a 2020 National Academy of Sciences (NAS) report, valued the U.S. sector at nearly a trillion dollars, or 5.1% of the GDP, based on 2016 data. The Congressional Research Office's 2021 "Bioeconomy Primer" estimated global growth of up to $4 trillion per year in the coming decade.

While such growth might be seen as a boon, "The idea of the bioeconomy is not new," says **David Zilberman**, agricultural and resource economics professor and a reviewer on the NAS report. "This is one of the oldest industries in the world," he says. "Wine, cheese, bread, kimchi—the old bioeconomy all came from fermentation," he says, referring to the basic metabolic process in which microorganisms such as bacteria or yeast, when sealed off from oxygen, convert carbohydrate molecules to acids or alcohols.

But in the last 20 years, tools like genomics, CRISPR gene editing, and artificial intelligence have amplified the power of plants and microorganisms, making fermentation more precise and helping organisms perform new functions or produce desired characteristics.

"Plants are the most powerful chemical factories in the world," says Zilberman, who won the 2019 Wolf Prize in Agriculture, an international award often referred to as the Nobel Prize for agriculture. "This is an incredible set of capabilities that can allow us to increase agricultural productivity, reduce land use, move from a nonrenewable economy to a renewable one, and help solve climate change," he says.

CIRCULAR SYSTEMS

Plant and microbial biology (PMB) professor **John Coates**, who leads Berkeley's Energy & Biosciences Institute (EBI), says the bioeconomy can include any products or processes that have a biological component. Chemistry and engineering, for example, can be used to upcycle agricultural wastes from food production into animal feed, fertilizers, and biofuels.

What's key, Coates says, is creating circular, sustainable systems that take carbon out of the atmosphere, then put it back into products and services, all without the planet-harming impacts of fossil fuels.

"We can still have a bioeconomy that's not sustainable," he cautions. For example, he says, ethanol-dedicated cornfields require carbon-intensive farming inputs—tilling, fertilizing, irrigating—and use land and resources that could be used for food crops. Many analyses find this practice cancels out ethanol's carbon benefits and creates waste-disposal issues and food versus fuel land-use concerns.

"Sometimes the technology is not the important thing," Coates says. "It's the entire lifecycle."

Addressing such lifecycle concerns, PMB professor **Sabeeha Merchant** is developing a sustainable process for producing a "designer oil" that can be used to make jet fuel. Plants can be engineered to produce the oil using their own sugar from photosynthesis, she says, but her lab is trying to make it with green algae, an aquatic organism that grows quickly. "Getting algae to make the oil using its own sunlight-produced sugar is a circular system that's also more econom-

Anastasiia Sapon (2x)

With an $11.6 million grant from the Department of Energy, a team including Jeff Moseley (left) and Sabeeha Merchant is working to develop biofuel and bioproducts from a photosynthetic microalga.

ically viable," she says, "and it avoids competition between biofuels and food crops."

Genomics and CRISPR have been critical tools. "Genome sequencing is at the center, because we need to know what an organism is capable of doing, and all of that information is in its genome," she says. While genes for the photosynthesis protein are well known, Merchant says, her lab focuses on how environmental influences affect the process. CRISPR's precision editing accelerates the search for beneficial genes that, for example, protect against light stress or adapt to iron deficiency. Then, she says, "We can take all those genes and put them into our production organism."

Merchant—together with PMB professor **Krishna Niyogi** and researchers **Jeff Moseley** and **Melissa Roth**—recently won an $11.6 million grant from the Department of Energy (DOE) supporting this work.

"Plants are the most powerful chemical factories in the world."

— **DAVID ZILBERMAN**

REDUCE, REUSE, AND UPCYCLE

Circular systems can also clean up messes that are already here, such as hazardous waste (which often includes contaminants like heavy metals) and biowaste, the organic detritus left from food, lumber, and agricultural production.

PMB assistant professor **Norma Cecilia Martinez-Gomez** works with microorganisms that take up rare earth metals present in medical waste and e-waste like batteries and old smartphones, which can then be upcycled into other products (see page 14).

Coates has identified bacteria that convert perchlorate, a potentially toxic chemical used in everything from herbicides to rocket propellant, into a harmless compound. He's also working to reduce the cost of producing bioplastics, which are still four times more expensive than petroleum-based plastics.

Elena Zhukova (Zilberman)

David Zilberman has spent decades researching the bioeconomy's potential to address climate change, increase agricultural productivity, and reduce land use.

“Sometimes the technology is not the important thing. It’s the entire lifecycle.”

— JOHN COATES

“There are plenty of microorganisms that will eat organic waste matter and will make bioplastics,” he says, but he’s seeking microbes that can make production efficient at a commercial scale. As with much of biotech, he says, the big challenge is making new manufacturing processes economically competitive with established, fully-optimized systems like plastic production.

GETTING TO THE MARKETPLACE

Such scale-up hurdles must be overcome to reap the benefits these new technologies can bring, experts agree.

Ouwei Wang (BS ’12 Microbial Biology, PhD ’18 Microbiology) has solved—and commercialized—one scaling challenge. The precision fermentation used by industry is more engineered than the traditional process, controlling factors like pH, dissolved oxygen, and agitation rates. However, Wang says, it’s still a batch system, with lots of unproductive time repeatedly setting up the reactor with feedstock, adding a reaction agent, and waiting for the growth period.

A process called continuous fermentation breaks through these limitations, keeping feedstock continuously going in and fermented material coming out, much like a flour mill keeps grain feeding in and flour coming out. However, Wang explains, because the reactor isn’t sealed off like a closed system, dust or ambient bacteria can get in. “It can ruin the whole batch because there’s always growth,” he says, adding that the active bacteria can break down over long production times.

As a student in Coates’ lab, Wang developed an additive that can be introduced into the continuous-fermentation bioreactor to prevent and treat contamination. Coates, who also runs EBI’s incubator program, saw the immense applied value of the work and connected Wang with Berkeley’s robust entrepreneurship ecosystem.

During R&D for his new company, Wang programmed the reactors using machine learning, a form of AI that “automatically detects failure events and takes actions accordingly, much like a self-driving car corrects itself,” he says, “and it continually self-adjusts to stay in its most productive state.”

Today, Wang’s start-up, Pow.bio, has helped more than 20 companies from across the bioeconomy make products like organic acids, high-value enzymes, food additives, and probiotics, increasing their production at least fivefold while reducing their manufacturing footprint.

More infrastructure is needed, Wang says. “The science is there—we can make bioplastics, biofuel, and food products, but there simply are not enough bioreactors to do the work.” With a dearth of fermentation courses at large universities, including UC Berkeley, there’s also a lack of expertise, he says.

Even amid these challenges, Wang finds the work rewarding. “It feels like I’m actually helping to solve a problem that people care about,” he says.

New ventures like Wang’s require investors. **Kulika Weizman** (PhD ’16 Microbiology) a principal at a venture capital (VC) firm, applies a pragmatic lens to potential bioeconomy investments. As a graduate student in molecular and cell biology professor **Jamie Cate**’s EBI lab, she conceived her first startup: converting biowaste from yogurt manufacturing into a low-calorie sugar alternative.

Turning waste into a sweetener was an attractive idea, Weizman says, but the project taught her tough lessons about bioeconomy supply chains and demand, and the company soon pivoted to another product. These lessons now inform her VC work.

“Technology is a solution in search of a problem,” she warns. A self-described technologist, as an investor, she says, she takes a “market-first” perspective. “We look for problems where customers are in pain and willing to pay for solutions today, then screen for technologies that address that directly.”

And while investors generally prioritize the financial bottom line over societal problems, “the two often overlap,” she says. “A lot of burning global crises today are the driving forces that feed into the market-needs perspective.” As a case in point, her recent investments include personalized medicine and renewable construction materials.

Coates, who himself has founded four startups, says entrepreneurship and investment are critical to solving lab-to-production challenges. But to mitigate climate change, he says, the bioeconomy itself will have to scale.

Mathew Burciaga (Lab)

"Agriculture and construction are the two main industries large enough to make an impact at a global scale," Coates says. Research efforts, led by Rausser College faculty at the Innovative Genomics Institute, are already underway to improve carbon sequestration and crop yields in the agriculture industry (see page 22). Potential in construction includes converting biowaste into building materials and seeding microbes into materials that aid in sequestering atmospheric CO_2.

If these two industries can be turned into carbon-negative cycles, "Then they can account for a lot of carbon uptake," Coates says. "We have to start thinking about scale as something that's going to have a global impact."

THE INNOVATION SUPPLY CHAIN

Zilberman's research synthesizes all these points along the trajectory from an idea to a commercial product—what he calls "the innovation supply chain." California sets a strong example, he says, with research universities winning public funding, like Merchant's recent DOE grant, entrepreneurial faculty like Coates and alumni like Wang, and Silicon Valley's strong VC culture.

Both the pandemic and the Russia-Ukraine war have underscored the importance of resiliency in supply chains, he says. Just as other supply chains need multiple sources—buyers, suppliers, transport—the same is true for educating new generations of innovators. "We need to develop new knowledge and new supply chains to grow biofuel," he says, "but you need to have people who can do it."

Policy support is critical across the trajectory, Zilberman says, especially for R&D, including the infrastructure needed to turn research into a product. In developing countries, he notes, infrastructure may include other elements, such as improving roads that carry raw materials from a supplier to a manufacturing center.

He also calls for "sound, science-based regulation," referencing what he considers Europe's particularly restrictive approach to biotech, and more mechanisms for providing credit and long-term investments in new supply chains for plant-based or biotech products.

Finally, he emphasizes the need for global climate change policies. "A global carbon tax would create incentives for companies and countries to move to renewable technologies, and penalties from that system can be used for R&D for lower-carbon alternatives," he says.

Zilberman sees Rausser College of Natural Resources at the center of the bioeconomy's innovation supply chain at UC Berkeley because its departments are complementary. "We have people developing the most advanced agricultural knowledge and creating new biological systems and working on climate change," he says. But the College can't do it alone, he adds. "Because we are located in a world-class university, we can integrate advances from the top people working in biotechnology, information sciences, chemistry, and engineering."

From what Merchant observes in her students, the will is strong. "When I was a student, most of us were just intrigued by the idea of discovering something that nobody else knew," she says. "But today's students want to improve the world. They want to solve problems. They want to do something that has an impact."

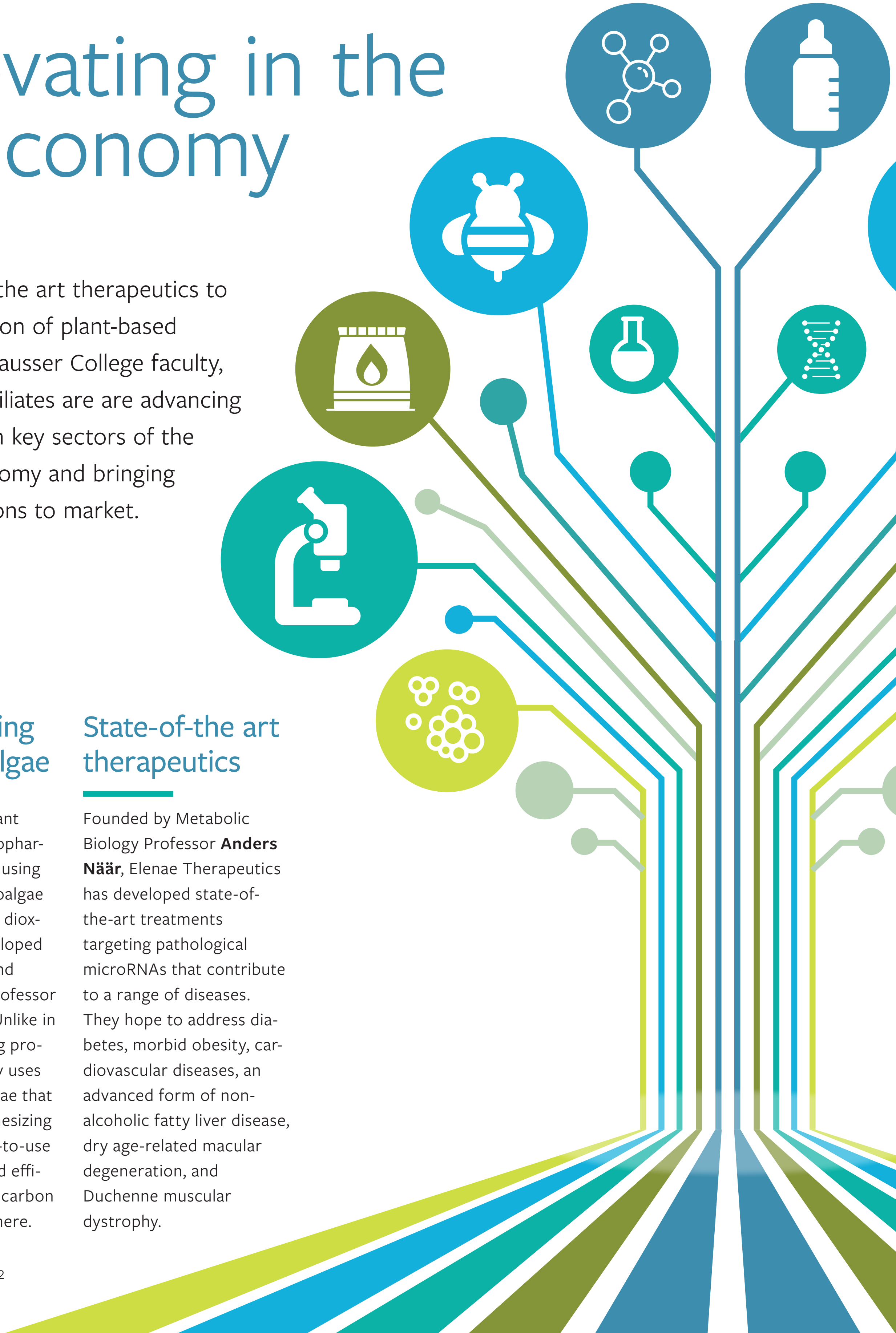
The future depends on it, Zilberman says. "We really need to educate the people who will develop technical solutions, educational solutions, and policy solutions to address the challenges of the bioeconomy," he says. "If we do that, I think we will really change the world." BI

Mathew Burciaga

John Coates (middle) says bringing lab discoveries to a manufacturing scale that competes with traditional markets is a key challenge for startups in the bioeconomy.

BUILDING THE BIOECONOMY

Innovating in the Bioeconomy



From state-of-the art therapeutics to a new generation of plant-based bioproducts, Rausser College faculty, alumni, and affiliates are are advancing research within key sectors of the global bioeconomy and bringing these innovations to market.

Manufacturing with microalgae

Tilden Bio makes plant essential oils and biopharmaceutical proteins using solar-powered microalgae that feed on carbon dioxide—a process developed in the lab of Plant and Microbial Biology Professor **Anastasios Melis**. Unlike in other manufacturing processes, the company uses blue-green microalgae that are capable of synthesizing and secreting ready-to-use products quickly and efficiently while pulling carbon in from the atmosphere.

State-of-the art therapeutics

Founded by Metabolic Biology Professor **Anders Näär**, Elenae Therapeutics has developed state-of-the-art treatments targeting pathological microRNAs that contribute to a range of diseases. They hope to address diabetes, morbid obesity, cardiovascular diseases, an advanced form of non-alcoholic fatty liver disease, dry age-related macular degeneration, and Duchenne muscular dystrophy.

From fecal waste to biofuel

Sanivation is advancing sanitation in East Africa by converting fecal waste into biomass-based fuel. Co-founded by **Emily Woods**, MS ’18 Energy and Resources Group, the company partners with local governments to design, build, and operate fecal sludge treatment plants that produce fuel briquettes from local waste, providing a safe alternative to firewood for heating and cooking. Each plant is self-sustaining, with operational costs supported by the revenue generated from the sale of fuel.

Real honey without bees

Using precision fermentation and plant science, MeliBio produces sustainable, bee-free honey that matches the taste, quality, and nutrition of its traditional counterpart. The company’s plant-based honey aims to support populations of wild and native bee species by reducing ecosystem competition from commercial honey production. *TIME* magazine named their product one of the 100 Best Inventions of 2021. **Aaron Schaller**, PhD ’19 Molecular & Cell Biology, is co-founder and CTO.

A precise reflection of human milk

More than 180 human milk oligosaccharides (HMOs)—naturally occurring sugars that promote healthy immune systems and neurological development in infants—are found in breast milk. But sourcing and production issues make it hard for commercial infant formulas to include these critical nutrients. NAMUH is working to develop a nutritionally comparable alternative to breast milk that includes HMOs through an advanced yeast-based fermentation process. Co-founded by **Chaeyoung Shin**, PhD ’16 Chemical Engineering, the company received early support and guidance through participation in the Energy and Biosciences Institute’s incubator program.

New frontiers in medicine

Daniel Nomura, a professor in the departments of Nutritional Sciences and Toxicology, Chemistry, and Molecular and Cell Biology, is pioneering the development of medicines that work against disease-causing proteins previously considered “undruggable.” He co-founded Frontier Medicines, a precision medicine company that is deploying groundbreaking scientific approaches in chemoproteomics, covalent drug discovery, and machine learning to develop medicines, starting with anticancer therapies. He also recently founded Vicinitas Therapeutics, a biotechnology company developing novel therapeutics for cancer and genetic disorders.

Biological solutions to control pests

Oxitec provides targeted, nontoxic, and environmentally sustainable biological solutions for controlling pests that spread disease, threaten food production, or harm ecosystems. Their Friendly™ technology creates male insect pests that carry a self-limiting gene, which prevents female offspring from surviving to adulthood, thus reducing pest insect populations. The company has commercialized Friendly mosquitoes in Brazil, partnered with the government of Djibouti to control malaria-spreading mosquitoes in the Horn of Africa, and developed Friendly moths that can counteract pest resistance to farmers’ crop protection tools. **Rakim Turnipseed**, PhD ’17 Environmental Science, Policy, and Management, is the company’s director of global field programs.

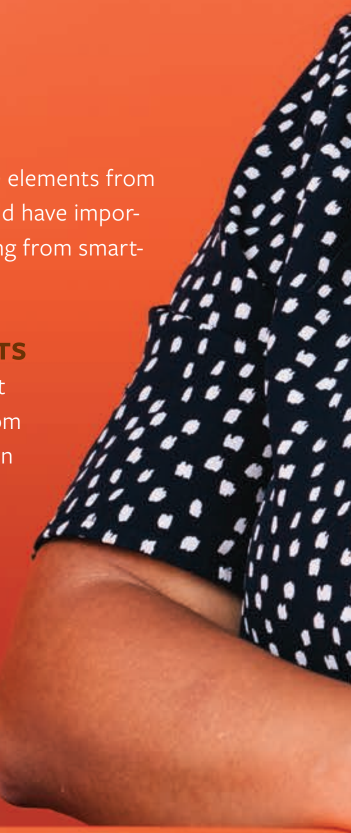
MICROBE MINERS

Cecilia Martinez-Gomez's engineered bacteria recovers valuable elements from old smartphones, cleans up medical wastewater, and more

BY ZAC UNGER | PHOTOGRAPHY BY ANASTASIIA SAPON

Mention bacteria and most people generally think of dirt and disease. Fair enough; bacteria cause cholera, strep throat, salmonella, and a host of other ailments we'd all rather avoid. We spend enormous amounts on antibacterial soaps, and we worry about the dire consequences when bacteria evolve to evade our defenses.

Yet the vast majority of bacteria are harmless, and some, according to **Cecilia Martinez-Gomez**, an assistant professor in the Department of Plant and Microbial Biology, can actually become powerhouse cleaning agents. Martinez-Gomez is engineering bacteria that are likely some of the most efficient "scrubbers" ever discovered, able to protect the environment—and potentially our bodies—from heavy metals and medical waste products. She's also developed bacteria that can be used to "mine" valuable elements from discarded electronics, an approach that could have important impacts for the production of everything from smartphones to military equipment.



RECOVERING RARE EARTH ELEMENTS

Down at the bottom of the periodic table, set aside from the elements we all remember from high school, you'll find fifteen elements known as lanthanides. These metallic elements with unfamiliar names like ytterbium and dysprosium are collectively known as Rare Earth Elements (REEs) and are found in many products and materials we use daily. REEs are in the magnets that

Assistant Professor Cecilia Martinez-Gomez is a pioneer in the nascent field of lanthanide chemistry.

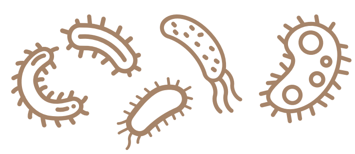
power up our laptops and other electric motors; they're in the polishing agents for windshields and mirrors; and, crucially, they're in the smartphones upon which we all increasingly rely. These elements are also essential for our military, making up critical components of guidance, night vision, and stealth systems.

Unfortunately, all this technology is not without cost. Lanthanides have toxic effects on humans, and, although our use of them has exploded in recent decades, we've barely studied the long-term effects of constant exposure. The process by which they're extracted from the ground is also chemically intensive, often fouling groundwater and soil near mine sites.

With the demand for REEs on the rise, it's imperative that we figure out how to recycle them, rather than adding them to landfills every time we swap out our phones for the latest model. That's exactly the effort that's going on in Martinez-Gomez's lab, and, fascinatingly, she's using genetically modified bacteria to hunt down and retrieve these valuable metals. "No matter how much chemistry we know," she says, "we can't compare to the incredible machinery the microbes have developed on their own over millions of years." For years, REEs were largely dismissed as having no significant role in biological processes, perhaps due to their toxicity. But Martinez-Gomez and other pioneers in her field weren't convinced. They began to research whether microbes could act as "micro-miners" that are able to extract and bioaccumulate REEs in pure form from parts of phones and batteries.

"Our resources are connected—even our waste should be used to produce something of value."

— CECILIA MARTINEZ-GOMEZ



What followed was a series of experiments and genetic manipulations to find (and enhance) species of bacteria that could process lanthanides. "We don't know exactly how microbes are sensing them, but we do know that they secrete molecules that combine with the lanthanides," says Martinez-Gomez. Those molecules recognize gates in the membranes that allow them to selectively bring the lanthanides in. The mechanism for how these microbes bring in the metals is tightly regulated by inherent biology; each microbe can only bring in so much material. "What we're doing is modifying the genome in order to make the process more selective, and also much more efficient, so that they can really hyper-accumulate pure metals into the cell," says Martinez-Gomez.

REVOLUTIONARY ADVANCES

In the beginning, Martinez-Gomez and her colleagues broke up cell phones and speakers with a hammer in order to gather the parts that contained REEs. Now, they partner with a recycling company that delivers the electronics already ground into a fine powder. That e-waste goes into a bioreactor with sterile water, a few phosphates and sulfates, and the microbe *Methylobacterium extorquens* at very high concentrations. "Then we have millions and millions of cells accumulating metals," she explains, "and afterward we break the cells and do a very simple purification from there."

Creating a cellphone-eating bacteria that can produce purified REEs sounds easy when Martinez-Gomez describes it. But the concept is actually the kind of revolutionary advance that leapfrogs the quest for sustainability wildly forward. It's so audacious that Martinez-Gomez and her colleagues from San Jose State University and Lawrence Livermore National Lab recently received a million-dollar grant from the Advanced Research Projects Agency-Energy (ARPA-E), the government agency dedicated to rapid progress in advanced energy technology.

The government's interest is no surprise given the geopolitical implications of Martinez-Gomez's work. The domestic supply of these vital materials depends on the largesse of rival superpowers like China, currently the largest producer of REEs. Though U.S. extraction of rare earth elements has increased over the last decade, a recent U.S. Geological Survey report identified China as the source of 78% of all refined REEs imported between 2017 and 2020. That makes the ability to recycle and preserve REEs a tantalizing prospect for our domestic economy. "I want to contribute to helping the United States be independent from a foreign supply," says Martinez-Gomez.

To be clear, the technology is not yet ready to digest and

Cecilia Martinez-Gomez (right), project scientist Nate Good (left), and PhD student Alexa Zytnick check the status of a bioreactor where bacteria accumulates neodymium from discarded smartphones.

repurpose all our castoff electronics. But for a radically new process, that day is closer than one might think. “Our max is still currently ten liters,” says Martinez-Gomez. “We’re not yet at the point where we can scale it to the level we would need to have constant production and be profitable.” However, with the ARPA-E funding, Martinez-Gomez’s lab is staffing up and making plans to move quickly. She has patents in various stages of approval, and the goal is to have a viable product to release to the public in four years.

A MYRIAD OF POTENTIAL APPLICATIONS

The underlying science has promise even beyond capturing e-waste. The rare earth metal gadolinium, for example, is widely used in contrasting agents during MRIs. While largely harmless to patients during those brief clinical scans, once expelled via urine, the lanthanide accumulates at high concentrations in the water supply and can become harmful to people. Working with her graduate students, Martinez-Gomez established a fast-paced series of selective pressures on bacteria, making them mutate faster than normal. “Essentially we fed them gadolinium and made that the only source they had available to them,” she says. Not only did the bacteria evolve to tolerate this toxic compound, they mutated to *prefer* it, hyper-accumulating large quantities. Gadolinium-loving microbes can potentially be deployed in wastewater facilities, gobbling up heavy metals before they can pose a threat to human health.

Martinez-Gomez is doing similar work to coax bacteria to bind up methane—a greenhouse gas eighty times more potent than carbon dioxide—so that it is not released to the atmosphere where it can contribute to climate change. “These are emergent areas that not many people are working on,” Martinez-Gomez says. “We’re discovering mechanisms that nobody has described before and that’s incredibly exciting.” Far from being territorial, Martinez-Gomez eagerly hopes more scientists will join the field of lanthanide chemistry to help discover other possible applications.

Known as a generous collaborator and enthusiastic mentor, Martinez-Gomez recalls her first exposure to science as a kid roaming the halls of the National University of Mexico in Mexico City where her father was an administrator. “During the summers I was so bored, but I saw these researchers and everybody seemed so happy, so I got up the nerve to knock and say “I’m here every day anyway, so can I do anything to help?” A series of scientists opened their doors, let her sit in on lab meetings, and explained their research in terms she could understand. By her senior year of high school, she was working on high-level projects. From there, she kept adding disciplines to her skill set, becoming proficient as a biochemist, microbiologist, geneticist, and chemical engineer.

Martinez-Gomez continues to deepen the pure scientific understanding of how microbes behave, always keeping her eye on the real-world implications of her work. “I really believe in the idea of a circular bioeconomy,” she says. “We need to think of the world like people going on a mission to Mars. Our resources are connected—even our waste should be used to produce something of value.” With the insatiable desire for growth ingrained in today’s global economy, Martinez-Gomez’s work helps us see bacteria not as something dirty, but as an important contributor to our effort to create a sustainable future.

GETTING TO CARBON NEGATIVE

Rausser College faculty are helping scale markets for carbon capture, storage, and management

BY MATHEW BURCIAGA
ILLUSTRATION BY GIULIO BONASERA

When it comes to the challenge of addressing worldwide carbon emissions, **Van Butsic** says, we should think of an overflowing bathtub. He likens the steps citizens and corporations are taking to decrease the amount of carbon dioxide entering the atmosphere to the first thing you might do if your tub starts to overflow: stop the water going in. "But turning off the faucet only solves one part of the problem," he says. "You've also got to pull the plug."

In this claw-footed, porcelain analogy for climate change, pulling the plug equals removing existing carbon from the atmosphere. Researchers across the globe have demonstrated their ability to combine practices from environmental science, chemistry, biology, engineering, and other fields to do this. They've developed specialized equipment that can capture carbon directly from the air or bind it with rocks for long-term storage. Others are using biomass—like trees and plants that would otherwise burn in wildfires or decompose—to produce electricity, heat, fuels, and bioproducts while capturing and storing the emissions associated with their production.

Improving carbon removal technologies and processes is key to ensuring a sustainable future for society, and it plays a part in the long-term success of the bioeconomy: an emerging sector focused on developing alternatives to products derived from fossil fuels. Researchers like Butsic, an associate professor of Cooperative Extension in the Department of Environmental Science, Policy, and Management (ESPM) and two of his Rausser College colleagues—**Matthew Potts** and **Daniel Sanchez**—hope to use their expertise to reduce how embedded carbon is in our everyday lives. Their work at Carbon Direct, Inc., a firm that offers end-to-end carbon management through scientific and advisory services, enables organizations around the world to reduce, remove, and monitor emissions for real climate impact.

OPTIMIZING CURRENT EFFORTS

While the idea is not new, offsetting our carbon emissions—that is, reducing or removing the amount of carbon dioxide in one place to compensate for emissions elsewhere—has become an integral part of our efforts to reach net zero by 2050. Many major emitters in energy, manufacturing, and other industries have already taken important steps to enhance nature's ability to store carbon. They adopt business practices that promote environmental conservation, direct funds to advance reforestation and restoration efforts, and advocate for improved ecosystem management practices that reduce the risk of stored carbon being released.

Matthew Potts, S.J. Hall Chair in Forest Economics in ESPM and a leading expert in nature-based solutions to climate change, says we need to go beyond these current carbon storage efforts given how embedded emissions are within the global economy and supply chain. "If we're going to get within the realm of the emissions reduction goals set by the Paris Agreement then we need to build a carbon removal sector that is twice the size of the current carbon footprint of the oil and gas industries," he says.

Potts, who is also Chief Science Officer at Carbon Direct, stresses that "clients need to realize that high-quality, nature-based solutions aren't forever solutions." Though these are acceptable for the short term, he says, companies need to tap quantitative and qualitative research to properly evaluate and transition to hybrid or engineered forms of carbon removal—which can store carbon for centuries to millennia rather than years to decades—while optimizing their present-day effort to store carbon in trees and forests.

Sanchez, an assistant professor of Cooperative Extension in ESPM, says Carbon Direct's interdisciplinary team of scientists and economists are well-suited to guide clients toward high-quality projects that will remove large amounts of carbon with little risk of it seeping back out. "The Earth has its own ledger," he says. "You can only say you're offsetting your emissions so much with low-quality solutions before you realize that the math isn't adding up."

Carbon Direct takes a holistic approach to carbon management by evaluating new and promising technologies while working to optimize natural and working lands to store as much carbon as possible. Forests are a central part of present-day carbon management efforts because they are one of the most readily available carbon sinks. "Trees can sequester carbon dioxide from the atmosphere and store it for meaningful amounts of time," explains Butsic, "which ideally limits global warming and associated climatic effects."

Much of Butsic's academic research combines forest science, geospatial analysis, and statistical modeling to understand how climate-driven changes in land use affect the durability and stability of forest carbon. Even though advances in research and modeling—paired with better satellite imagery and analytical tools—make it easier to manage large-scale forestlands, Butsic says that growing wildfires and worsening ecosystem disruption increase the risk that carbon stored in forests will be released.

ADVANCING NEW TECHNOLOGIES

Engineered carbon removal projects are still in their infancy. They're generally expensive and low volume, with little present capacity for the type of commercial scale needed to notably reduce global emissions. As an expert on carbon-negative systems that can use biomass to generate heat and electricity and produce biofuel and other products, Sanchez guides Carbon Direct toward projects with the greatest promise and potential for growth.

At Berkeley, Sanchez directs the Carbon Removal Lab, which works to commercialize a range of technologies and products that remove carbon dioxide from the atmosphere. Much of his research focuses on transforming low-value and waste biomass from forests and lumber production into new structural wood products like plywood sheets strong enough for construction, transportation fuels, or other high-value chemicals. He also supports outreach efforts geared toward policymakers and technologists to help encourage adoption of these new approaches.

Sanchez says private investment from major emitters will help build carbon removal facilities and support the development of new technologies that he says, "are a lot more durable—and a lot higher quality—than what nature has to offer."

Carbon Direct is setting the bar for quality in carbon management with their Criteria for High-Quality Carbon Dioxide Removal. Developed in partnership with Microsoft, the criteria serve as a blueprint for both project developers and buyers to ensure that projects deliver real climate impact. The company also worked with Shopify, Alaska Airlines, and Mitsubishi Corporation, and recently secured $60 million in Series A funding.

In addition, Carbon Direct has developed a software platform for organizations looking to automate carbon removal across their operations. Now, organizations can analyze their carbon footprint with the company's proprietary measurement tool, purchase high-quality carbon management portfolios, and embed carbon purchasing directly into their platforms with the Carbon Direct API.

Beyond helping clients reduce emissions and procure carbon credits, Carbon Direct's efforts to grow quality carbon removal supply have also extended to improving protocols and standards. The company partnered with EcoEngineers and Charm Industrial to launch a prototype protocol that establishes a standard of measurement for bio-oil sequestration: a new carbon removal practice that transforms waste biomass into bio-oil and injects it into geological formations deep underground for permanent storage.

Sanchez notes that stronger regulatory policy and government action are also needed to grow the carbon credit market. The federal government is committing $369 billion in new spending on clean energy and climate mitigation over the next decade as part of the recently passed Inflation Reduction Act. On top of offering consumers incentives to purchase electric cars and make their homes more energy efficient, the bill increases the tax credit for capturing carbon—a change that may help bring some projects over the finish line.

"Costs are coming down rapidly, and we expect many technologies to have wide commercial application in the next decade," adds Butsic, who is optimistic about the development trajectory for direct air capture, mineralization, and other carbon removal technologies. Each advancement will improve our ability to remove carbon from the atmosphere, allowing us to tug—and hopefully remove—the drain plug and solve the problem of our overflowing tub.

Jared Stapp, PhD '22 Environmental Science, Policy, and Management, works on geospatial analysis and forest management at Carbon Direct.

Carbon Direct is advancing both nature-based and engineered carbon removal projects.

Climeworks (bottom); Zane Persaud on Unsplash (rock); Carbon Direct (Stapp).

Cultivating Resilience

Researchers are using synthetic biology and CRISPR methods to help plants fight pathogens, improve crop yields, and store more carbon

Amanda Nguyen/RIPE Project

A research team led by professor Krishna Niyogi and researchers at the University of Illinois recently demonstrated that multigene bioengineering of soybeans improved photosynthesis and increased crop yields in field trials.

BY ROBIN DONOVAN

Gaze over a field of wheat rustling in the wind, and it's easy to get lost in the beauty of an idyllic, pastoral scene. Biologist **Ksenia Krasileva** sees something different: a commodity crop grown repeatedly on the same tract of land, requiring herbicides, pesticides, and fertilizer. For over a century, agricultural producers have been planting genetically identical monoculture crops—like single species of corn, wheat, and other staples—to improve harvest yields. But the same genetic similarities that led to bountiful harvests also left our food systems susceptible to pests and pathogens. Hotter, drier growing seasons fueled by climate change have also added another layer of challenges.

Krasileva and other Rausser College of Natural Resources scientists affiliated with UC Berkeley's Innovative Genomics Institute (IGI) are working to address these issues through synthetic biology and CRISPR gene editing techniques. By developing cutting-edge methods to help plants resist pathogens, improve crop yields, and even remove carbon from the air, they are pioneering sustainable approaches to agriculture—a key part of the new bioeconomy. Their work offers promising advances for the planet by helping to slow global warming, supercharge photosynthesis, and alleviate world hunger.

FIGHTING PLANT PATHOGENS

Fungal plant pathogens can seriously threaten farming productivity by causing significant—or sometimes total—destruction in fields. Rusts, a category of fungal pathogens named after their dust-like orange spores, can reduce crop output and spread over vast distances by air. Other fungal pathogens like rice and wheat blast are capable of ravaging entire fields and becoming resistant to commonly used fungicides. Humans can breathe in the pollen grain-sized fungal spores when plant epidemics occur, further underscoring the connection between plant health and human well-being.

A major problem, says Krasileva, an assistant professor in the Department of Plant and Microbial Biology (PMB) and the Center for Computational Biology, is that plants can't learn to fight new pathogens the way humans do. "Plants don't have circulating immune cells, which means they don't have adaptive immunity," she notes. "They're born with a set of genes that determine which pathogens they can recognize."

When a new pathogen is introduced, it wipes out susceptible plants that cannot recognize it. Individual plants that recognize the pathogen are able to mount an immune response and survive, passing these functional immune responses to future generations. Immunity happens, then, at the population level, shifting over generations rather than during the lifespan of an individual plant.

But pathogen recognition in plants requires genetic diversity. In modern farming, many crops are monocultures, or genetically identical plants, which are often planted year after year on the same swathes of land. "When you have a genetically uniform crop, pathogens have an advantage," Krasileva says. "A virulence molecule outcompetes one genotype, and it's got them all."

Identifying genetic sources of disease resistance in plants' wild relatives and integrating them into crops is a laborious process. Instead, Krasileva hopes to improve crop immunity by modifying immune receptors called NLRs, or nucleotide-binding leucine-rich repeat proteins, which act as molecular antennas capable of detecting pathogens and activating a plant's immune system.

As part of their inquiry into plant diversity, Krasileva's lab has been investigating various species of duckweed, which are genetically simpler than many other plants and can reproduce very quickly, making them an excellent candidate for research. **Erin Baggs**, a graduate student in Krasileva's lab, has identified five duckweed species that lack most NLRs and other defense components previously thought to be indispensable in plants. These species seem to rely, instead, on antimicrobial peptides. Now, the team is also investigating how this natural defense barrier can play a role in plants fending off pathogens. "There are many ways organisms withstand pathogens and communicate with each other," Krasileva says. "We're just scratching the surface of that understanding. I am excited to learn more lessons from biodiversity."

As climate change intensifies, fungal pathogens like stripe rust have adapted faster than the field crops they afflict.

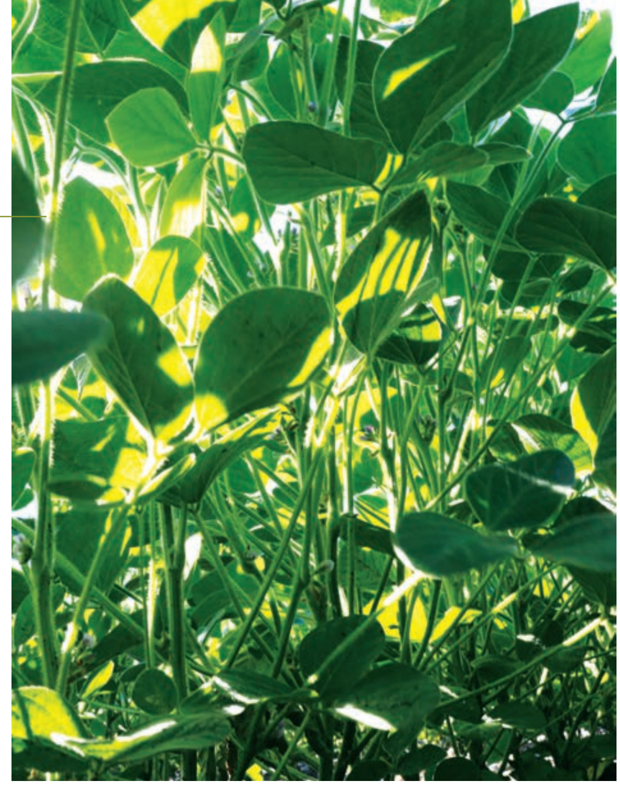
As the effects of climate change intensify, many fungal pathogens—like stripe rust—have adapted to survive in warmer and drier areas faster than the plants they affect. By better understanding the ways that plants, bacteria, and other organisms fight off disease, Krasileva hopes to add to the growing body of scientific knowledge that can help plants stay ahead of disease, even in the face of major change.

FASTER PHOTOSYNTHESIS

Another stream of research uncovering new understanding of plant functions, led by PMB professor **Krishna Niyogi**, focuses on increasing the efficiency of photosynthesis. Photosynthesis is the process by which plants convert water, sunlight, and carbon dioxide into food (sugars) and oxygen. When the sun is most intense, plants can't use all the energy they absorb for photosynthesis. Instead, they dissipate the excess by giving off heat—a process plants can activate quickly but are mysteriously slow to turn off. This often results in wasted energy.

Now, Niyogi and his team have identified the genetic activities responsible for regulating this process. By inserting new genetic material that allows the plant to produce more of three key proteins involved, the researchers have been able to speed up the shut-off response—even when light levels fluctuate—which allows plants to retain as much energy as possible for the important work of growing via photosynthesis.

This discovery could have important implications for increasing crop yield and alleviating hunger around the world. The researchers started a decade ago with a pilot project to



Modified soybean plants from a field trial at the University of Illinois.

Allie Arp/RIPE Project

modify tobacco by inserting genetic material from *Arabidopsis*, a small flowering plant. After proving that the technique improved photosynthetic efficiency and biomass in tobacco—which was chosen because it is a crop plant that allows for faster experimentation—the team worked to show that the same gains could be achieved in a food crop. Niyogi's lab and collaborators at the University of Illinois were able to modify soybeans to increase seed production by up to 30 percent using the same DNA construct, a first-of-its-kind finding recently published in *Science*. "This advancement could provide a buffer against the effects of climate-linked crop impacts while potentially increasing yield for farmers who need to boost their output," Niyogi says.

The three genes Niyogi and his collaborators modified are found in all plants. So, it's possible that scientists could alter the expression of a plant's own genes to achieve the same outcome without incorporating DNA from other plant species.

A new IGI initiative in which Niyogi is involved focuses on editing sorghum and rice varieties to remove carbon from the atmosphere more efficiently by improving photosynthesis and increasing root biomass. The research is a collaboration including **David Savage**, a professor in the Department of Molecular and Cell Biology; **Brian Staskawicz**, a professor in PMB and director of sustainable agriculture at IGI; **Peggy Lemaux**, a professor of Cooperative Extension in PMB; **Pamela Ronald** (PhD '90 Molecular and Physiological Plant Biology), a professor at UC Davis; and **Myeong-Je Cho**, director of the IGI Plant Genomics and Transformation Facility. With **Jennifer Pett-Ridge** ('05 Soil Microbial Ecology) of Lawrence Livermore National Laboratory and **Jill Banfield**, a professor in the Department of Environmental Science, Policy, and Management, the team will work to optimize root development and root exudates that can promote carbon sequestration in the soil.

ACKNOWLEDGING UNCERTAINTIES

Even as they create exciting possibilities for addressing some of the world's largest problems, the scientific advances made possible with synthetic biology and CRISPR technology also bring with them uncertainties and potential risk.

"When you deal with environmental applications of CRISPR, as opposed to human health ones, you are putting new or novel entities into the environment," says **Nertila Kuraj**, a postdoctoral researcher at the University of Oslo. "You don't know how they will adapt to the natural environment, how they will interact with other species in the ecosystem, and what the long-term impacts will be." While a visiting scholar at Berkeley Law, Kuraj collaborated with law professor **Dan Farber** on a project aimed at assessing risk and uncertainty in regard to gene editing for environmental purposes.

"There should be transparency about how risk assessment and safety are established and defined," says Kuraj, who is working to connect social scientists concerned with the risks of genetically modified plant species with the researchers developing them. The IGI has also invested in such partnerships; its Public Impact Team is working to align societal values with genome-engineering advances through public dialogue and policy research.

At present, crops edited using CRISPR are regulated as genetically modified organisms (GMOs) in the E.U., but not in the U.S. The USDA allows plants to be modified using their own genetic material, as Niyogi is hoping to do with soybeans. He says the team's new methods can be layered with other promising approaches to alter the soybean's DNA using only genetic material from the soybean itself, rather than using *Arabidopsis* DNA. This process could allow it to be considered non-GMO in the U.S.

Despite being frequently misunderstood by the public, the GMO distinction holds importance for farmers, legislators, corporations, and consumers. For scientists, creating crops that address world hunger means steering clear of GMO designations whenever possible. Legislation lags scientific advances, so new regulations can quickly become not just unenforceable but obsolete.

Kuraj hopes that scientists and ethicists will maintain open communication with an eye toward allowing progress while staying transparent, incorporating social justice principles, and respecting Traditional Ecological Knowledge. She and Farber are planning an interdisciplinary conference to foster these types of conversations. "I think it's possible to have the necessary degree of interdisciplinarity to understand each other," Kuraj says, as she works to bridge plant biologists, CRISPR experts, and social scientists. "You have to foster it; it will not come out of nothing."

BUILDING THE BIOECONOMY

Bioremediation Bacteria Hunter

DREW HENDRICKSON, BS ’19 MICROBIAL BIOLOGY AND CHEMICAL BIOLOGY

BY KRISTIN BAIRD RATTINI

Drew Hendrickson’s job title is Head of Organism Discovery and Assay Development for BluumBio, an innovative bioremediation company based in Berkeley. But one might think of him as a bacteria hunter. His fascination with bacteria, first sparked in his teen years, has propelled his passion for identifying enzymes in nature and engineering them to break down toxins and restore degraded landscapes.

It was the environmental degradation caused by the Deepwater Horizon oil spill in 2010 that set Hendrickson on his path toward UC Berkeley and bacteria hunting. “It was this doomsday moment, with crude oil in the ocean and on the beaches,” he says. “But I was amazed by how quickly the deep-sea bacteria growing on underwater oil seeps could help clean things up. Humans made a mistake, but the bacteria were ready to go.”

A PERSONAL AND ACADEMIC HOME

As a “sensitive, gay, Filipino boy” whose military family moved frequently, Hendrickson felt more comfortable in nature than among his peers. He later found an accepting and nurturing environment at Berkeley and became a leader of the UNITY Resource Center, a student group that promotes identity exploration and community engagement through a lens of gender and sexual diversity. He organized workshops as well as a drag show on campus and attended the Creating Change Conference in Washington, D.C.

Hendrickson started out as a chemical biology major. "I thought that chemistry was like eating my vegetables: It was good for me," he says. "It taught me the 'how,' but I didn't have my 'what.'"

> "Humans made a mistake, but the bacteria were ready to go."
>
> **— DREW HENDRICKSON**

Upon joining the lab of **Norman Terry**, longtime professor of plant and microbial biology who passed away earlier this year, Hendrickson found his motivation—his 'what' and 'why'—in microbiology. "I loved how bacteria were so intimately at the middle of everything, how they affected water, soil, plants, and human health," he says. He added microbial biology as a second major.

Terry's lab was engineering bacteria and plants for environmental remediation of petroleum hydrocarbons in the polluted soil around a former Shell petroleum refinery. The team gathered four native species of plants from the site and screened more than 36 consortia, or collections of bacteria attached to plant roots. As part of a Sponsored Project for Undergraduate Research (SPUR) grant from Rausser College, Hendrickson helped collect and analyze bacteria to see how well they could break down contaminants and promote plant growth. The best-performing bacteria were added to seedlings to be replanted on site. The experience formed the basis of Hendrickson's senior thesis.

Among his colleagues in the lab was **Katherine French**, a postdoctoral researcher who mentored him through the thesis project. After graduation, Hendrickson spent two years at Lawrence Berkeley National Lab researching bacterial adaptation in a subsurface watershed that was contaminated by the Manhattan Project. "It was an opportunity to learn something valuable out of the trauma on the land and understand how bacteria adapt to the stresses of radioactive pollution," he says.

COMING INTO BLUUM

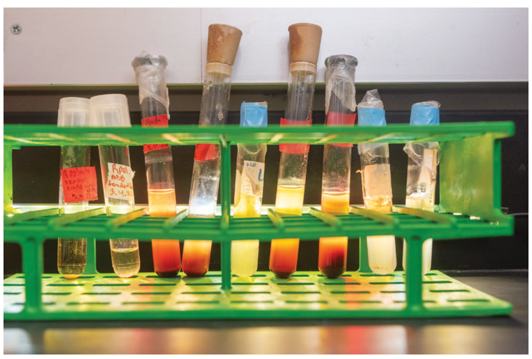
In 2021, French invited Hendrickson to join a team of synthetic biologists, genetic engineers, and plant biologists in her new enterprise: BluumBio. An early participant in the UC Berkeley Energy & Biosciences Institute's incubator program, the company selects microbes and plants from polluted soil and groundwater and evolves them in the lab to eat the toxic waste in situ, eliminating the need for costly removal of contaminated substrates.

Using a process called directed evolution, Hendrickson and his colleagues improve bacteria to address environmental pollutants like PCBs—highly carcinogenic chemicals formerly used in industrial and consumer products—and PFAS, so-called "forever chemicals" present in many modern-day products that hardly degrade in the natural environment. "We screen thousands of mutants for top-performing variants and in months can develop optimized proteins for clients that would otherwise take 100 to 200 years to evolve in nature," he says.

Among BluumBio's clients is UC Berkeley, which is working to remediate PCB, arsenic, and heavy metal pollution at the Richmond Field Station—a former explosive manufacturing site acquired by the University of California in 1950. He's also surveying three other California sites with PFAS pollution, including the Travis Air Force Base Superfund Site.

Hendrickson speaks excitedly about his ever-growing microbial armamentarium designed to take on such toxins. "This month I've grown an acidophile, a thermophile, magnetotactic bacteria, photosynthetic algae, and fungi that degrade chlorinated compounds," he says. "It's very fun and satisfying to have a new microbe at the end of the day."

His experiments don't stop when he clocks out. In his free time, he loves cultivating "bizarre organisms" like bioluminescent microbes, mantids, and carnivorous plants. Hendrickson also grows orchids from the Philippines to feel closer to his ancestry. He recalls growing up hearing stories about gender-fluid Filipino shamans, who communicated with the spirits of nature to heal the land—an inspiration for his own work cultivating bacteria for future bioremediation challenges.



Drew Hendrickson's culture collection in the BluumBio lab includes *Rhodopseudomonas palustris* (left), a bacterium that has potential to be used as a biofertilizer that can also degrade toxins.

Mathew Burciaga

Beth and Michael Miller with UC Berkeley Chancellor Carol Christ during the 2022 homecoming football game.

Collective Impact

HOW RAUSSER COLLEGE'S STRONG COMMUNITY INSPIRED PARENTS BETH AND MICHAEL MILLER TO SUPPORT UNDERGRADUATE EXPERIENCES

BY LINDA RAFFERTY

When their daughter Annie chose to attend UC Berkeley—a school over 2,500 miles from home—Beth and Michael Miller were excited to know she was attending one of the top public universities in the world, but they also felt hesitant about the size of the school. "On such a large campus, there are so many resources, but I also just wanted to know that she'd be able to make meaningful connections," says Beth, noting that their other three children had gone to smaller schools much closer to home.

From the moment Annie arrived on campus, the Millers' fears were assuaged. "We were incredibly impressed by the community Annie found at Rausser College, especially the unique advising program," she says. "That has been such a game changer."

The Millers have loved seeing their daughter pursue her passion for creating a more sustainable world through her classes and beyond. After taking Professor **Kate O'Neill**'s International Environmental Politics class, she participated in O'Neill's Zero Waste Lab through the Sponsored Projects in Undergraduate Research (SPUR) program. Beth laughs about how she surprised friends by giving an update on the Berkeley experience: "Annie has been wearing a hazmat suit and sorting through the garbage at the dorms, doing a waste audit," she says. "Now, when I think of garbage, I think of Annie: she's made our whole family think carefully about how our choices can keep things out of the landfill."

Fast forward three years: Annie is a senior majoring in both society & environment and data science. The Millers co-chair the university-wide Cal Parents Board and actively support Rausser College of Natural Resources—and encourage others to do the same. They have welcomed fellow parents at Homecoming, answered questions for prospective students and their families at Cal Day, and reached out to parents during Big Give, Berkeley's day of giving.

In addition to being generous donors to the Rausser College Fund for Natural Resources (which funds programs geared toward undergraduate students), the Millers established a campus Fiat Lux Scholarship, which provides monetary, community, and academic support to underrepresented and first-generation students from California. They also give to the Basic Needs Center—a UC Berkeley initiative that supports students' overall well-being and where Beth is now a member of the advisory council.

"Equity has always been important to us," says Michael, a founder and managing director of Crewcial Partners, LLC, a New York-based firm that provides consulting services to nonprofit institutions. "We recognize the advantages we have received in life and how the world really works for others. We wanted to take that luck and pass the opportunity on."

Beth says she truly enjoys talking to other parents who are also excited about Cal, and she's motivated by the collective impact they can make. "It's amazing to see how many small donations add up to a mountain of money that can be really helpful to achieve the College's goals," she says. "I hope everyone who can give will realize the value of giving to this incredibly special place."

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Keegan Houser

Wildfire Tests Blodgett Forest

PHOTOGRAPH BY ARIEL ROUGHTON

When the Mosquito Fire (smoke pictured) entered Blodgett Forest Research Station in early September, the "living laboratory" was put to the test. Research Stations Manager **Ariel Roughton** worked with ground crews to ensure that fire suppression operations took the highly valuable research into consideration. After returning to the facility once the fire had been pushed back, Roughton and Berkeley Forests Co-Director **Rob York** documented mixed impacts to the research plots. One area treated by pyrosilviculture—which blends applications of prescribed fire with traditional forest management methods—suffered low-severity impacts. "I've worked for the last 20 years for this moment," said York, who is also a professor of cooperative extension in the Department of Environmental Science, Policy, and Management, in an interview with the *New York Times*. "Here's an actual, real-life test. It's not just computer models."

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