MAKING THE WORLD WORK BETTER

MECHANICAL ENGINEERING
UNIVERSITY OF MICHIGAN

2022–2023 ANNUAL REPORT

me.engin.umich.edu/annualreport2023

2022-23
By the Numbers

Research Dollars Received

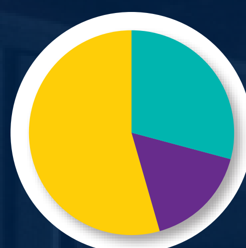
NIH	$2,930,196
NSF	$5,513,622
DoE	$6,901,785
DoD	$11,628,657
All Other	$15,556,566
FY23 Total:	**$42,530,826**

BEST PROGRAMS IN THE U.S.

#4
Undergraduate Program

#4
Graduate Program

U.S. News & World Report



Faculty

Assistant Professors	18
Associate Professors	9
Professors	35

Cover image: Jenna Stolzman working on the “Using Systems of Advanced Burners for Reduction of Emissions” project in Professor Margaret Wooldridge’s lab.

Dear Friends...

I hope this message finds you safe and well. This year, the University of Michigan Department of Mechanical Engineering (U-M ME) has embarked on groundbreaking research projects to address the most pressing challenges facing our world.

To curb the effects of climate change, the transportation and energy industries are setting ambitious goals to revolutionize how we live and travel. Global shifts towards greater inclusivity are creating new opportunities for those who have been historically excluded, and advancements in medicine are opening new frontiers in the fight to keep communities healthy. This work could not be done without the expertise of mechanical engineers.

Looking back, I feel a sense of pride at all our ME community has accomplished and an inspiration to continue making forward strides in our mission to make the world work better. I'm excited to share some of our news and accomplishments with you now.

Innovating Battery Design

A new $10.95 million research center, led by ME professors Jeff Sakamoto (Director) and Neil Dasgupta (Deputy Director), aims to enable the development of advanced batteries and fuel cells for electric vehicles. Through this center, U-M and eight partner institutions will explore the use of ceramic ion conductors as replacements for the traditional liquid or polymer electrolytes in common lithium-ion batteries for electric vehicles and in flow cells for storing renewable energy in the grid.

Shifting Paradigms in Engineering Education

ME assistant professor, James Holly, Jr., spoke at The Grainger Foundation Frontiers of Engineering 2022 Symposium of the National Academy of Engineering on the need for faculty to have a robust understanding of social inequity, to utilize cultural knowledge as an asset, and to leverage insights from perspectives of racially-marginalized peoples in engineering classrooms.

Leveraging AI to Combat Antibiotic-Resistant Infections

A new computer model developed in the Violi Lab, which is led by ME professor Angela Violi, can identify whether and how a nanoparticle and protein will bind with one another, an important step in designing antibiotics and antivirals on demand. The model, named NeCLAS, uses machine learning—the AI technique that powers the virtual assistant on your smartphone and ChatGPT. "In my ideal scenario, 20 or 30 years from now, I would like—given any superbug—to be able to quickly produce the best nanoparticles that can treat it," Violi said.

Faculty Recognition

Our faculty continue to be recognized by prestigious institutions and professional societies for their many contributions to research, education, and service. A few examples include the NSF CAREER Award, the ASEE Ralph Coats Roe Award, the ASB Borelli Award, and two inductions into the National Academy of Engineering.

I hope reading about the accomplishments of our ME community gives you the same sense of pride and inspiration as it gives me. The work is not done, but the extraordinary gains we have earned over the past year make me hopeful about the future of our world.

As always, we're grateful for your time and support of ME.

Ellen Arruda
Tim Manganello/BorgWarner Department Chair and Maria Comninou Collegiate Professor of Mechanical Engineering

$11M DoE Center for Next-Gen Battery Technology

A new $10.95 million research center, led by Michigan Engineering and funded by the U.S. Department of Energy, could help enable the development of advanced batteries and fuel cells for electric vehicles.

It focuses on understanding an emerging branch of science involving mechanical and chemical phenomena that affect advanced battery designs.

U-M and eight partner institutions will explore the use of ceramic ion conductors as replacements for the traditional liquid or polymer electrolytes in common lithium-ion batteries for electric vehicles and in flow cells for storing renewable energy in the grid.

“The recent discovery of ceramic ion conductors that simultaneously exhibit unprecedented performance and stability has the potential to change the electrochemical energy storage technology landscape,” said Jeff Sakamoto, professor of mechanical engineering at U-M and director of the new center.

Ceramic ion conductors could help advanced batteries pack more power than lithium ion batteries of the same size. However, when these new conductors are in contact with other components, researchers have noticed some new and unusual behaviors arising from that blend of mechanical, electrical, and chemical interactions.

“Our new center seeks to bridge fundamental knowledge gaps related to mechano-chemistry with a diverse group of researchers who come from disparate fields of study,” said Sakamoto.

The four-year grant establishes a DOE Energy Frontier Research Center (EFRC) at U-M, the Mechano-chemical Understanding of Solid Ion Conductors (MUSIC). Established in 2009, the EFRC program is designed to "tackle the toughest scientific challenges preventing advances in energy technologies."

Ceramic ion conductors represent one of those advances, and MUSIC is charged with performing the basic science needed to explore their potential impact on a variety of technologies. Those include long-duration energy storage and hydrogen fuel cells.

"We have decades of fundamental research into ion conduction in ceramics to work with, and we're applying that knowledge toward emerging applications such as batteries and fuel cells," said Neil Dasgupta, MUSIC's deputy director and an associate professor of mechanical engineering at U-M.

"However, critical barriers remain before widespread commercialization can be realized—many of which center around the unique mechanical properties that emerge at solid-solid interfaces in electrochemical cells. An overarching goal of MUSIC is to reveal the fundamental mechanisms of how mechanical stresses and strains interact with electrochemistry, which will inform future efforts to scale up and accelerate commercialization of next-generation

We have decades of fundamental research into ion conduction in ceramics to work with, and we're applying that knowledge toward emerging applications such as batteries and fuel cells.

> **Michigan continues to be at the center of mobility, and U-M is a critical hub where all of the players—automakers, legislators, regulators, academics, and researchers—interact and examine the issues at play.**

energy storage technology," he added. Traditional lithium-ion batteries power almost everything we use, from cars to laptops. They typically use flammable liquid electrolytes to shuttle ions back and forth between the cathode and anode in a cell. In addition to greater energy density, replacing those liquid electrolytes with ceramic ion conductors has the potential for improved safety.

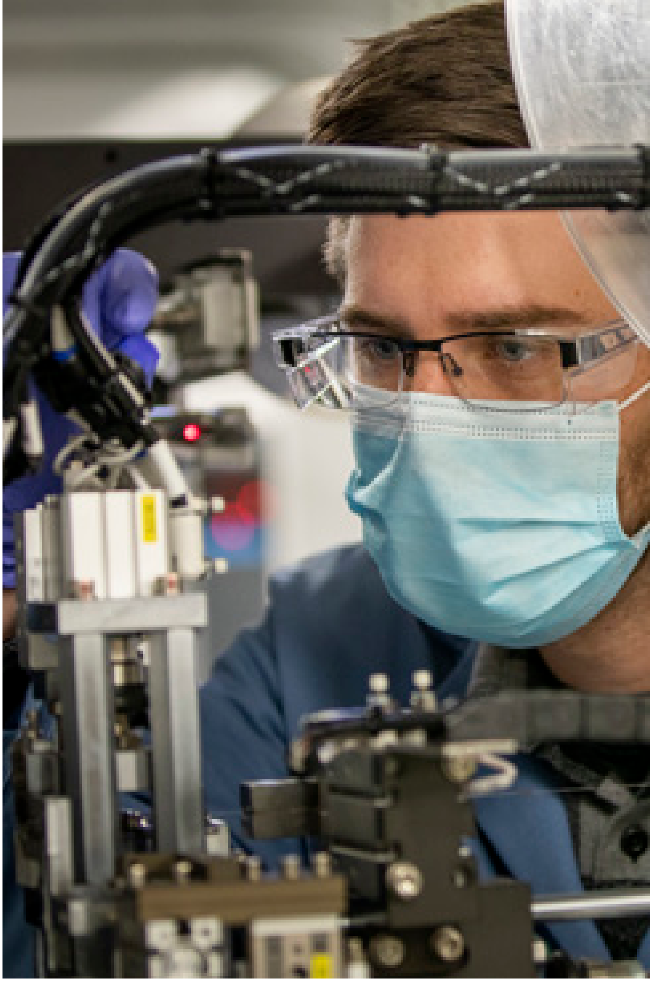
For the buying public, range anxiety and a charging infrastructure that needs rapid growth are among the factors delaying widespread adoption of EVs. Vehicle prices, a factor greatly impacted by the battery's cost, is another hurdle.

MUSIC researchers will look at manufacturing techniques using new materials as a means of lowering battery costs. And they'll examine how the introduction of ceramic ion conductors impacts degradation—loss of charge capacity—in lithium metal, sodium metal, and other solid state configurations.

MUSIC is the latest addition to an expanding portfolio of research projects at U-M tied to the future of mobility. In July 2022, the State of Michigan approved a budget that included $130 million for a new EV center led by Michigan Engineering. And U-M is already home to the Walter E. Lay Auto Lab, Mcity autonomous vehicle testing facility, the University of Michigan Transportation Research Institute, and a founding partner of the American Center for Mobility in Ypsilanti.

In addition, the U-M Battery Lab continues to play a significant role in cross-pollinating experience, knowledge, and know-how from state-of-the-art lithium-ion technology and manufacturing with ceramic ion conductor research. The solid-state battery research that is part of MUSIC started in 2015 at U-M and is now an integral part of the U-M Battery Lab.

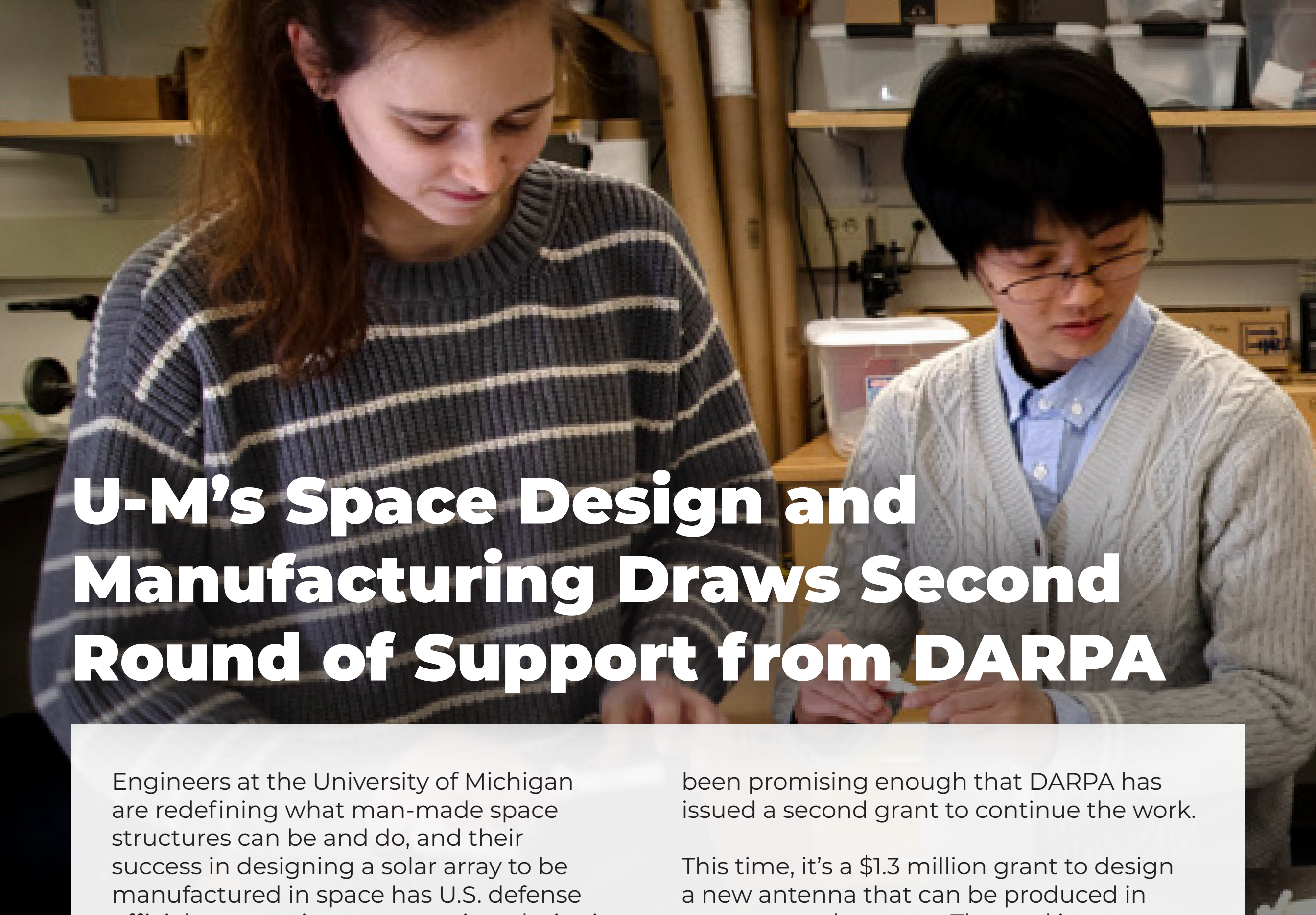
"Michigan continues to be at the center of mobility, and U-M is a critical hub where all of the players—automakers, legislators, regulators, academics, and researchers—interact and examine the issues at play," said Alec D. Gallimore, the Robert J. Vlasic Dean of Engineering.



"From conducting state-of-the-art research in key technologies such as batteries, to training next-generation engineers, to planning future infrastructure and dozens of other concerns, Michigan Engineering is immersed in all of it," he added.

Partner institutions in MUSIC include: Massachusetts Institute of Technology; University of Texas, Austin; Northwestern University; Georgia Institute of Technology; Princeton University; University of Illinois at Urbana-Champaign; Oak Ridge National Laboratory; and Purdue University.

Sakamoto is also a professor of materials science and engineering. Dasgupta is also an associate professor of materials science and engineering. Gallimore is also the Richard F. and Eleanor A. Towner Professor, an Arthur F. Thurnau Professor and a professor of aerospace engineering.



U-M's Space Design and Manufacturing Draws Second Round of Support from DARPA

Engineers at the University of Michigan are redefining what man-made space structures can be and do, and their success in designing a solar array to be manufactured in space has U.S. defense officials supporting a new project designing an antenna.

The things we build and send into space are limited by the fact they're built and tested on Earth. Anything made on the ground needs to be packaged up, stored aboard a rocket, and shot beyond the atmosphere. It creates space and weight issues that restrict the size of structures we use in space research and exploration.

But we don't have to do it that way. The weightlessness of space provides the possibility to build enormous structures, but they would have to be made there. The Defense Advanced Research Projects Agency (DARPA) has been funding researchers at U-M to help make it happen.

In 2021, DARPA provided $1.58 million to a team led by Serife Tol, a U-M assistant professor of mechanical engineering, to design a new modular solar array that can be 3D-printed in space. The project is part of the Novel Orbital Moon Manufacturing, Materials and Mass Efficient Design (NOM4D), and the U-M team's work has been promising enough that DARPA has issued a second grant to continue the work.

This time, it's a $1.3 million grant to design a new antenna that can be produced in space or on the moon. The goal is to create lightweight and highly precise structures based on advanced manufacturing technologies.

That includes techniques used to make metamaterials, which behave differently from natural materials. They are made of repeating—or periodic—structures and can be designed to create new mechanical properties and more.

For Tol, "on-orbit," or "in-space" manufacturing opens up an off-world of design opportunities.

"We're looking for novel designs, ones that aren't limited by the constraints of space launches or deployability," she said, as the team prepares for its second go-round with the NOM4D program. "Without those limits, we can explore creating structures that are much larger than those on Earth and enable drastic performance increases. To this end, we're creating new space designs based on periodic architecture, the so-called metamaterials."

3D printers can crank out the small building blocks of these larger creations. That allowed the U-M team to successfully design its enormous solar array, which can perform far beyond what can be launched into space from Earth. Even so, current plans would send the raw materials to space, which is why mass efficiency—or the power production per unit mass—remains an important measure.

"Today we are limited in the size, both the mass and the volume, that we can launch from Earth," said Andrew Detor, NOM4D's program manager, in a recent podcast. "The NOM4D program is really about fundamental materials and manufacturing technologies and enabling the construction of large structures in orbit. Things like solar farms, the more solar cells you can put out in terms of area, the more power you can harvest."

The U-M team's previous work on the array is proof. "Compared to a state-of-the-art solar array producing 300 kilowatts of power, our team's array is capable of producing 1 megawatt of power with higher mass efficiency and precision," Tol said. Expectations for the new antenna are equally optimistic.

The current standard for a mesh reflector antenna used for satellite communications is the Harris reflector, which is roughly 12 meters in diameter. U-M engineers are designing an antenna that will be more than 100 meters across.

The challenge lies in creating the support for that expanded surface area. A larger antenna requires more support in the form of ribs beneath its blanket-like surface to prevent the pillowing effect—deformations in the mesh surface that affect accuracy. However, this approach can significantly increase the mass of the structure, which is not desired.

"Because of the plethora of metamaterial designs that in-space manufacturing can produce using 3D printing, we will be able to address and solve several issues, such as pillowing, using our approach," said Anthony Waas, the Richard A. Auhull Department Chair of Aerospace Engineering, and a member of the research team.

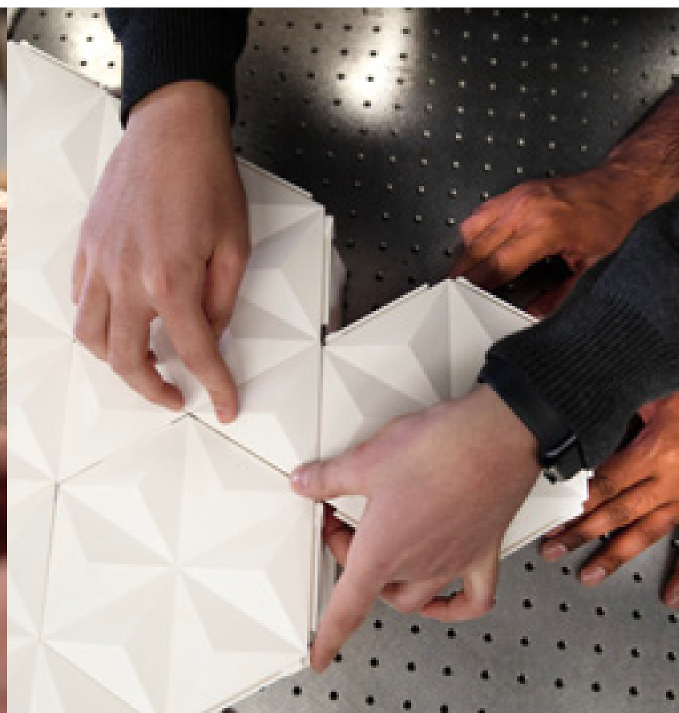
Following the success of the solar array, the team has progressed into the second of NOM4D's three phases.

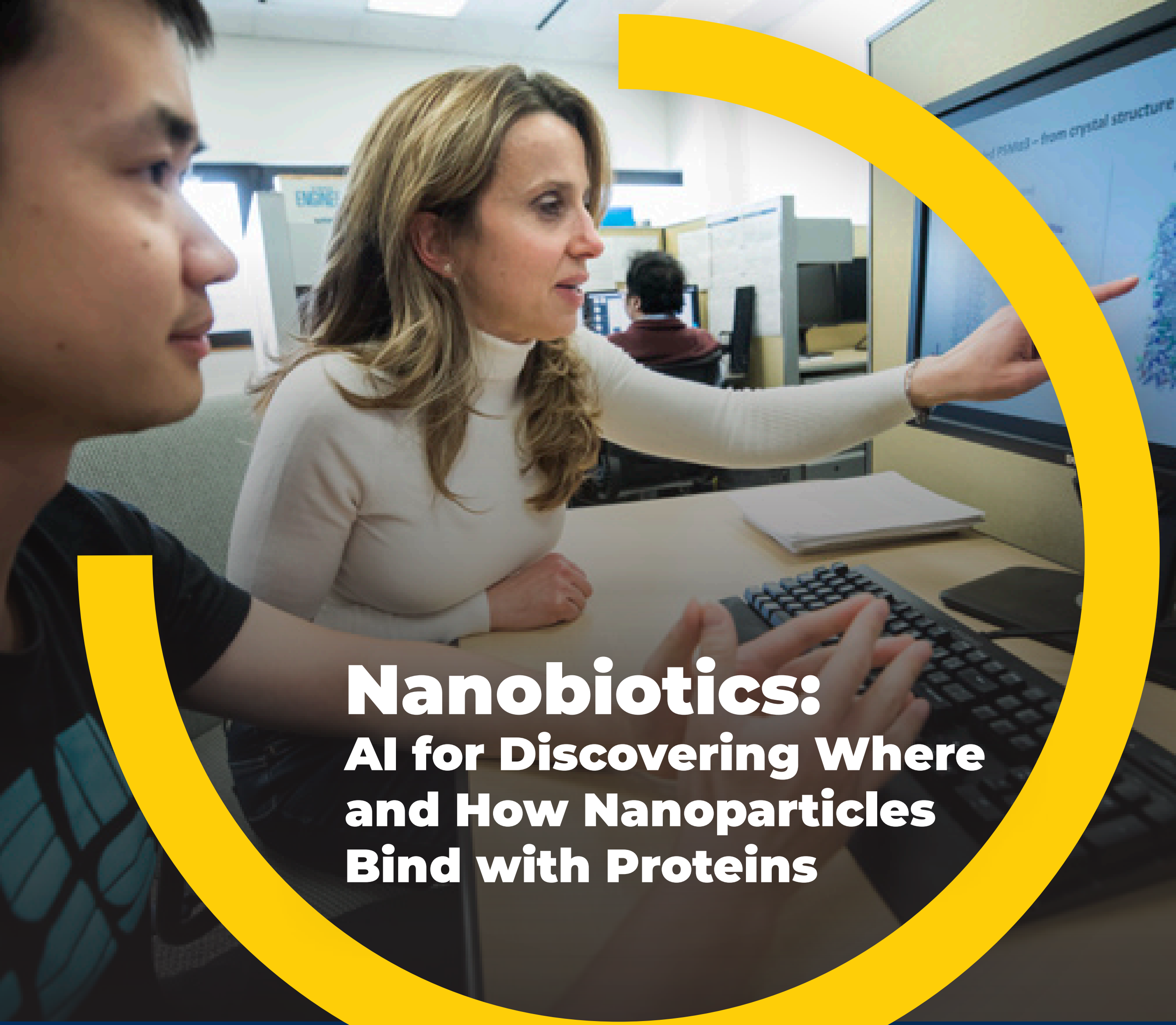
Efficiency targets were the focus of the first round, and increasing mass efficiency is at the heart of the second, to be demonstrated with the antenna project. The third round will involve demonstrating precision with infrared sensing.

"Assuming current space technology trends continue, in 10 to 20 years we expect to see advances that will enable DoD [Department of Defense] to take full advantage of the NOM4D-developed technologies and capabilities," said Bill Carter, NOM4D's founding program manager in DARPA's Defense Sciences Office, when the program kicked off last year.

We're creating new space designs based on periodic architecture, the so-called metamaterials.

"This includes robotic manipulation sufficient to enable assembly of large structures from NOM4D-manufactured components, enhanced on-orbit mobility, and routine refueling of on-orbit assets," he said. "We also anticipate several other advantages, including more affordable space access and launch costs in LEO [low-earth orbit], GEO [geosynchronous orbit], cislunar orbit [the space between Earth and the moon], and beyond."





Nanobiotics:
AI for Discovering Where and How Nanoparticles Bind with Proteins

Identifying whether and how a nanoparticle and protein will bind with one another is an important step toward being able to design antibiotics and antivirals on demand, and a computer model developed by Arthur F. Thurnau Professor of Mechanical Engineering Angela Violi can do it. The new tool could help find ways to stop antibiotic-resistant infections and new viruses—and aid in the design of nanoparticles for different purposes.

Learn more about this story. Visit:

ummecheng.in/3utJeBe

Train the Trainer: Battery Bootcamp

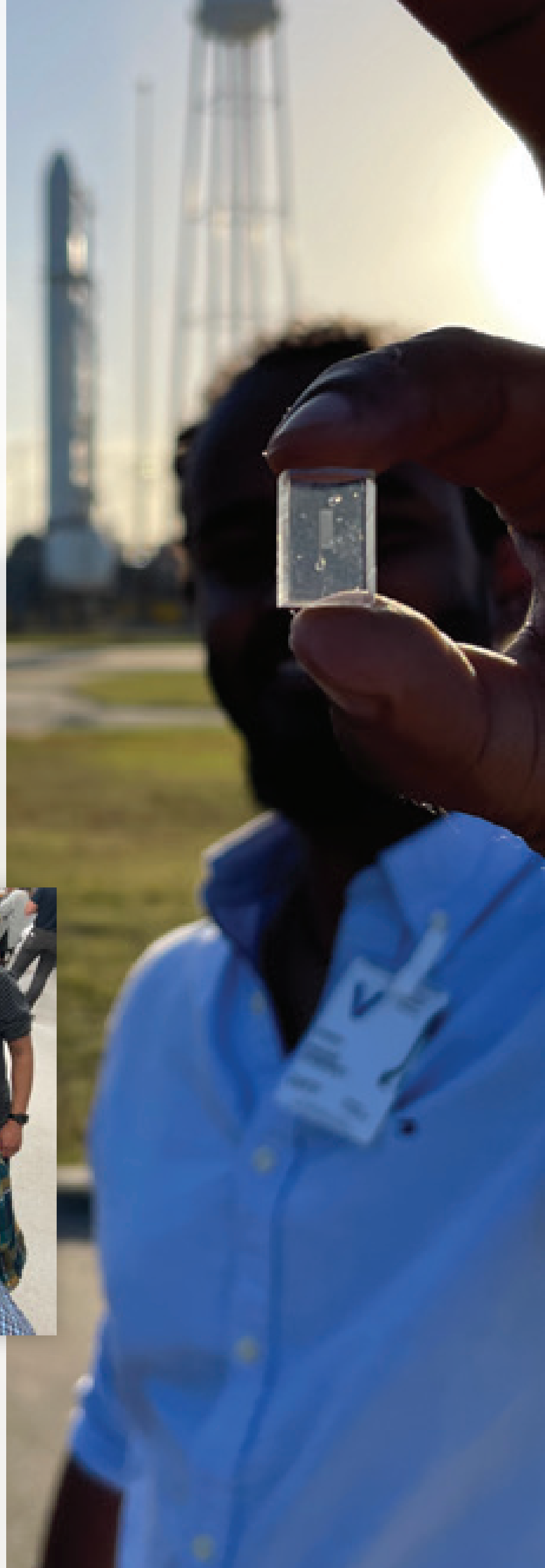
Battery technology is moving fast as global efforts focus on greener energy. To support the transition away from fossil fuel, Anna Stefanopoulou, University of Michigan William Clay Ford professor of technology and professor of mechanical engineering, and fellow faculty members hosted a four-day Train the Trainer: Battery Bootcamp for community college faculty and the UAW assistant research director. Attendees took away valuable lessons to bring back to their classrooms, including low-cost experiments and demonstrations with drill pack disassembly, cell cycler setup, and safe handling of cells.

Learn more about this story. Visit:

ummecheng.in/3Rny9eg

Gravity's Impact on Bone Cells—Experiments Heading to the International Space Station

Allen Liu, U-M associate professor of mechanical engineering, and members of his research team recently launched a pair of experiments exploring bone density aboard a Northrop Grumman Corp. Antares rocket to the International Space Station. These experiments in space will help shed light on osteoporosis, a condition affecting hundreds of millions of people around the world—as well as how to keep astronauts safer. The results will provide insight into how changes in gravity affect the mechanical characteristics of bone cells—and bone formation—to provide better diagnostics and treatments for people dealing with bone decay.



Learn more about this story. Visit:

ummecheng.in/411Olok

Bachir Abeid — Paying it Forward

Bachir Abeid, PhD student in Mechanical Engineering, may have left his childhood home in Smara, one of five settlements in Algeria's Tindouf Province that were established after war in the region displaced many Western Saharans, but through all of the transitions and the triumphs, there's one thing that remains constant: his sense of where he comes from. Bachir firmly believes in paying forward the opportunities that were once given to him.

Learn more about Bachir. Visit:

ummecheng.in/49UqISS

Saima Jamal — Going Beyond ME

Saima Jamal, an undergraduate senior in U-M Mechanical Engineering shares her experiences beyond ME working with NASA's Jet Propulsion Laboratory in Los Angeles, California—a childhood dream come true—and then relocating back to the east coast, to Greenbelt, Maryland, where she supported NASA Goddard through the Brooke Owens Fellowship as a Space Science Mission Operations Intern.

Learn more about Saima. Visit:

ummecheng.in/3uHl9a8

MECHANICAL ENGINEERING
UNIVERSITY OF MICHIGAN

2022–2023 ANNUAL REPORT

me.engin.umich.edu/annualreport2023

Designed by Michigan Creative, a unit of the Office of the Vice President for Communications | MC 230218