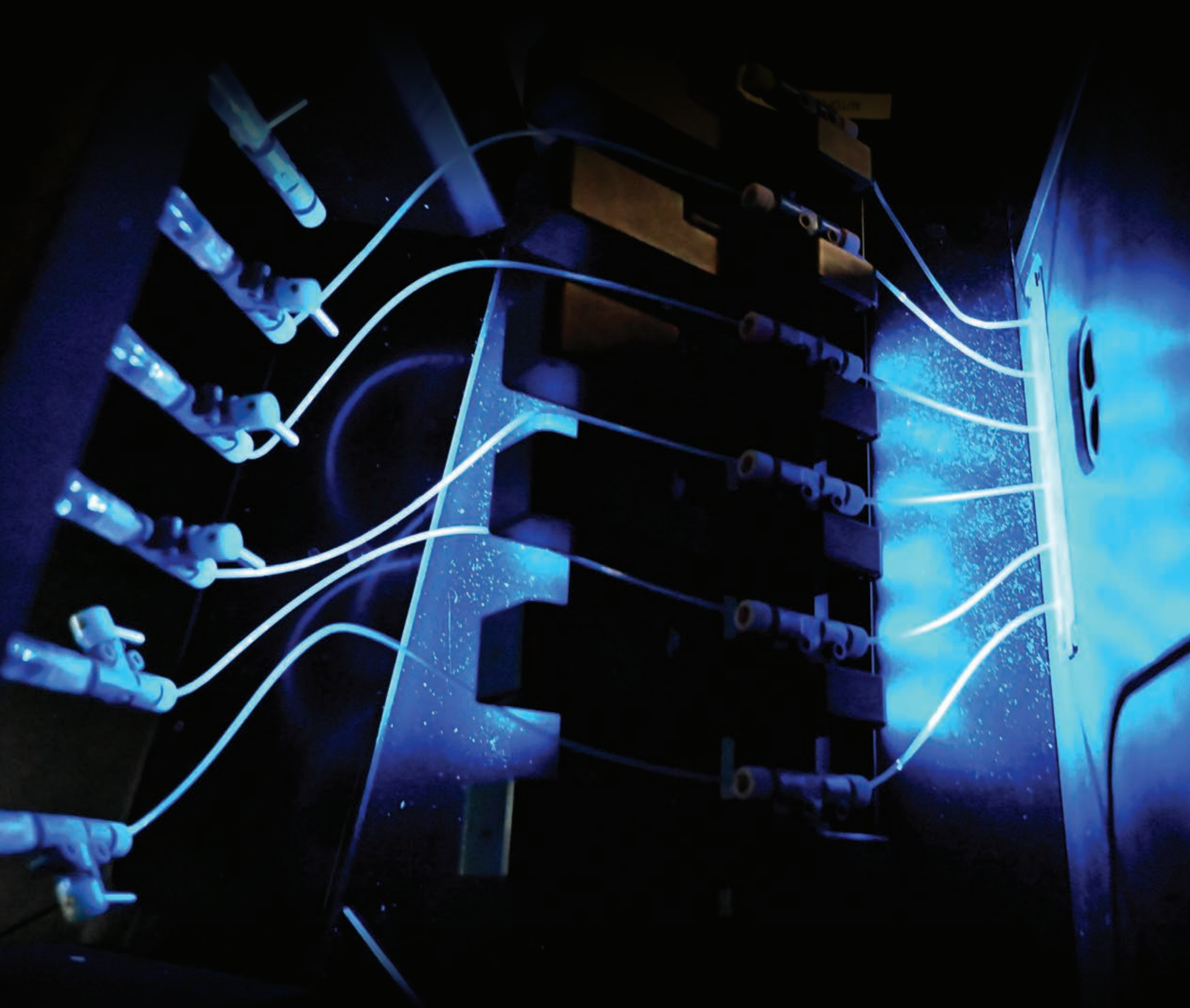
ALFRED P. SLOAN FOUNDATION



2021 HIGHLIGHTS

ALFRED P. SLOAN FOUNDATION

Cover: A microfluidics system in the lab of Rockefeller University researcher Dr. Shixin Liu. These syringes are just one component of a larger microscope that allows simultaneous manipulation and visualization of single-molecule interactions in real time and which Liu and collaborators are using to explore the role of mechanical force in DNA transcription. Liu's experiments are part of the Sloan Foundation's new Matter-to-Life program, which aims to sharpen our understanding of the principles and mechanisms that guide the complexification of matter towards life.
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The Alfred P. Sloan Foundation is a nonpartisan, not-for-profit grantmaking institution dedicated to improving the welfare of all through the advancement of scientific knowledge. The Foundation works in four different areas to help drive the research frontier forward.

RESEARCH & DISCOVERY The Foundation believes that scientific discovery is a chief driver of economic prosperity and that the research enterprise is a vitally important engine of human progress. We help scholars conduct cutting-edge research across a range of disciplines, from astronomy to particle physics to energy economics. Our research grants focus on underexplored topics; innovative methods; and risky, adventurous projects where success holds the promise of truly transformative discovery.

DIVERSITY, EQUITY & INCLUSION Scientific progress is too important to belong to any one gender, race, or ethnicity. We partner with researchers, educators, administrators, and students on initiatives to increase access to scientific education, enhance meaningful participation in the scientific process, and change the culture of scholarship in ways that make it more open, responsive, and affirming to all.

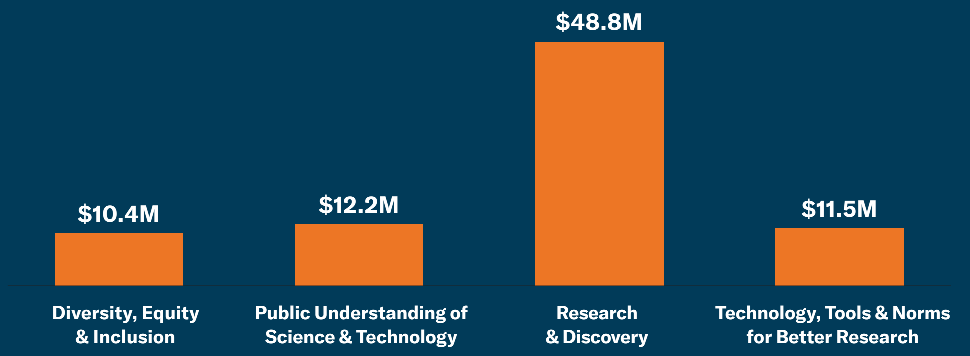
TECHNOLOGY, TOOLS & NORMS FOR BETTER RESEARCH In recent decades, developments like computing and the internet have created new challenges and opportunities for researchers. We work with technologists, programmers, engineers, and scholars to develop innovative new tools, practices, and institutions that give researchers the ability to generate, analyze, and share knowledge at unprecedented speed and scale.

PUBLIC UNDERSTANDING OF SCIENCE & TECHNOLOGY In our increasingly technological world, it is more important than ever that the fruits of scientific discovery be accessible to everyone. We partner with artists across a diverse range of media to help tell stories that expand and deepen public engagement with science and technology.

Founded in 1934 by Alfred P. Sloan Jr., the industrialist who made General Motors a household name, the Sloan Foundation was created out of Mr. Sloan's firsthand experience watching scientific and technological innovation drive prosperity and lift American standards of living. Today, we strive to uphold the legacy of that founding insight and to be guided in all our actions by the values of the scientific enterprise: impartiality, empiricism, curiosity, rigor, and the conviction that a careful, systematic understanding of the forces of nature and society, when applied inventively and wisely, can make the world a better place for all.

2021 Grantmaking at a Glance

At year-end 2021, the Sloan Foundation had assets totaling approximately $2.3 billion. During 2021, the Foundation awarded over $82.9 million in grants to support projects across our four focus areas:



* The Foundation awarded an additional $2.3 million in grants to support nonprofit initiatives and New York City-based projects that advance the Foundation's mission.

The Promise of Great Ideas

The COVID-19 pandemic has reshaped our perceptions of the world, drawing our attention both inward and outward. Inward, to the screens that were for a time our only bridge to family, friends, and colleagues. And outward, to the world, as we faced together the first global emergency of our lifetimes.

The pandemic had similar effects here at the Sloan Foundation, driving us to look both inward at the fundamental purposes and processes animating our grantmaking, and outward at the opportunities we have to use scientific discovery to make the world a better place. It is a remarkable privilege to be in the position to make nearly $100 million in grants each year. And with this privilege comes a profound responsibility to address issues that really matter.

If—as our tagline asserts—the Sloan Foundation is "driven by the promise of great ideas," then which ideas have the greatest promise, and what are we driven to do with them?

Some insight into this question may be found in the way we structure our grantmaking. Each of Sloan's programs addresses a big question, one motivated by an important fact about our world. Let's consider these programs in turn, making explicit the facts and the questions those facts imply:

> **Energy & Environment:** *Earth is warming because of human activity.* How will we, as a society, manage the transition to a low-carbon energy future?
>
> **Technology:** *Our lives are increasingly shaped by rapidly evolving technologies.* How has information technology changed the nature of scholarly research, and how can we take advantage of those changes?
>
> **Matter-to-Life:** *The mystery of life is as old as human consciousness.* What are the physical principles underlying the complexification of inert matter into living beings?
>
> **Sloan Digital Sky Survey:** *The universe has a discoverable history.* What do millions of stars and galaxies, studied as a group, have to teach us about that history?
>
> **Higher Education:** *Racism and sexism remain profoundly destructive forces, influencing our society at both individual and structural levels.* How can we create a science ecosystem in which everyone participates equally?
>
> **Economics:** *Industrial capitalism has created both enormous benefits and unequal access to those benefits.* How can the rigorous methods of modern economics produce knowledge that can be used to make our society more just?
>
> **Public Understanding of Science:** *Understanding of science and confidence in it are indispensable if we are to use reason to improve our society.* How can science be infused into all culture, so that science is fully appreciated as a normal human endeavor?

Grantmaking throughout our programs is inspired by these very big questions. And it is not uncommon, in fact, for a project to address more than one.

In the stories you'll read in these pages, we've strived to represent the breadth of the Foundation's activities, although we can touch only on a small fraction of the work we fund. This modest selection of stories, however, already illustrates that we, through our remarkable grantees, are answering questions and addressing issues that really do matter.

For example, it is critical to achieving a low-carbon energy system that we have a meaningful quantification of the impact of continuing to burn fossil fuels. As you'll read, the latest work on the social cost of carbon, led by our grantee Resources for the Future, provides an indispensable tool for those who are developing economic and regulatory policies to drive the clean energy transition.

Similarly, it is foundational to our democracy to understand our population—who we are and how we live. The decennial census is the ultimate big data archive for social scientists, and reconciling its extraordinary research potential with considerations of individual privacy requires sophisticated mathematical techniques. In this report, you can read about Cynthia Dwork who, with Sloan's support, developed rigorous new tools that are now being deployed by the Census Bureau.

Preserving privacy is but one of the challenges of modern information systems. Surveillance, misinformation, harassment, and other ills have come to define our online lives as much as the conveniences and democratizing possibilities that dominated early, utopian visions of what the internet might become. A Sloan-supported podcast from the Electronic Frontier Foundation, *How to Fix the Internet,* helps listeners make sense of these powerful forces that affect us all so deeply.

The internet isn't the only technology with the potential to make science more inclusive. Another is the advent of very small and cheap satellites that almost anyone can launch. Sloan grantee Daina Bouquin has been leading an effort to develop local public libraries around the world into centers for downloading data from these satellites, so the full democratizing potential of this new technology can be realized.

Some of the biggest scientific questions lurk inside the smallest living system: the cell. We now know about DNA, of course, but it's a foundational and perplexing puzzle that our cells transcribe DNA with so few errors, thereby passing on so faithfully the information that defines who we are. As you'll read, researchers at Rockefeller University are exploring the intriguing new idea that the mechanical forces tugging on the ends of the RNA that does the transcribing are a critical piece of the puzzle. As with much of the science that Sloan supports, this research is deeply interdisciplinary, using sophisticated new techniques from physics to investigate an age-old problem in biology.

One of the most important big questions that concern us at Sloan is how we can create a science ecosystem in which everyone participates equally. Colleges and universities seeking to address racism, sexism, and inequality in their programs do so under increasingly shifting legal constraints. For more than a decade, Sloan has supported the Diversity and the Law project, whose purpose is to provide institutions with expert guidance on how to effectively pursue these critical goals. This work, so vital to the pursuit of justice and excellence, is described eloquently in the interview with Sloan grantees Shirley Malcom and Jamie Lewis Keith.

And finally, a word about one of our oldest and most impactful programs, the Sloan Research Fellowships. Since 1955, the Foundation has been identifying and supporting promising young scholars, providing them unrestricted funding at the outset of their careers. We make 118 awards annually, in the fields of chemistry, computer science, earth system science, economics, mathematics, neuroscience, and physics. In contrast to our other grantmaking, these are bets on researchers, but not on specific projects; on individual scientific minds, rather than individual scientific questions.

More than 50 former Sloan Research Fellows have gone on to win the Nobel Prize, but the larger impact is on the thousands of scientific careers the fellowships help launch. The Foundation is making bets on potential, and on the future. We can't presume to know what the most important questions will be years from now, nor what sorts of answers those questions will require. Thus our commitment to renewing the community of scholars who will develop, in the years to come, the great ideas whose promise we are driven to support.

I hope you enjoy reading *2021 Highlights.* I hope, too, that you come away as convinced as I am that at the Sloan Foundation we are addressing questions of true importance, commensurate with the scale of the challenges our society faces and of the scientific mysteries that still confront us.

Adam Falk

— Adam F. Falk,
President, Alfred P. Sloan Foundation

A set of small satellites, known as “smallsats” or “cubesats”, is ejected from the Japanese Small Satellite Orbital Deployer on the International Space Station on June 17, 2019.

Science, Cubed

The vanguard of the newest frontier in satellite science is coming from an unlikely source: the world’s libraries.

We're living in a golden age of democratized space exploration. Gone are the days when satellites were the exclusive province of national governments and telecom giants—nowadays, just about anyone can create and launch a satellite, thanks in large part to the evolution of "cubesats" or "smallsats", small satellites with big ambitions to support scientific research.

Smallsats are booming in popularity. Smaller and cheaper than traditional satellites, they're opening entirely new avenues of space exploration—offering enormous troves of data for science, relaying signals between distant radio stations, and inspecting the condition of traditional satellites to make sure they're still fit for work. They've even been some countries' first-ever satellites in orbit. But if we want to make the most of all these new satellites gathering cosmic insights, we need somewhere to send their data.

Daina Bouquin is head librarian at the Harvard-Smithsonian Center for Astrophysics, and she's leading a Sloan-backed effort to get more people involved with space exploration while providing critical infrastructure to capture smallsat space mission data through a program called the Library Space Technology Network (LSTN).

"We've been offering kits to libraries across the globe so they can install their own satellite ground stations and plug into a global network," says Bouquin. "We've already organized builds in Moldova, Chile, Texas, and Massachusetts, and each of these receivers is allowing smallsats to communicate with Earth."

Dara Cavness is director at the Public Library in Marathon, Texas. In addition to running curbside book pickups to keep kids reading during Covid lockdowns, helping older neighbors register for pandemic support services, and assisting the National Guard with popup testing facilities, Cavness has been hard at work installing Marathon's LSTN ground station.

TOP: Installed on the roof of the John G. Wolbach Library in Cambridge, MA, this antenna is one node in a network of ground stations that receives research data from smallsats launched into orbit by scientists.

BOTTOM: Students participate in a satellite ground station community build at Biblioteca Municipală „B.P. Hasdeu" in Chișinău, Moldova.

"Putting together the antenna was straightforward using the tools and instructions sent by Daina's team," says Cavness. "Things got a little tricker when it came to configuring the IP address. We don't have a dedicated IT team—but someone in town with the right skills got the antenna connected to the network, and it's been up-and-running since."

"A librarian's job is to support their community... The joy in this work comes not only through fostering interactions, but in enabling great research that changes how we think about the universe and our place within it."

—Daina Bouquin

Cavness's station has now been used 1,122 times by dozens of satellites built by groups all over the world. And the network to which the receiver belongs is supporting numerous international satellite missions. Following the success of this project, Cavness is considering how to bring her community together with similar projects.

Bouquin, meanwhile, is also working on another challenge with smallsats—a lack of comprehensive metadata to describe these missions. Metadata is data that provides information about other data. Just like books in a library contain a wealth of metadata to help us successfully find the book we're looking for—title, author, or genre—the reams of information generated by smallsat missions would be much easier to navigate if there were metadata standards in place.

"Smallsat missions have plenty of metadata, but it's messy. Different missions develop unique protocols and record metadata differently, meaning it can't be readily used by others. This severely restricts the findability and potential use of these datasets. It also makes it harder for smallsat teams to learn from each other," says Bouquin.

"That's why we've been working on MetaSat, an open metadata toolkit for smallsat missions," Bouquin says. "MetaSat provides a common vocabulary for a global community, giving each part of a mission context and helping data from different missions be understood universally."

MetaSat is already being used by Libre Space Foundation's SatNOGS, a global network of satellite ground stations receiving data from scientific and research satellites—including Cavness's station in Marathon—and it will also be used by the NASA Small Satellite Reliability Initiative Knowledge Base, an online tool combining best practices for smallsat missions.

For Bouquin, strengthening community through ground station builds and creating technology through MetaSat exemplifies her mission: "A librarian's job is to support their community. As the community's needs evolve, the library must evolve to meet those needs," says Bouquin. "The joy in this work comes not only through fostering interactions, but in enabling great research that changes how we think about the universe and our place within it."

Maze Runners

Advancing diversity at the nation's colleges and universities requires navigating a complex, ever-shifting labyrinth of laws, regulations, prohibitions, and directives. Meet the scholars building a map though the maze.


Shirley Malcom


Jamie Lewis Keith

For over 40 years, the American Association for the Advancement of Science's Shirley Malcom has been spearheading efforts to accelerate diversity, equity, and inclusion (DEI) in STEMM higher education. And since the 1990s, the Alfred P. Sloan Foundation has been supporting her, including work on how campuses can navigate an evolving legal landscape. To meet this moment, Malcom and long-time collaborators Jamie Lewis Keith and Art Coleman of EducationCounsel have released a fresh set of resources designed to help colleges and universities make good on their DEI goals in legally sustainable ways.

Why is it important to diversify America's college and university campuses?

Malcom: There are so many reasons! For one thing, we need to remedy a history that locked talented people out of opportunity for centuries. That history has created disparities in the present we need to address, and making sure campuses are diverse and inclusive is one way of doing so. This generation is the intellectual and innovative future of our country—research cannot be excellent, and innovation cannot be responsive, without tapping into the talents of every young person. But then there's the challenge of making it happen.

That must be hard given the many challenges to race-conscious policies in recent years, including the upcoming Supreme Court case.

Keith: Exactly. We've been working together for over 20 years, and we've had to be attentive to changes in the law every step of the way. Since we and a team of colleagues published our first handbook in 2010, we've had to rethink how we help universities achieve their diversity, equity, and inclusion goals by being more systemic and responding to evolving research on what works. We must keep strategies as simple as possible—while attending to legal design standards. The pandemic has elevated everyone's awareness of educational inequities, and it's the most difficult time for higher education in decades. So it's important that colleges have the resources they need to stay committed, regardless of what the Court decides. That's what we provide.

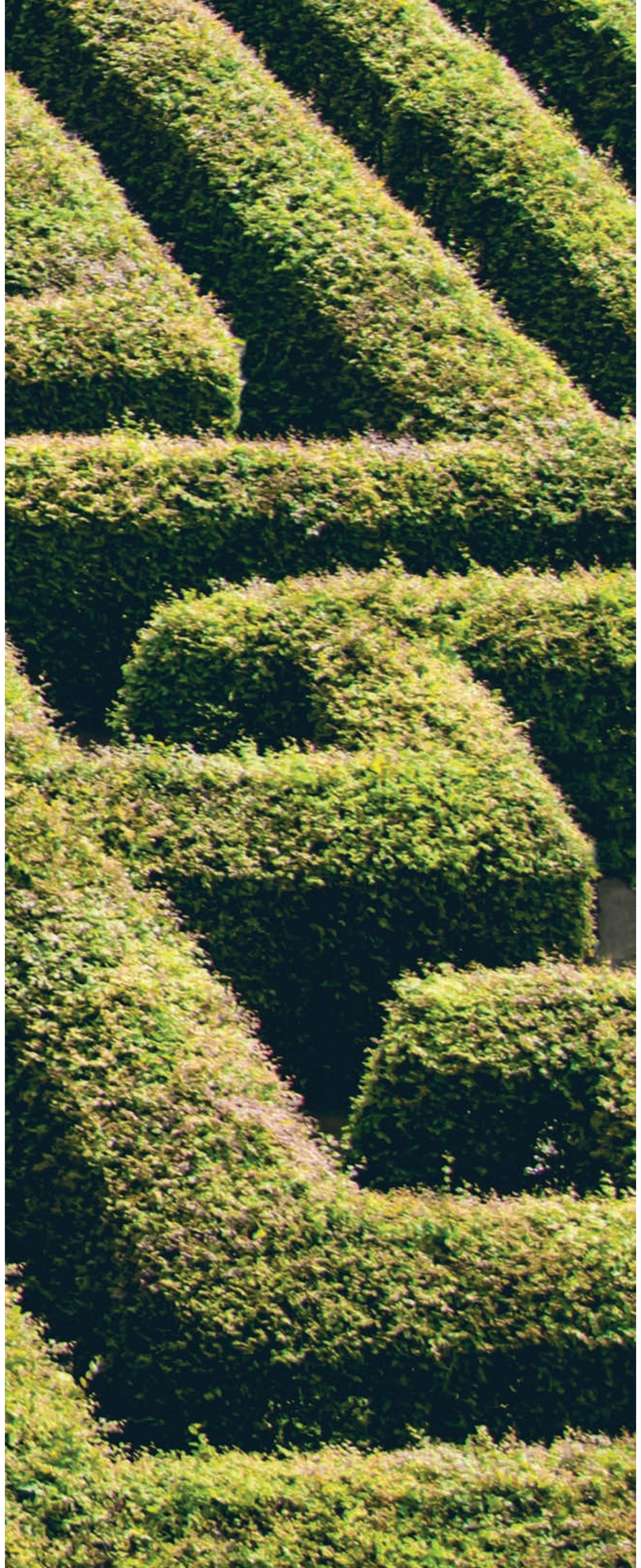
> **"This generation is the intellectual and innovative future of our country—research cannot be excellent, and innovation cannot be responsive, without tapping into the talents of every young person."**

What's in your new trove of resources?

Keith: We've put together an entire constellation of materials for our *Diversity and the Law* project—step-by-step guides for designing faculty employment and student enrollment policies, templates for university DEI management systems and statements, guidance on navigating the current and evolving legal landscape, and research sources, to name a few. They're all free and intended to provide practical guidance that people in policy and legal roles can use. Our new handbook serves as a robust legal resource, but now it's just one part of an ecosystem of materials to help multidisciplinary teams in higher education create more inclusive campuses.

How are people using the new tools?

Malcom: We recently delivered a curriculum for AAAS's SEA Change Institute that tested our resources with seven universities. Over two years, we got the chance to work closely with them on some of the concepts they were finding most difficult, like building a solid, data-driven evidence base to evaluate their policies. The curriculum provides links to resources that help put ideas into action. Our resources have now been downloaded hundreds of times, and every download marks an opportunity to create diverse campuses that better serve students and society.



Keith: As one example, our design guides included UC Berkeley's excellent rubric for assessing a candidate's contributions to diversity, equity, and inclusion. Its simple scorecard helps an interview committee assess whether faculty candidates are likely to perform well in engaging a diverse student population. The rubric and our similar criteria have been adapted by others in the UC system and beyond.

What's next for *Diversity and the Law*?

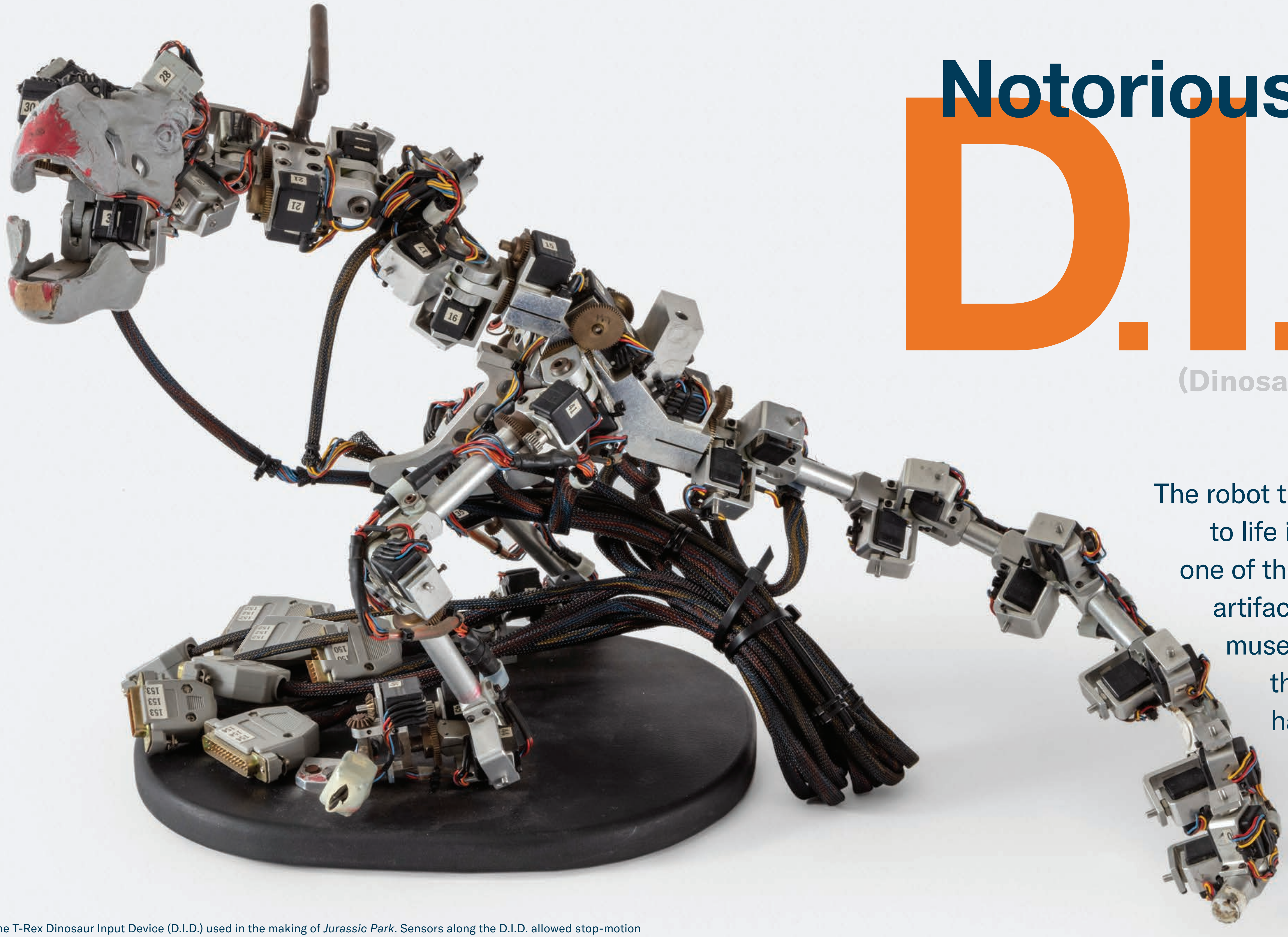
Malcom: The pandemic has shown that the future is less certain than we think. It also made it impossible for students to sit for admissions tests. Universities have been carrying out *huge* experiments on the components of holistic admission criteria. While we don't yet have all the data, early reports by some suggest they attracted more diverse applicant pools—and admitted more diverse applicants—yet noted that class performance looks about the same as before. This suggests the predictive value of admissions tests isn't as great as some people believe, and marks an unexpected opportunity to have a broader conversation about merit, what it means, and how we identify it. This is one of the many things we're inviting colleges to think about.

Keith: The landscape will continue to shift, but we will continue our collaboration, bringing energy, candor, and wise strategies to institutions to help position them well to persist and succeed. The mounting challenges in our world only make us more determined to advance a brighter future.

The full selection of *Diversity and the Law* resources is available at: aaas.org/programs/diversity-and-law

Notorious D.I.D.

(Dinosaur Input Device)



The robot that brought dinosaurs to life in *Jurassic Park* is just one of the priceless Hollywood artifacts on display at a new museum that is celebrating the central role science has played in American cinema, both behind and in front of the camera.

The T-Rex Dinosaur Input Device (D.I.D.) used in the making of *Jurassic Park*. Sensors along the D.I.D. allowed stop-motion animators to feed poses into graphics software for manipulation by digital animators. The D.I.D. marked a paradigm shift in cinema, bridging the worlds of physical and digital special effects and resulting in the film's iconic depiction of the Tyrannosaur.

"Science is an essential part of the history of filmmaking, which is why science is prominent throughout the museum. We're the Academy of Motion Picture Arts and *Sciences*, after all."

In the historic Saban Building on L.A.'s Wilshire Boulevard sits the Academy Museum of Motion Pictures, a new space established by the Academy of Motion Picture Arts and Sciences to "advance the understanding, celebration, and preservation of cinema". The museum is the city's—and the nation's—first institution solely devoted to the art and science of cinema, which is a surprise given that Hollywood has been the global center of filmmaking since its beginnings more than a century ago.

The museum opened its doors in September 2021, and during its first four months some 315,000 visitors flocked to its remarkable collection of filmmaking relics and public programs—including many dedicated to the science of filmmaking and science storytelling.

"The museum is a long time coming and we're thrilled to finally open our doors," says Bill Kramer, Director and President at the Academy Museum. "Science is an essential part of the history of filmmaking, which is why science is prominent throughout the museum. We're the Academy of Motion Picture Arts and *Sciences*, after all."

Kramer thinks about science "on both sides of the camera", which is reflected in the museum's Sloan-supported programming. In front of the camera, the museum regularly screens films with scientific content, which Kramer says demystifies the work of scientists and illustrates the social value of science. During the museum's Oscar Sundays series, visitors can attend select screenings of Oscar-nominated science-themed films, including introductions by scientists and filmmakers speaking about the intersection of science and cinema. The series uses seminal and celebrated films like *The Matrix* and *Interstellar* as avenues to engage audiences with important topics like virtual reality, virology, and artificial intelligence.

Behind the camera, the museum turns its attention to the science and technology that have driven the evolution of filmmaking. The museum hosted a digital program exploring the contributions of Black visual effects artists, taking its attendees—including many young students—through the artists' process, and how they weave live action with computer-generated images to create the visual worlds that drive compelling storytelling. The museum continues to inspire filmmakers with Branch Selects, a weekly screening series that highlights the work of all Academy branches, including visual effects, cinematography, and sound.

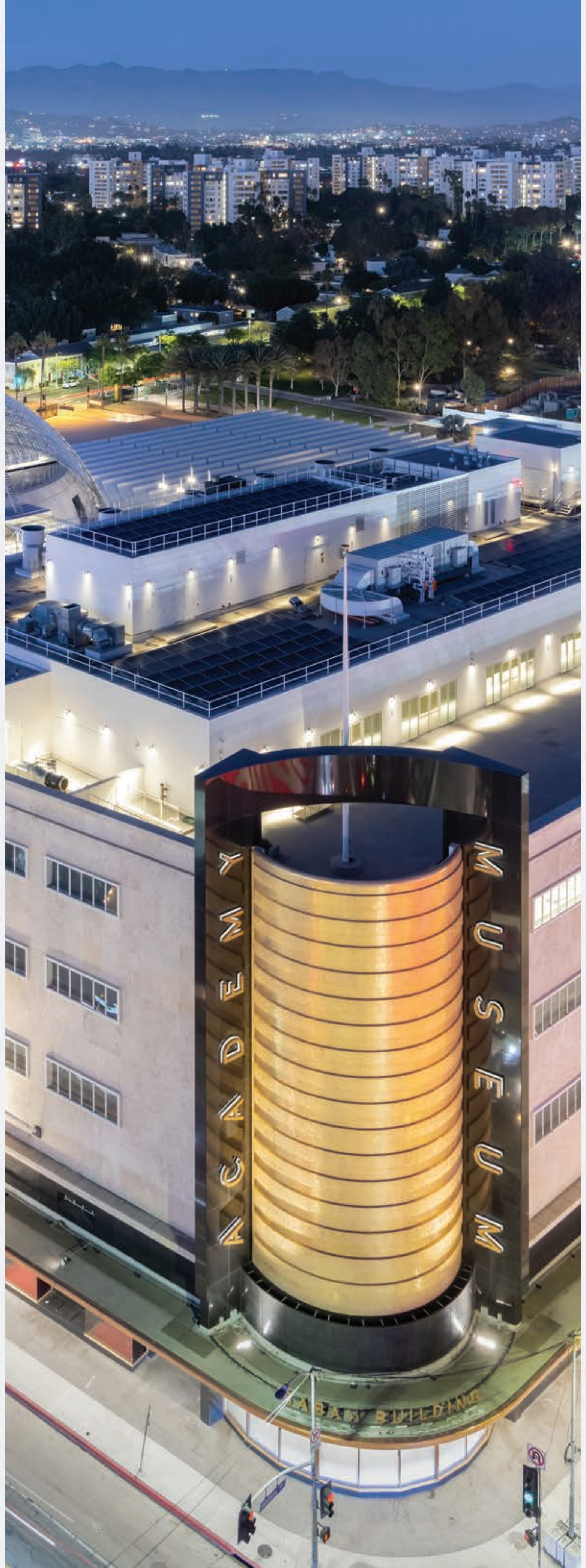
The Academy has been collecting important cinema artifacts since its founding in 1927 and its stunning collection—the largest of its kind—allows the public full access to a century of film.

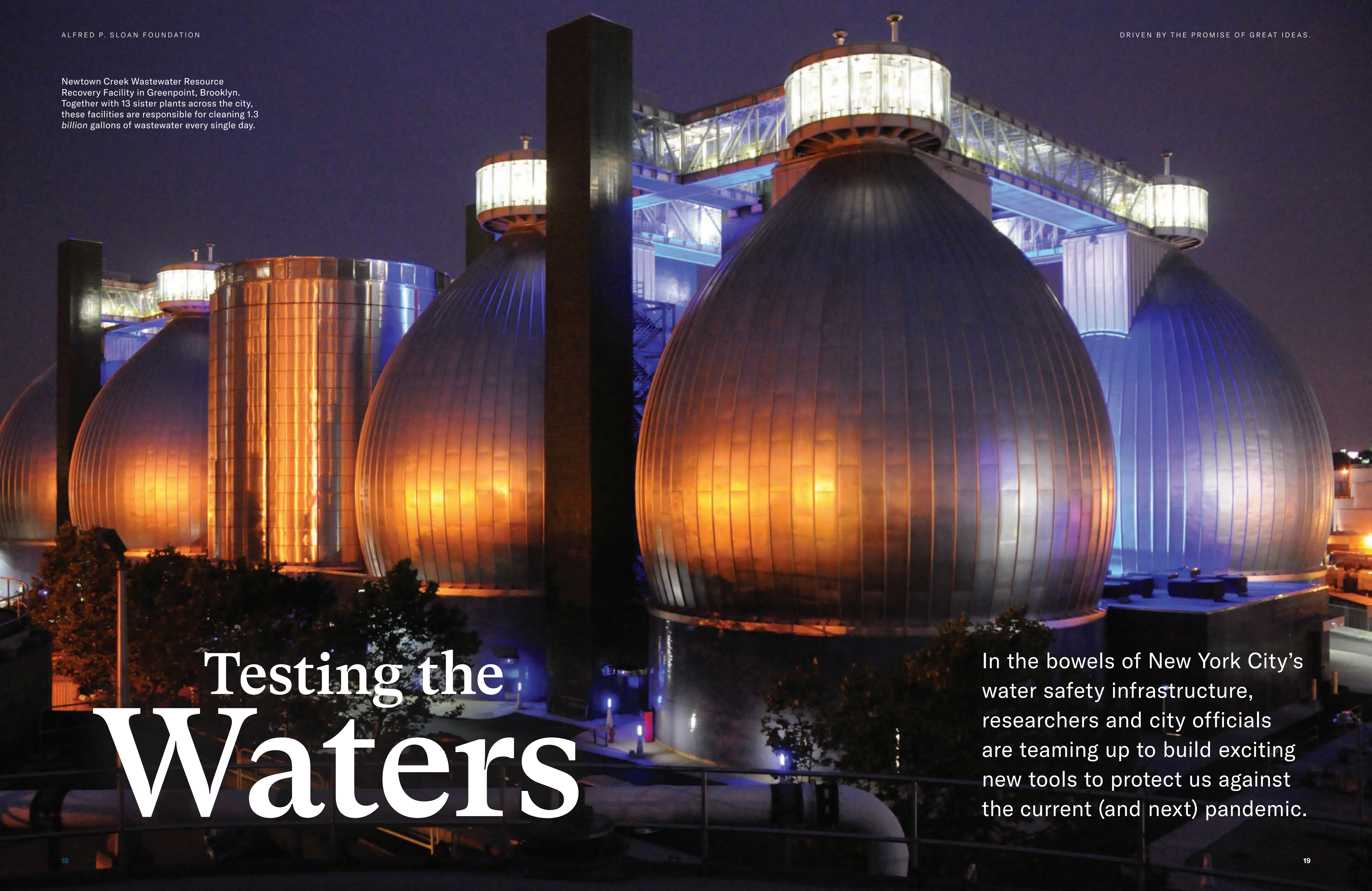
"One of our most prized objects is the T-Rex dinosaur input device from *Jurassic Park*," says Kramer. "It marked a paradigm shift in visual effects, bridging the worlds of physical and digital special effects."

The dinosaur input device is a representation of a T-Rex skeleton. Sensors along its length capture the poses created by stop-motion animators. These are later fed into graphics software for manipulation by digital animators. The device helped *Jurassic Park*'s filmmakers overcome one of the iconic film's central creative problems—how to depict prehistoric creatures in a way that was both scientifically-driven and would dazzle moviegoers.

"Other objects, like Garrett Brown's Steadicam, are unassuming but equally revolutionary," adds Kramer. "The invention of a handheld camera that allows a filmmaker to move *and* shoot at the same time completely changed how movies can be made. It's had an incalculable impact on the industry and continues to inspire visitors.

"Ultimately, we want to show people the distinction between art and science is artificial—and cinema is where they truly unite. We want to create a memorable experience for our visitors, inspire the next generation of film artists, and create an emotional response that—like great cinema—sparks conversation and brings people together."





Newtown Creek Wastewater Resource Recovery Facility in Greenpoint, Brooklyn. Together with 13 sister plants across the city, these facilities are responsible for cleaning 1.3 *billion* gallons of wastewater every single day.

Testing the Waters

In the bowels of New York City's water safety infrastructure, researchers and city officials are teaming up to build exciting new tools to protect us against the current (and next) pandemic.

On a 54-acre plot in Brooklyn's Greenpoint neighborhood, just off Newtown Creek, stands an imposing constellation of eight egg-shaped, metallic domes. Towering at 140 feet tall, the domes have become a bit of a local landmark since they went up in 2010, and however striking they are during the day they're even better after sundown, when blue lights add some dramatic illumination.

The aesthetic beauty of the domes is a bit of visual irony, considering what's going on inside. The domes house machines called sludge digestors, an essential component of the Newtown Creek Wastewater Treatment Plant, a facility responsible for treating and disinfecting waste generated by residents of certain neighborhoods in Brooklyn and Manhattan. Together with 13 sister plants across the city, these facilities are responsible for cleaning 1.3 *billion* gallons of wastewater every single day, including feces, urine,

Andrea Silverman

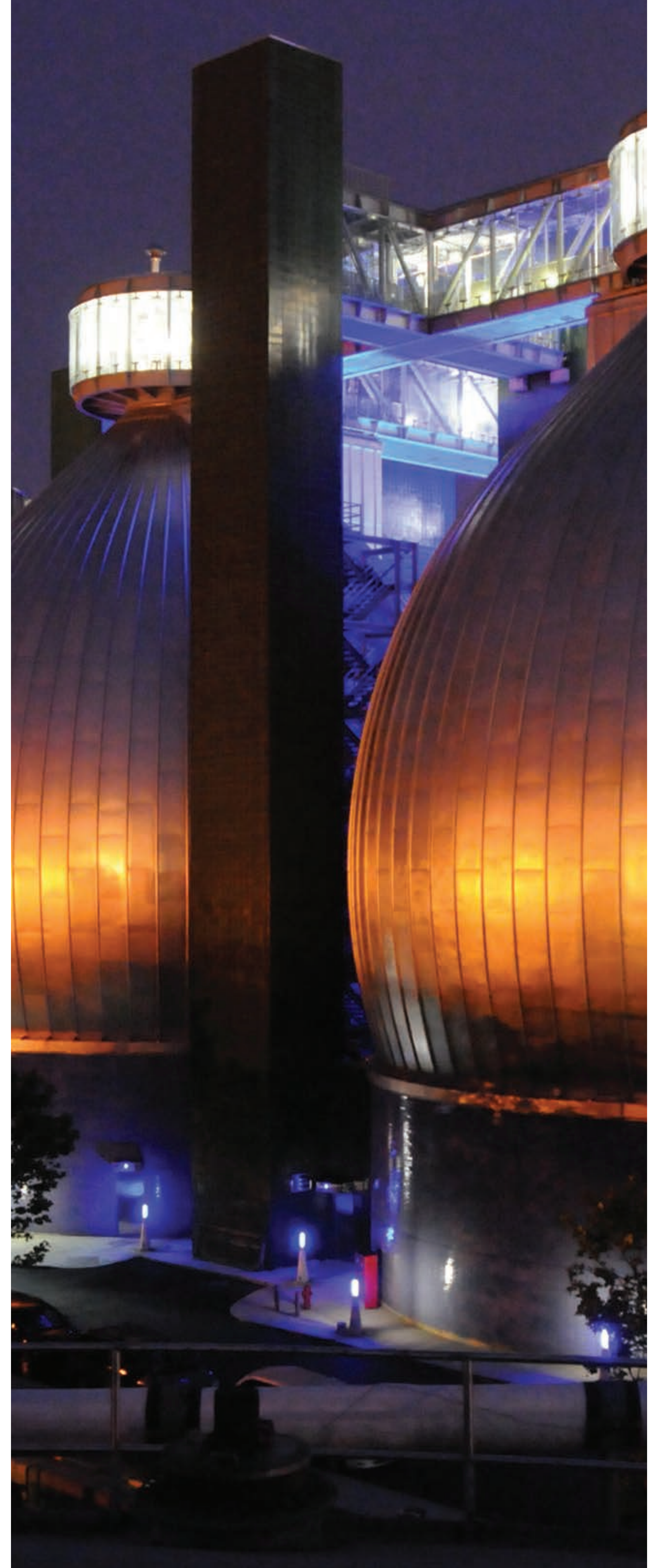
"When there are challenges that hinder clinical testing... wastewater data can be especially important."

and other water-borne waste that is flushed down toilets and washed down sink drains across the city. The plants are a vital cog in the modern machinery of civic hygiene—without them a city the size of New York couldn't exist—but in recent years they have also taken on an unexpected role in an unexpected battle.

They're helping New York City fight COVID-19.

"Wastewater-based epidemiology has a long history," says Andrea Silverman, an environmental engineer at New York University. "For some pathogens, if a person has an infection, they will excrete the pathogen through feces or urine. Sewer systems collect excreta from an entire city, so by sampling wastewater, you can get a picture of the health of an entire population."

Wastewater surveillance can be a powerful tool. In public health responses to a crisis, it's valuable to know how many people in a population are infected. Understanding the overall infection rate can help public health agencies plan for interventions like clinical testing programs or making sure hospitals are sufficiently resourced, and can inform lawmakers about what sorts of preventative measures are



advisable. And it's particularly useful for a virus like SARS-CoV-2. "When there are challenges that hinder clinical testing—asymptomatic cases that go unnoticed, at-home tests that don't get reported to public health agencies—wastewater data can be especially important," says Silverman.

So, with funding from the Sloan Foundation, Silverman partnered with the New York City Department of Environmental Protection (DEP) and teams of researchers at Queens College, Queensborough Community College, and The New School to develop and deploy protocols to track COVID-19 through the city's wastewater, protocols that have now been implemented. "Twice a week, we collect wastewater samples from each of New York City's 14 wastewater treatment facilities," says Silverman. "We concentrate the virus into a smaller volume, extract the viral RNA, and then quantify it. The DEP then shares that data with the NYC Department of Health and Mental Hygiene and through NYC's Open Data platform—where it's available for everyone to use."

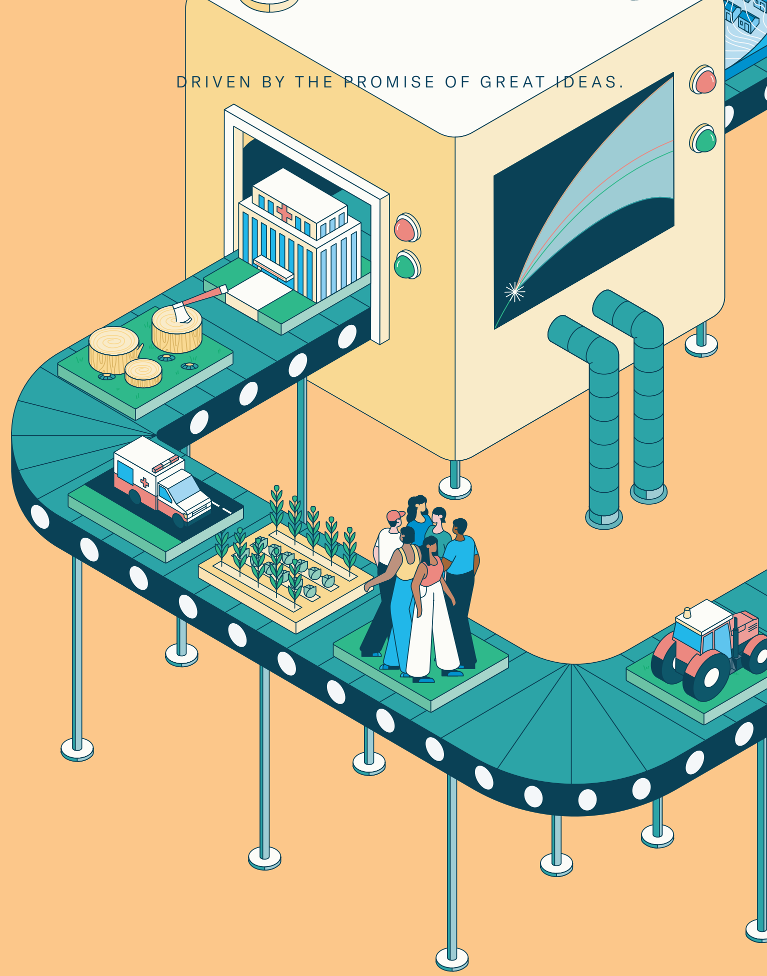
The new data isn't just being used locally, Silverman says. The city has integrated the project into the Centers for Disease Control's National Wastewater Surveillance System, a new public health tool to coordinate pathogen tracking across the U.S. But Silverman says the biggest impact may yet lay ahead. "Thinking beyond COVID-19, many researchers are turning their attention to other pathogens, including influenza and viruses we haven't previously monitored with this approach. This won't be the last pandemic, and wastewater surveillance has the potential to better prepare us for the next."

Model Citizens

A team of researchers has built a model that makes clear the true cost of carbon emissions and that could pave the way for better climate change policies.


David Anthoff


Kevin Rennert

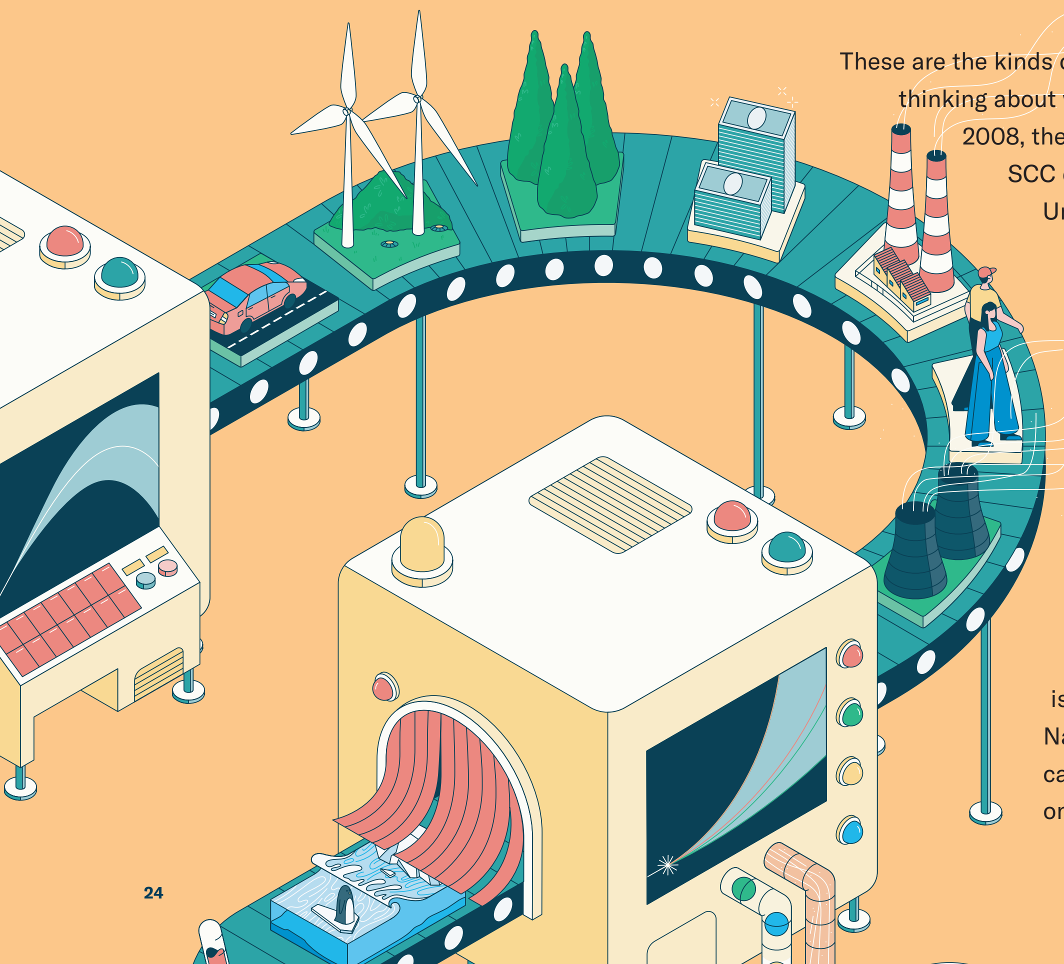


It's arguably the most important number you've never heard of. The Social Cost of Carbon (SCC) is an estimate, in dollars, of the economic damage caused by emitting one ton of carbon dioxide into the atmosphere. This elusive number helps researchers and policymakers quantify the cost or benefit of almost everything the government might do, such as expanding public transit or mandating new automotive emissions standards.

"Essentially, the SCC allows us to quantify climate change in economic terms for policymakers," says Kevin Rennert of Resources for the Future, a DC-based nonprofit behind a new and improved model for calculating the SCC that is nearing its public release.

"We use projections of economic and population growth and the associated future carbon emissions to model the resulting climate responses, like sea level and temperature changes. Next, we calculate the economic impacts over time of damages caused by those changes and convert those impacts into present-day values. We repeat this process thousands of times with different inputs to estimate an average value *and* a range for the dollar cost of emitting a single ton of carbon."

The economic effects of climate change on the economy are manifold—and interconnected. Heat and drought effects, for instance, are expected to coincide, a disastrous combination that could lead to significant crop yield reductions in the United States and across the globe. In addition to considerable economic impacts, low crop yields also have implications for food security and child mortality.



These are the kinds of scenarios policymakers are thinking about when making decisions. And since 2008, the U.S. government has mandated SCC estimates in federal rulemakings. Until now, however, available models have relied on small, isolated teams to compile huge amounts of data into different modeling systems that are incompatible with each other and, in some cases, use proprietary software.

The models used to date by the U.S. government had sufficient room for improvement—and the number is so important—that in 2017 the National Academy of Sciences called for an improved model, one with more robust scientific underpinnings that is publicly available for anyone to use. The Alfred P. Sloan Foundation has supported Rennert and his colleagues in making those recommendations a reality.

"Essentially, the social cost of carbon allows us to quantify climate change in economic terms for policymakers."

David Anthoff is an environmental economist who helped develop the new model: "As well as improving the model's scientific basis, our approach fundamentally changes how science gets done. Instead of relying on a small group to do everything in sequence, we have many experts working in tandem on different components that we combine into a powerful end result.

"Our model is decentralized and it's open source—so it's more robust and anyone can access, recreate, or modify the calculations for themselves. And that's exactly what's been happening. People from all over the world have been using our platform to inform their work. This is the value of open science."

While the new model is a vast improvement over its predecessors, it's not without its limits. Every aspect of the model is loaded with uncertainty, as nobody can say for sure how the world will look far into the future. Another key question is how much value to place on the future relative to the present, which can have a tremendous impact on SCC dollar range estimates. But by combining hardcore stats with expert predictions, it *is* possible to create a model that accounts for those uncertainties to produce a plausible range of estimates.

"There's no question that there is plenty of uncertainty, but we can't just exclude the SCC from policy decisions because of it," says Rennert. "To do so would be to say the effect of climate change is precisely zero dollars. We can have a debate about its value—but precisely zero is clearly incorrect. The better approach, and the one we take, is to incorporate the best available science to transparently quantify that uncertainty and account for it in policy analysis."

The team's model has the potential to influence how the government thinks about climate damages in major decisions. Although the SCC is already being used to inform local, state, and federal policy, the possibility of the Biden Administration shifting from an interim SCC value of $51 per ton to a much higher value is likely to face challenges being integrated into policy. So with the modeling work now complete, a larger challenge looms—helping this new value gain mainstream political acceptance.

Sky, Robot

The future of the world's most highly cited telescope depends on the construction of a robotic octopus with 500 arms wielding thousands of hair-thin cables with micrometer precision. Can it be done?

The Sloan Foundation Telescope at Apache Point Observatory

Until recently, Frances Cope and Muwen Shi were plate-pluggers for the Sloan Digital Sky Survey's (SDSS) Sloan Foundation Telescope at Apache Point Observatory in New Mexico. Every day, they meticulously fastened thousands of cables into laser-drilled holes in aluminum plates. Each hole corresponded to a point of interest in the night sky, such as a star. After passing through the telescope, photons from that star slipped through the designated hole in the plate. Then they traveled down the fiber-optic cables to a waiting spectrograph, a machine that separates wavelengths of light. The readout revealed the composition of the star and how it moved through space.

"We see all the beauty out there on a clear night, but that's just with the naked eye," Cope says. "We were plugging plates so that the observers could see far beyond that."

When Cope and Shi arrived at work each morning, they might have had ten plates to plug with a thousand cables per plate. That night, their colleagues on the night shift would swap out the plates every hour in a delicate ritual timed to Earth's rotation. The night sky doesn't take days off, so Cope, Shi, and others took turns working on weekends and holidays.

The first 21 years of the SDSS were made possible by the dedication of daytime plate pluggers, nighttime plate changers, and numerous scientists and engineers. The Sloan Foundation has provided about a quarter of the SDSS's total funding since the survey's inception. The effort has yielded the most detailed maps of the universe in existence.

In 2021, the collaboration prepared to enter a new phase to ensure it could continue producing cutting-edge astronomical data: the telescope was going robotic.

Making the switch was a trying process. In addition to pandemic-related setbacks and supply chain issues,

Research engineer Julia Brady stands beside a robotic Focal Plane System (FPS). Each FPS deploys 500 robotic fiber positioner units—like the one held by Brady—in a hexagonal array that covers the telescope's focal plane, replacing the fiber plug-plates that have been used by the Sloan Digital Sky Survey for more than 20 years.

Veteran Sloan Digital Sky Survey plate-pluggers Muwen Shi (left) and Frances Cope (right) flew to Ohio from New Mexico to help solve mechanical challenges with the new machine's assembly.

there were mechanical challenges in building the new machine, which relies on hundreds of robotic arms to automate observing. Attached to each arm are three fiber-optic cables roughly the width of a human hair. Some of the cables broke as the project team in Ohio tried to assemble the machine. "We were doing such a specialized job that there were no tools for it," says Julia Brady, a research engineer who coordinated the installation team at Ohio State University.

Fortunately, SDSS's director Juna Kollmeier and Apache Point Observatory's director Jamey Eriksen knew of two experts in tasks requiring focus, patience, and dexterity.

With the project timeline in jeopardy, Cope and Shi flew in from New Mexico. In a fourth-floor astronomy lab, they peered through powerful magnifying lenses at the glass strands connected to each robot arm and then later carefully slotted the robots into holes in a large black hexagon that contains all the fiber-optic cables. Piece by piece, they helped assemble the machine that would advance the science they'd supported for nearly a decade.

"I used to lie in bed at night and wonder what we might be able to discover with the updated instrument," Brady says. "Now, we finally get to find out."

"It feels bittersweet, but I'm excited about the scientific progress," Cope says.

The new system will lead to more data and faster response times. Instead of the twenty minutes it took to manually change plates, and the full day of lead time required to determine which plates to plug, the robotic arms can rearrange themselves in just a few minutes. That capability not only reduces gaps in data collection but also means SDSS can react in real time to objects of interest identified by other telescopes. A second identical setup is under construction and will eventually survey the southern sky from Las Campanas Observatory in Chile.

Cope and Shi feel a strong connection to the new system, which is now installed and collecting data at Apache Point Observatory. "We only worked on it in Ohio for six weeks, but it felt like our child by the time it arrived here," Shi says. Now, Cope and Shi maintain the robots and telescope so they can produce data for years to come.

"I used to lie in bed at night and wonder what we might be able to discover with the updated instrument," Brady says. "Now, we finally get to find out."

Census & Sensitivity

New math has made it possible, for the first time, to rigorously quantify and protect privacy in datasets—with big consequences for the nation's most important survey.

The U.S. census underlies many demographic descriptions and decisions made by the government and major corporations, from redrawing voting districts to helping retailers decide where to open new stores. It underpins some $1.5 trillion per year in allocated funds—including Medicare, Supplemental Nutrition Assistance, highway funding, and school lunches. It's kind of a big deal.

By law, individual census responses are kept anonymous, both to encourage citizens to participate and respond truthfully, and to protect the identities of respondents. In the wrong hands, unmasked identities—like a person's ethnicity or sexual orientation—could be used in all sorts of nefarious ways.

Taking this legal and moral responsibility seriously, in 2019 researchers at the Census Bureau, led by chief census scientist John Abowd, conducted a study of whether modern computational techniques threatened the privacy of census respondents. The results were unambiguous. With modern computers and commercially available datasets, the researchers, working with aggregate, supposedly anonymized census tables, were able to unmask the identities of 45% of the population.

So, in 2020 the Census Bureau turned to a new approach: differential privacy, a recently developed method for measuring and protecting the privacy of people included in sensitive datasets. For Cynthia Dwork, a computer scientist who helped pioneer the approach with Sloan Foundation support, its adoption by the U.S. census marks a historic moment.

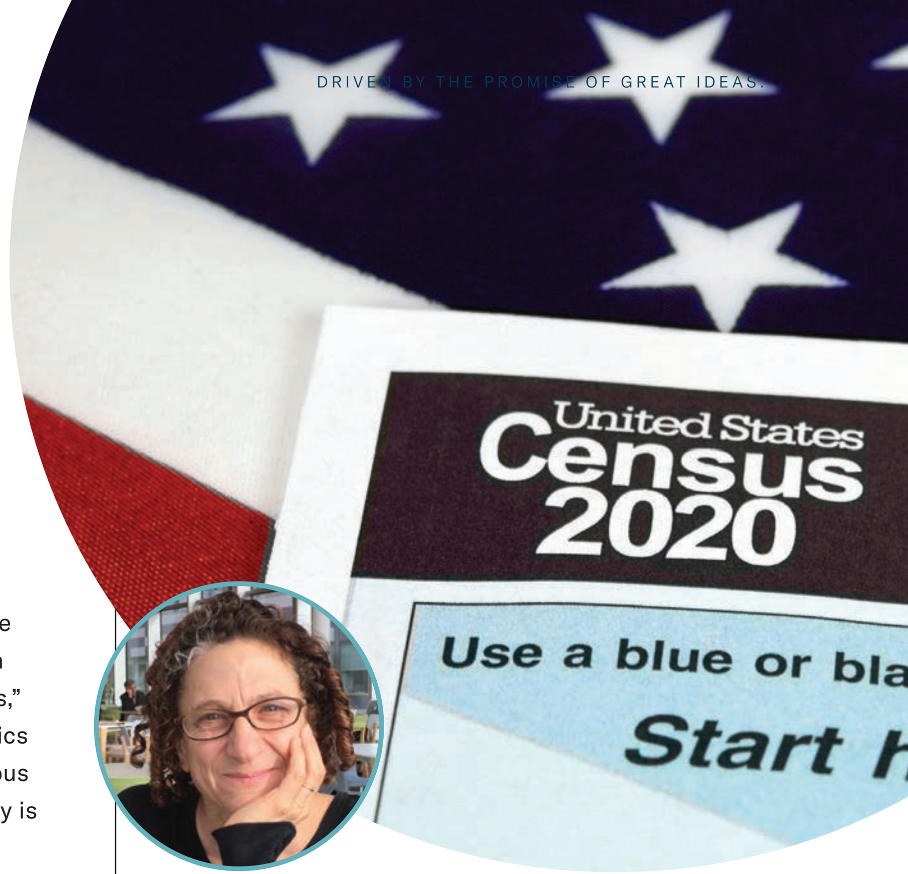
"When implemented with appropriate parameters, differential privacy ensures that anything learned about you from participating in a survey like the census is equally likely to be learned about you if you don't participate," says Dwork. "The beauty of this approach is we can gain important insights about the population as a whole without revealing information on a given individual."

All datasets are subject to a tradeoff between accuracy and privacy—the more information you reveal about the members in the dataset, the higher the risk of revealing the identity of any individual member. Differential privacy's primary advance is that it allows one to quantify just how much privacy is lost with each query of a dataset, providing a precise measure of the state of the accuracy/privacy tradeoff.

"A good analogy is cumulative radiation exposure from things like X-rays and mammograms, which accumulate over time to cancer-causing dosages," says Dwork. "Privacy loss from aggregate statistics works the same way—small, individually innocuous doses of privacy erosion accumulate until privacy is completely compromised."

Dwork says that just as the number of medical images you can safely have taken depends on the radiation dosage delivered by those images—you can have more dental X-rays than mammograms, for instance—there is a limit on the number of measurements in a dataset before privacy is destroyed, which is related to the accuracy of those measurements. Just like a lead-filled vest provides some protection against X-rays, Dwork developed techniques that minimize how much privacy is sacrificed by querying a dataset.

> **"The beauty of this approach is we can gain important insights about the population as a whole without revealing information on a given individual."**



Cynthia Dwork

"Differential Privacy *controls* the privacy-eroding radiation dose by injecting small amounts of carefully calibrated randomness into the statistical computations, resulting in a lightly blurred view of the dataset as a whole," says Dwork. "Just as medical researchers understand how radiation accumulates over multiple measurements of the body, we understand how privacy erosion accumulates over multiple statistical measurements. This is the key to differential privacy's success—it means that it's programmable.

"We can design simple, differentially private building blocks, and a skilled engineer can combine them in creative ways to release large numbers of statistics, while adhering to a cap on privacy-eroding radiation. The choice of the cap is a policy decision, and a judicious choice must balance inspecting the body with keeping it healthy."

Differential privacy has now been adopted by major technology companies including Apple, Google, and Microsoft to protect the identities of their users. But for Dwork, the fact that the Census Bureau has taken on the gargantuan task of applying differential privacy to its billions of datapoints is a significant step forward—for all the citizens who will benefit from the most secure census in U.S. history.

Tour de Force

In a padded room, on a floating table, sits a box that holds an experiment so delicate it'll be ruined if someone breathes on it. Its purpose: to unravel a puzzle at the heart of every living cell.

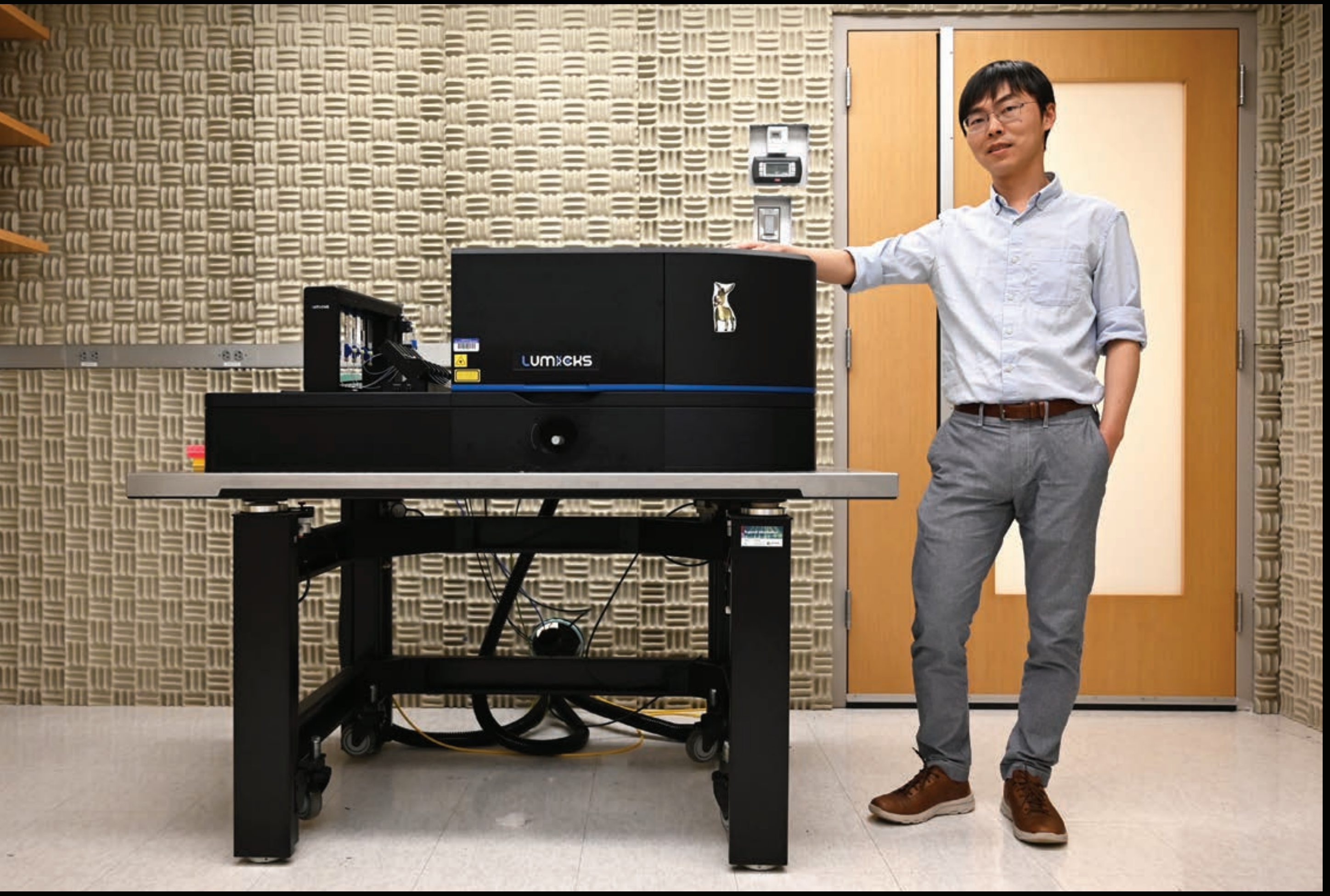
This microfluidics system in the lab of Dr. Shixin Liu delivers ingredients to two cell-sized beads in view of Liu's microscope. Those beads, in turn, are the testing ground for experiments on the role mechanical force plays in DNA transcription.

A strand of DNA is a busy place. Enzymes zoom back and forth. Molecules float through cell plasma, colliding with DNA and the molecular machinery working away on it. It's a bit like a crowded, two-way train track, if you imagine boulders raining down on the tracks. And yet, despite the chaos, molecular machines do their work with remarkable accuracy. RNA polymerase, which transcribes DNA into RNA, the template for proteins, makes an error in just one of every 100,000 nucleotides it assembles.

In a basement lab at Rockefeller University in New York, Assistant Professor Shixin Liu and graduate student John Watters are trying to figure out how—seemingly against the odds—molecular machines do their jobs with such high fidelity.

Liu and fellow Rockefeller University heads of labs Gregory Alushin and Amy Shyer are designing experiments from multiple angles to help answer this question. The work is funded through the Sloan Foundation's Matter-to-Life program, a new multi-million-dollar initiative that supports research exploring, among other things, the physical principles that govern how biological molecules are able to do what they do.

Shixin Liu and his C-Trap. This single-molecule microscope combines optical tweezers, fluorescence microscopy, and a microfluidics system to allow simultaneous manipulation and visualization of single-molecule interactions in real time.



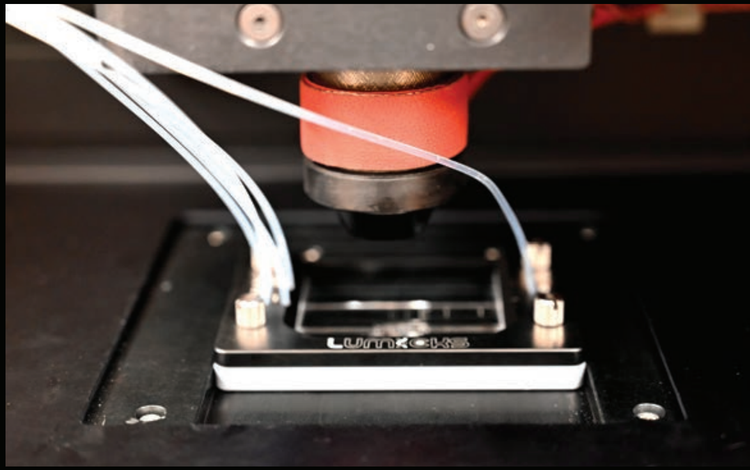
Mechanical force—generated by these machines but also modulated by all those collisions in the cell—is an important but poorly understood factor in biology. Liu seeks to change that. He studies how force affects RNA polymerase's uncanny ability to correctly produce RNA from DNA. "RNA polymerase is a remarkably accurate, robust, and efficient machine," Liu says. "And, it has its own built-in proofreading mechanism. If it makes an error, it can go back, fix it, and continue producing the correct transcript." Liu and his colleagues want to understand how exactly that error control system works, and what role mechanical force might play.

Using an approach called single-molecule manipulation, they are studying how force—push, pull, and collisions—affect RNA polymerase's accuracy. The researchers pinch a pair of tiny plastic beads, each the size of a cell, using powerful lasers. The laser beams press on the beads from either side, suspending them, much like tweezers. The researchers then attach RNA polymerase to one bead and the DNA template it is motoring across to the other bead. This lets the researchers control how hard to push or pull the polymerase as it assembles RNA.

Measuring minute forces is delicate work. "When I started my lab, I asked the university, *what is the most stable floor on campus?*" Liu says. That's how he ended up in a basement surrounded by foam-padded walls and floating tables, both of which dampen vibrations. The entire experiment is enclosed in a box so no one breathes on it.

Liu's lab pairs optical tweezers with a second single-molecule detection method called fluorescence microscopy, which involves attaching a glowing dye to a target molecule. After tagging RNA polymerase, the researchers can see where it is located on a strand of DNA and whether it is producing RNA.

The combined tools are so powerful that Liu hopes to observe exactly when RNA polymerase makes a mistake. "With optical tweezers alone, it's like you're pulling a string blindfolded." Liu says. The researchers can measure the force RNA polymerase exerts as it strains against the bead, but they can't see the molecule. "Combining optical tweezers and fluorescence, you feel the force and see the magic at the same time." With that information, they will be able to determine how accurately RNA polymerase works at different forces. All those collisions and perturbations might slow the RNA polymerase down and give it time to check its work. Or perhaps RNA polymerase works better uninterrupted, and collisions introduce errors. It's anyone's guess right now.



The "optical tweezer" in Dr. Liu's lab, a laser capable of holding microscopic objects exquisitely still.

> **"Combining optical tweezers and fluorescence, you feel the force and see the magic at the same time."**

Liu believes, and theory suggests, that—at least in some cases—force could very well be helpful. "That's a concept that's kind of counter-intuitive, but I think it will be very profound if we can prove that experimentally," Liu says. The results, which Liu expects in the near future, could fundamentally shape our understanding of how biomolecular machines operate.

Pod Save the Internet

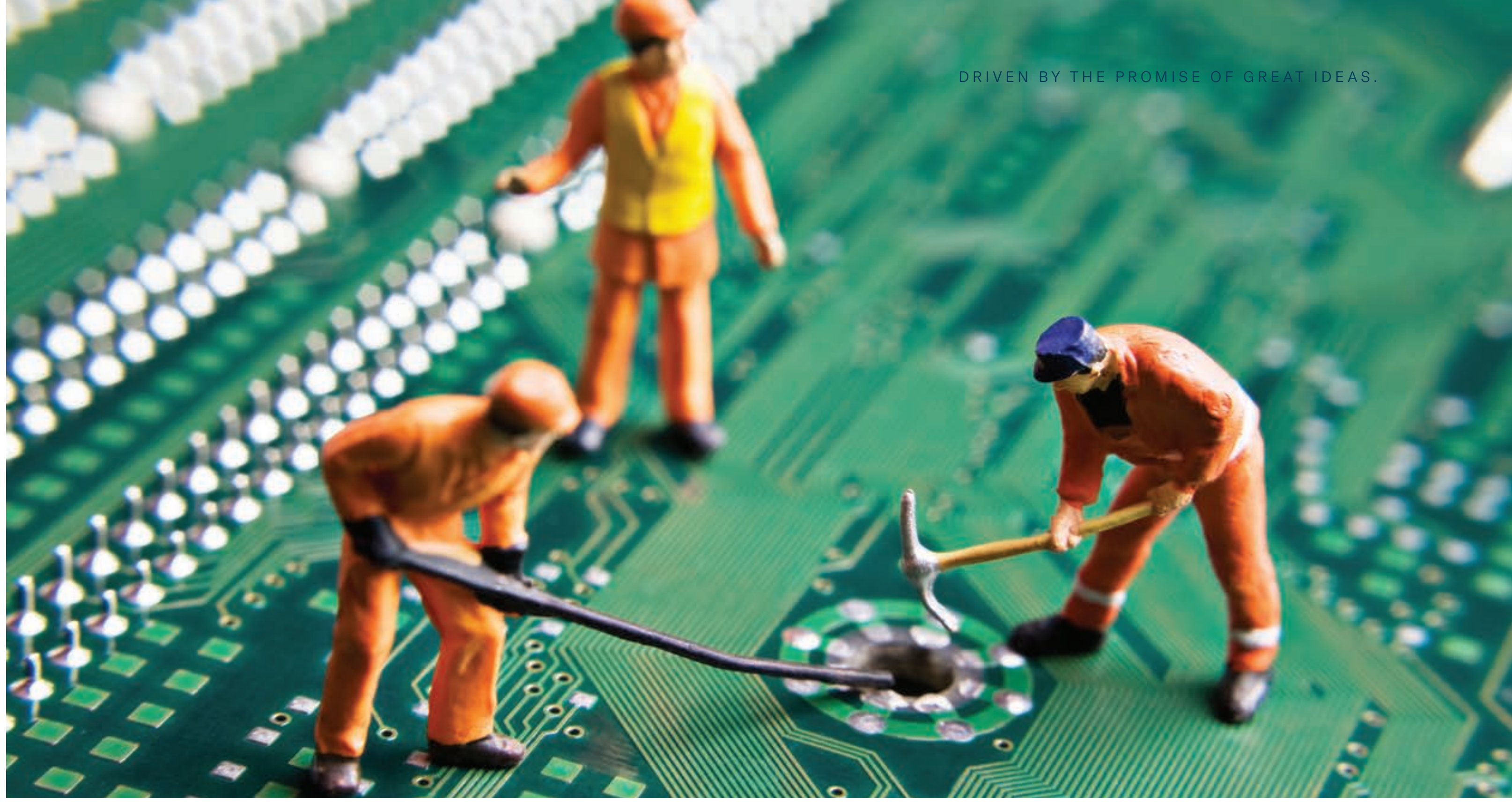
Cindy Cohn's new Sloan-supported podcast asks viewers to join her in imagining a better internet. An interview with a practical utopian.

What's your mission at the Electronic Frontier Foundation?
For over thirty years, we've been defending citizens' online rights and warning about the dangers of surveillance, advertising, and content moderation. In the early days of the internet, we were influential in debates on free speech, privacy, and encryption. We helped create a strong vision of the future, including potential civil liberties benefits, but also foreshadowed the dangers that could come if we didn't make good choices. It wasn't all utopia—but there was optimism. Now, people have lost the vision of a better future and they're increasingly mired in all the things that have gone wrong—online surveillance capitalism and platform censorship, for example. We still think that technology can support a more just world, so we have an obligation to articulate what the internet *could* look like if we got things right. Because you cannot build a better future unless you can imagine it.

Why did you decide to deliver this message through a podcast?
We chose podcasting because it's the perfect medium to capture back-and-forth discussions and reach large audiences—this season hit over 80,000 listens. I wanted to capture genuine conversations between people feeling their way through complex issues, something short-form radio and blogs often struggle to capture. There's something wonderful about how people consume podcasts versus traditional media. There's a slowness, a thoughtfulness to it, which stems from the fact that it doesn't *need* to be rushed. Podcasting also allows us to produce content that's evergreen—we're not the news, although there are plenty of great podcasts doing that. We wanted to make a podcast where people can find value in the episodes long after the news cycle has moved on.

Cindy Cohn

Too many hot takes may well be part of the problem, so it makes sense you'd aim to avoid them.
That's exactly right. I didn't want to provide practical information that people could go away and immediately use, like how to set up encrypted instant messaging or disable personalized ads. That stuff's important, and our free Surveillance Self-Defense guides exist for that purpose. But with the podcast, I wanted to frame these issues in their wider context to help our listeners understand how these issues affect them and the underlying values. Encryption is one great example—even if you aren't the target of a police investigation, you need to understand how encryption serves the values of protecting liberty and respecting privacy.



"[T]echnology can support a more just world, so we have an obligation to articulate what the internet *could* look like if we got things right."

Do any of the episodes stand out in your memory?
My cohost Danny O'Brien and I had the pleasure of speaking with so many brilliant, curious people. In addition to featuring established speakers from places like the Stanford Center for Internet and Society, the podcast was also a great opportunity to offer a platform to new voices. Matt Mitchell, the founder of CryptoHarlem—which provides free workshops on privacy, anti-surveillance, and digital security for Harlem residents—has rightly become one of the go-to voices in digital privacy. He talked about the challenges faced by residents in his neighborhood living in state-owned properties surrounded by 24-hour CCTV, microphones, and floodlights. Matt is helping his community understand these issues so they can protect their privacy, and he also offered insight into how other people can support their communities. It's a fantastic episode that people should check out!

So, since you've been thinking about this for a while... How *do* we fix the internet?
Stay tuned for the next season to find out! But honestly, I think my colleague Cory Doctorow, a journalist and sci-fi writer who is featured on an early episode, said it well: we need to "seize the means of computation!" That's a recurring motif throughout the episodes. It means giving individuals and communities the power to build the tools they really need. And on the flip side, it means limiting the power of big tech and governments to control and surveil us. Over and over, we heard that the right way to a better future is for users to fully reclaim control of our online experiences. If we can get that right, we just might fix the internet.

***How to Fix the Internet* is available wherever you listen to podcasts.**

Meet the Fellows

Since 1955, the Sloan Research Fellowships have honored the very best young scientists at a pivotal stage in their careers. Here are just a few of the 118 extraordinary researchers that make up the 2021 class of Sloan Research Fellows.

Ishmail Abdus-Saboor

Columbia University

Neuroscience

Quantifying individual responses to pleasure and pain

Simple as it sounds, successfully distinguishing hot from cold or the caress of a feather from the prick of a needle hinges on very sophisticated processing by the central nervous system. And while we're pretty good at quantifying a person's response to a given stimulus, we're less good at explaining the *phenomenology*, or experience, of a particular sensation—a highly subjective and deeply personal quality that can vary wildly between individuals exposed to exactly the same stimuli.

Ishmail Abdus-Saboor is a sensory neuroscientist unpacking the phenomenology of pleasure and pain, and he's particularly interested in how the body can distinguish touch sensations, like a soft caress versus a hard punch. He's using mammalian animal models to quantify responses to pleasure and pain and relating that data to humans based on our shared genetics and neuroanatomy—and finding out how and why behavioral responses vary so much among different individuals. In doing so, Abdus-Saboor hopes to pave the way for better alternatives to existing pain medications.

Anela Choy

University of California, San Diego

Earth System Science

Getting to the bottom of ocean nutrient recycling

The open ocean is the largest habitat on the planet. And it isn't a faraway dumping ground—it's intimately connected with civilization and deeply influenced by human activities like recreation, fishing, and shipping. While our activity continues to reshape the state of this ecosystem, we are still learning about how the ocean functions, including how organic matter flows through and connects species, and how those species contribute to essential nutrient recycling.

Anela Choy is a biological oceanographer bringing important answers to the surface. Her team heads out to sea for weeks at a time, trawling to collect data and samples, to piece together how animals feed on one another and how this contributes to biogeochemical cycling. By striving to understand open ocean food webs across the global ocean, Choy believes we can begin to appreciate the pressure environmental change and commercial fishing place on these delicate and vital ecosystems, and perhaps learn how to maintain them for future generations.

Elena Manresa

New York University

Economics

Revealing unobserved differences in economic data

Scientific data can be hard to parse, but big data in economics has an added level of complexity that would make the most formidable quantum physicist uncomfortable—the role of human decision-making. A dataset can tell us a lot about humans, but it fails to capture what economists call "unobserved heterogeneity", the unseen reasons *why* a person has decided to, say, take out life insurance or move cities. As if that wasn't enough, the datasets used by economists are often enormous and incredibly noisy.

Elena Manresa is an econometrician using AI and machine learning to cut through the noise. By clustering people into groups based on things a dataset *can* capture, then following people over long stretches of time, unobserved differences impacting outcomes emerge. Manresa has used the technique to help explain wage inequality—finding that differences in salary are largely driven by unobserved differences in worker talent—and contends her approach has much to reveal about society and the policies that might improve it.

Luisa Whittaker-Brooks

University of Utah

Chemistry

Developing better materials for solar technologies

One reason the green energy revolution is not yet a reality is we haven't cracked energy generation and storage—solar cells capture sunlight less efficiently than plants; batteries store energy but struggle to hold it long enough. Fundamentally, these are problems that concern materials. Understanding the composition, structure, and properties of the inorganic and organic nanomaterials essential to these technologies is the key to turning the green revolution from science fiction to science fact.

Luisa Whittaker-Brooks is a chemist working at the intersection of materials science and physical chemistry who specializes in novel photovoltaics and thermoelectrics. She is interested in mixed ion-electron conductors, materials whose ions and electrons can be manipulated to optimize their use in solar cells, batteries, and electronics. On top of her prolific research program, Whittaker-Brooks is also working with government agencies in her native Panama to support the adoption of solar technologies.

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