College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

FALL 2022 NEWSLETTER

ENGINEERING PHYSICS

Accelerating materials development for clean energy

Greetings!

A new academic year means saying hello to new faces and goodbye to old friends. In addition to a new cohort of more than 100 first-year undergraduate students and about 25 new graduate students, we are welcoming a new faculty member, Juliana Pacheco Duarte. She is returning to Madison after a few years as an assistant professor at Virginia Tech to strengthen our research portfolio in thermal-hydraulic and safety analysis of nuclear energy systems.

At the same time, we say farewell to Professor Douglass Henderson. He has provided leadership to our department and college in so many ways over his career. Within our EP community, his contributions include bringing his research expertise to new areas such as homeland security and radiation treatment planning, forging ties to the medical physics department to expand our research network and support the BSNE radiation science option, and leading our department as chair from 2015-2019. He also leaves a college-wide legacy with the long-standing Graduate Engineering Research Scholars (GERS) program and the brand new WiscProf program. GERS has a clear track record of creating a supportive environment for graduate students from underrepresented groups who go on to become future leaders in academia and beyond. WiscProf will expand access for our college to a pipeline of outstanding faculty prospects from diverse backgrounds, while providing them an opportunity to learn more about faculty life. On a personal note, Douglass has been an important mentor to me for 30 years and played a role in my own success. He will be missed by us all!

In addition to the innovative work of our nuclear engineers, our engineering mechanics faculty are continuing to push boundaries with their high-impact research. With a new National Science Foundation grant, Associate Professor Jacob Notbohm is studying how biological cells move in collective groups, which is an essential process in cancer invasion, tissue development and wound healing. This interdisciplinary research promises to offer a new means to predict how cell forces bring about the collective migration, which is the first step to controlling the migration for applications in improving human health. And Assistant Professor Ramathasan Thevamaran has received a 2022 NASA Early Career Faculty Award. The award will support his work developing advanced composite materials with exceptional mechanical properties and thermal stability for dimensionally stable structural components to be used in future large telescopes and space structures.

Our students continue to receive traditional academic recognition. Sam Garcia (BSNE '21) and Nick Thoreson (BSEP '22) were both selected for the Department of Energy's University Nuclear Leadership Fellowship (UNLP) as graduate students in our programs. Sam was also selected for an NSF Graduate Research Fellowship—forcing him to choose between these two prestigious honors. One of our undergraduates also won a unique competition: Grace Stanke, a senior in nuclear engineering, was selected as Miss Wisconsin and will go on to compete in the Miss America competition in December. She is the first nuclear engineer to appear on the Miss America stage! Grace is using her platform to advance a social impact initiative around clean energy, with nuclear energy at its center.

With all of this activity, our entire EP community continues to work toward saving this planet and exploring the rest.

On, Wisconsin!

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Support a STAR Scholar

Effective solutions to today's challenges arise when we bring the brightest people to the table. When you make a gift to our STAR Scholarship fund, you'll help our college recruit the nation's best students so that they can become tomorrow's problem-solvers and difference-makers. Thanks to a commitment from The Grainger Foundation, there's also matching support available—meaning that you can double the impact of your support.

We need your help growing this important scholarship fund. To make a gift, contact Kyle Buchmann, senior managing director of development, at kyle.buchman@supportuw.org or (608) 630-1679.

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FOCUS ON NEW FACULTY

Juliana Pacheco Duarte, enhancing the safety of nuclear reactors

As an undergraduate student majoring in physics, Juliana Pacheco Duarte participated in a nuclear engineering workshop, and toured a nuclear power plant and a research reactor. That experience and her desire to help advance a reliable, zero-carbon energy source prompted her to shift her educational focus to nuclear engineering.

Today, her research focuses on analyzing the safety of nuclear reactors—both current reactors and advanced reactors—using a mix of experimental and computational methods.

In her experimental research, Duarte develops and applies advanced instrumentation techniques to better understand thermal-hydraulic phenomena, such as heat transfer and fluid mechanics, in the core of nuclear reactors. And she uses her experimental data to improve computational models that are used for reactor safety analysis.

Duarte joined the department as an assistant professor in fall 2022. She comes to UW-Madison from Virginia Tech, where she was an assistant professor in the nuclear engineering program in the mechanical engineering department.

Duarte says a big challenge that she aims to address with her research is dealing with uncertainty in the models related to certain heat transfer phenomena that occur in reactors during an accident scenario. A significant reason for that uncertainty is a lack of reliable data. “So that’s why we go into the lab, do more experiments and collect more data: to try to understand the phenomena and improve the models and decrease our uncertainties in the safety analysis,” she says.

While much of her research has been on light water reactors, which are the most common type of nuclear reactors currently in operation in the United States and abroad, Duarte plans to broaden the scope of her research at UW-Madison.

“One of the reasons that I came to UW-Madison was to expand my research into advanced nuclear reactors and collaborate with faculty here on ways to improve safety in the next generation of nuclear power plants,” she says. “The department also has a very strong group of fusion researchers, and I’m excited to collaborate with them on safety aspects of fusion reactors.”

In addition, at UW-Madison Duarte plans to research different types of coolant, such as molten salt and liquid metals, that are being proposed for new advanced reactors.

“With the excellent experimental facilities and faculty at UW-Madison, including a lot of materials science expertise in molten salt, I’m excited to collaborate in this area and make contributions on the safety and heat transfer side,” she says. “The department is very strong, and also very collaborative, and because of that I believe I’ll have a lot of opportunities to grow and also recruit exceptional students in nuclear engineering here.”

Duarte, who is from Brazil, earned a bachelor’s degree in nuclear engineering from the Federal University of Rio de Janeiro, a bachelor’s degree in physics from the State University of Campinas, and a master’s degree in electrical engineering from the University of Sao Paulo. She received her PhD in nuclear engineering and engineering physics from UW-Madison in 2018, with Professor Michael Corradini as her advisor.

She says UW-Madison stood out to her when she was applying to PhD programs due to its world-class experimental facilities and the engineering physics department’s outstanding reputation. And she made good use of those experimental facilities as a PhD student. Her doctoral research involved conducting experiments using a high-pressure loop that simulates the heat transfer in small modular light water reactors, and she says that experience doing experimental research has expanded the range of applications and areas she can contribute to with her work.

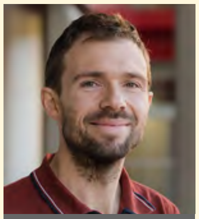
In addition to her research, Duarte is passionate about teaching and working with students—including providing valuable opportunities for hands-on learning. “I especially enjoy recruiting undergraduate students to work on research projects in my lab, which allows students with different levels of experience to work together and explore computational research or assist with experiments,” she says.

UW-Madison will partner with TerraPraxis, among others, on nuclear reactor open architecture, collaborating with and building on ideas developed by TerraPraxis and Bryden Wood to repower existing coal plant infrastructure. Image courtesy of TerraPraxis and Bryden Wood.

Engineers receive $2.8M in DOE nuclear research awards

Kumar Sridharan

Yafei Wang



Ben Lindley

The U.S. Department of Energy recently awarded more than $24.3 million through its Nuclear Energy University Program (NEUP) to support university-led nuclear energy research and development projects, including a total of $2.8 million for projects led by UW-Madison engineers.

UW-Madison is the lead institution for four of the 38 research and development projects awarded funding in 2022.

Grainger Professor Kumar Sridharan received $800,000 for his project, in which the research team will develop new material designs for control rod sheaths and neutron absorbers to improve accident tolerance and achieve higher fuel burnup in light water reactors. Researchers from Idaho National Laboratory and Westinghouse Electric Company are collaborators on the project.

Assistant Scientist Yafei Wang received $400,000 for his project. The researchers aim to develop ion probes to determine the optical basicity of molten fluoride salts and study its influence on structural material corrosion. Collaborators include Associate Professor Adrien Couet and Brookhaven National Laboratory.

Assistant Professor Ben Lindley received $800,000 for his project, in which researchers will perform a comprehensive assessment of the challenges and opportunities of open architecture for reducing the cost of advanced reactors. The team will perform a specific pilot study on the application of this methodology to nuclear coal retrofit at Kemmerer, Wyoming, and develop actionable recommendations that can be taken forward by the advanced reactor community. Researchers from the University of Wyoming, UC Berkeley, Idaho National Laboratory and TerraPraxis are collaborators on the project.

Lindley also received $800,000 for his project that aims to design a small modular high temperature reactor control rod that extends telescopically, which could significantly reduce costs. The researchers aim to develop the telescopic control rod to the point of being technically feasible and licensable, through a multidisciplinary design study encompassing theoretical and experimental work. Collaborators on the project include Couet, and researchers from Framatome, X-Energy and Idaho National Laboratory.

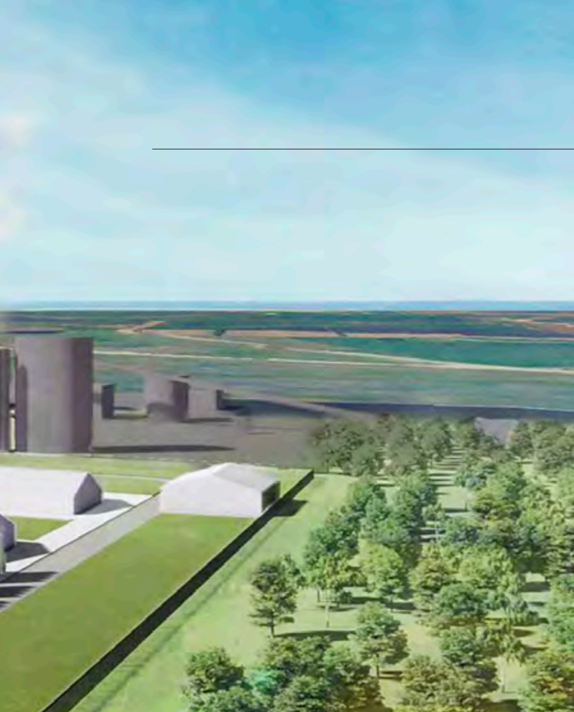
UW-Madison researchers are also collaborators on three of the seven Integrated Research Projects (IRPs) awarded funding in 2022. IRPs are multi-million-dollar, three-year projects executed by university-led consortiums that typically include multiple universities, industrial and international research entities, and the unique resources of the DOE national laboratories.

Mechanical Engineering Associate Professor Mark Anderson is a collaborator on a University of Michigan-led IRP that will provide scientific understanding to optimize the diffusion bonding process to be used in creating compact heat exchangers.

Department Chair Paul Wilson, the Grainger Professor of Nuclear Engineering, is a collaborator on an ambitious University of Oklahoma-led IRP. The researchers will develop and empirically evaluate a new approach to consent-based siting of interim storage facilities for spent nuclear fuel. The approach features a socially led engineering design process that gives members of the public, community leaders, and stakeholders in host communities an opportunity to co-design the facility they are being asked to host.

Izabela Szlufarska, Harvey D. Spangler Professor of Engineering and chair of the Department of Materials Science and Engineering, is a collaborator on a UC Berkeley-led IRP that aims to improve understanding of the role of impurities and fission products on the operational performance of molten salt reactors as well as potential impact on accident scenarios.

Read more: go.wisc.edu/neup22



Nick Thoreson

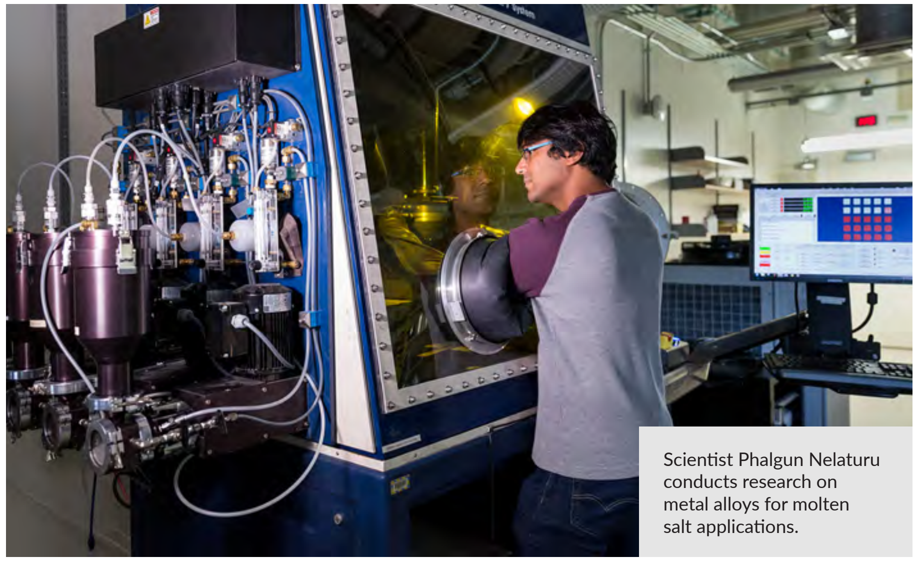
Grad student receives DOE fellowship

Nuclear engineering and engineering physics graduate student Nick Thoreson has earned a U.S. Department of Energy NEUP University Nuclear Leadership Program fellowship, which will support his research.

His graduate research focuses on the thermal hydraulics—heat transfer and fluid flow—associated with liquid sodium metal. Pure sodium metal melts at 98 degrees Celsius, and many next-generation nuclear reactor designs are based on using this metallic fluid as the coolant, instead of water.

Thoreson earned bachelor's degrees in physics and engineering physics from UW-Madison in spring 2022. A DOE Nuclear Energy University Program grant funded his undergraduate thesis project for the EP major, which he completed under the mentorship of Mechanical Engineering Associate Professor Mark Anderson, who is now Thoreson's graduate advisor. That project involved designing an experiment to study heat transfer to a liquid sodium stream under certain slow flow conditions expected to be seen inside heat exchangers of sodium fast reactors.

"This fellowship will allow me to dive into the interesting research questions I discovered during my undergraduate project over the next several years, and I will be able to continue making contributions to sodium thermal hydraulics research," says Thoreson.



Scientist Phalgun Nelaturu conducts research on metal alloys for molten salt applications.

Making new metals with machine learning means molten salt can't corrode

For clean energy sources like solar or nuclear, molten salt is somewhat of a wonder material. In concentrated solar power plants, for example, the sun's heat can be stored in the liquid for long periods of time. Conversely, next-generation nuclear reactors can use molten salt as a coolant and as a solvent for uranium fuel—making the reactors potentially smaller, safer, less complex and more economical than current nuclear power plants.

However, molten salt is well-known to corrode metal, so researchers are working hard to create metal alloys that can withstand constant wearing away, specifically when they're exposed at high temperatures. But progress has been slow going—and that, says Associate Professor Adrien Couet, also has kept molten salt technologies from reaching their potential in the energy industry, too.

"Developing those new materials is an extremely lengthy and costly process, which is why industry is lacking alloy options for developing molten salt technologies," says Couet.

That's about to change. Couet and his collaborators have developed an innovative and fast approach that brings together additive manufacturing, high-temperature corrosion testing, modeling, and machine learning to dramatically speed up the process of developing new metal alloys.

The researchers detailed their findings in a paper published May 7, 2022, in the journal *Advanced Science*.

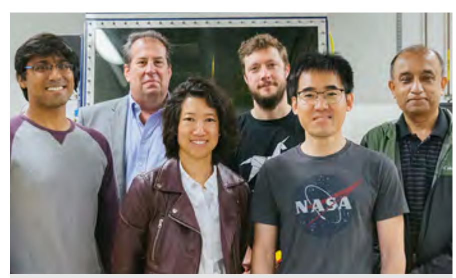
"Traditionally, a researcher could maybe investigate a handful of alloys over a few years," Couet says. "Now, with this new approach, we can study about 100 to 150 alloys in six months to a year, so it's a big acceleration of the process."

The new approach goes like this: First, the researchers use 3D printing to produce small metal blocks that roughly resemble Legos. Each one of the knobs on these 3D-printed blocks is made of a different alloy.

"This is a relatively new use of 3D printing, and it allows us to create many different types of metal alloys far more quickly than with conventional methods," says Yafei Wang, a scientist in Couet's research group and first author on the paper.

Next, the researchers deposit small molten salt droplets on the surface of each alloy and study how the materials hold up at high temperatures. These corrosion tests produce huge amounts of data, which the researchers analyze using machine learning methods. Couet says machine learning is allowing the team to zero in on materials that are especially promising.

In addition, the team discovered a new mechanism that affects alloys in molten salt corrosion. "This finding was unexpected, and it shows how our approach can also help drive new discoveries," says Couet.



The researchers developed an innovative approach to dramatically speed up the process of developing new metal alloys. From left: Phalgun Nelaturu, Dan Thoma, Bonita Goh, Adrien Couet, Yafei Wang, and Kumar Sridharan.

Cell mechanics offers new clue in genetic heart disease

Wendy Crone

Catecholaminergic polymorphic ventricular tachycardia (CPVT) is a mouthful of a heart disease that's essentially an invisible ticking time bomb for the estimated 1 in 10,000 people who have it. Often, the rare genetic disease goes undetected; those who carry it have hearts that appear structurally and functionally normal under typical circumstances.

But physical or emotional stress can trigger a life-threatening irregular heart rhythm, leading to a diagnosis that can arrive tragically late.

"If you don't have a known family history of the disease, the first appearance of the disease could be a sudden-death event," says Alana Stempien, a 2022 PhD graduate in biomedical engineering.

Stempien and Professor Wendy Crone, her PhD advisor, have worked with collaborators across the UW-Madison campus to uncover new details about the mechanical characteristics of heart cells in CPVT—basic science research that they hope might someday inform treatment strategies. They published their findings in the journal *Frontiers in Bioengineering and Biotechnology* in May 2022.

Stempien and Crone used an engineered, two-dimensional cell culture platform and image tracking technique to compare cardiomyocytes (the cells responsible for heart contraction) derived from a patient with CPVT with those from his mother, who didn't carry a CPVT mutation. To do so, they leveraged stem cell lines developed by collaborators in the UW-Madison School of Medicine and Public Health.

In analyzing the pulsing cardiomyocytes, the researchers found statistically significant differences in two mechanical measures: maximum contractile strain (deformation per contraction) and intrinsic contraction rate (speed of contraction). The patient-derived cells showed a higher strain and a slower rate. While the rate results meshed with previously reported research—validating their approach—the difference in mechanical strain was a new discovery. The mechanical attributes of cardiomyocytes in CPVT as a whole have rarely been explored in human cell cultures; most research has concentrated on the electrophysiology.

Recent PhD graduate Alana Stempien (pictured) and Professor Wendy Crone, her advisor, have worked with collaborators across campus to uncover new details about the mechanical characteristics of heart cells in CPVT.

"Finding this difference in mechanical function in itself is interesting, but I think it further implies that the mechanical function is something worth understanding more in this disease," says Stempien, who's planning to pursue a career in research and development in the biotechnology industry after completing the UW Cardiovascular Research Center Training Program in Translational Cardiovascular Science. "We always look at it from the electrical function, because it's an arrythmia disease; that's how it presents. But there are other aspects of function that are important, that could tell us more about the disease, and maybe give us more insight in the longer term in understanding and developing treatments."

Crone says other researchers could now investigate the biological underpinnings of those mechanical differences using this cell culture platform.

"This is very early basic science work that could enable future clinically relevant treatments," says Crone, whose research focuses on biomechanics at the cellular level. "It's very early and you don't know what's necessarily going to pay off, but this has some potential. It's identified something very clear in terms of a measurable quantity that we can test under different conditions."

Stempien and Crone have also worked with coauthor J. Carter Ralphe, a pediatric cardiologist, to examine mechanical cell function in hypertrophic cardiomyopathy, another genetic heart condition in which the heart muscle becomes too thick, impairing the heart's ability to pump blood.

Signal boost: Advance enables hyper-sensitive sensors

Ramathasan Thevamaran

A team of researchers from the UW-Madison and Wesleyan University has developed a new accelerometer that can take extraordinarily precise measurements. The advance opens the door to new sensors that are hyper-sensitive to tiny changes in conditions.

These hyper-sensitive sensors have potential applications in a variety of areas, including photonics, navigation systems, and biosensing. They could also be useful for monitoring the health of various structures, such as airplane wings and bridges.

The researchers published details of their advance in the journal *Nature* on July 27, 2022.

To achieve its high sensitivity, the team's electromechanical accelerometer exploits a complex spectral phenomenon, called an exceptional point, that occurs in certain systems where gain and loss in a system can be perfectly balanced by design. Scientists have been excited by the potential of using exceptional point-based sensors to take hyper-sensitive measurements, but a big barrier has hindered their development for practical applications.

These sensors will not only amplify the signal, but also the noise, and this renders their hypersensitivity useless.

Now, with their new exceptional point-based accelerometer, the UW-Madison and Wesleyan researchers have found a solution that delivers a threefold signal-to-noise-ratio improvement in the sensing performance of their device. In other words, they've circumvented much of the noise.

"This advance paves the way for exceptional point-based sensors to be used for practical applications," says Assistant Professor Ramathasan Thevamaran, who co-led the research.

Read more: go.wisc.edu/epsensor22

William Doniger says the excellent mentorship and opportunities he received at UW-Madison enabled him to accomplish his goal of becoming a researcher at a national lab, where he works on several pioneering molten salt technologies. Submitted photo.

Cutting edge: How an internship led one student from the factory floor to a national lab

Lawnmower blades and molten salt nuclear reactors have little in common. But for recent PhD graduate William Doniger (PhDMS&E '22), who currently researches corrosion-resistant materials and electrochemical sensors for next-generation molten salt nuclear reactors at Argonne National Laboratory, one was a direct bridge to the other.

Doniger, a Washington, D.C., native, came to UW-Madison as an undergraduate in materials science and engineering in 2011. During his studies he developed an interest in molten salt technologies through an internship at Watertown, Wisconsin-based Fisher Barton Inc., one of the world's largest suppliers of high-wear cutting and plowing components for agriculture. "Molten salts have an enormous variety of industrial applications including aluminum production, heat treatment of materials, and heat transfer fluids for solar and nuclear," Doniger says.

To stay ahead in the competitive agriculture industry, Fisher Barton is always looking for new techniques and coatings. When Doniger arrived in 2015, he was assigned to an R&D project to develop a steel surface modification process using molten salts that could be integrated into an existing steel heat treatment line.

"The heat treatment process step, which is carried out at 1,500-1,800 degrees Fahrenheit, made for a spectacular and challenging environment to engineer systems for," he says. "The high temperatures plus serious industrial electronics and automation meant you always had to be on your toes. It was a really cool project because it combined my love of materials science and electronics. So I was having a ball."

It was an influential internship for Doniger, whose mentor at the company was a former PhD physicist at Sandia National Laboratory. That experience helped Doniger decide that he wanted to pursue a career in research, and also helped him set a goal of working at a national lab. "I thought I'd like to get a graduate degree in order to continue to do what I saw my mentors doing, which was really cutting-edge research and development," he says.

Back on campus, Doniger joined the lab of Grainger Professor Kumar Sridharan, who was working on materials that can withstand the high temperature and aggressive environment of a next-generation nuclear power plant design called a molten salt reactor. The molten salt coolant enables the reactor to operate at higher temperatures and at lower pressure than current generation nuclear reactors, leading to improved safety and efficiency of the plant.

After completing his bachelor's degree, Doniger enrolled in graduate school as a member of Sridharan's lab. His PhD research focused on a crucial hurdle to commercialization of molten salt reactors: predicting how materials will degrade in the environment over many decades of service. He developed electrochemical techniques for studying molten salt chemistry, which is difficult to analyze with conventional methods. "I really enjoy working through the engineering challenges associated with such an inhospitable environment," he says. "Molten salts are in some ways more versatile than water-based solvents and could potentially have some really impactful applications in things like energy production and storage, carbon capture, battery recycling and nuclear fuel recycling."

At Argonne, which he joined in spring 2022, Doniger continues that research, working on several pioneering molten salt technologies, including applications for solar power and for addressing the nuclear fuel cycle.

"I am grateful that my chance encounter with a Wisconsin company willing to try new things, excellent mentorship, and opportunities at UW enabled me to accomplish the goal of becoming a researcher at a national lab," he says. "I am extremely excited about the future of molten salt solar and nuclear technologies. There is so much untapped potential for discovering new industrial processes enabled by molten salts. It really is like exploring a new frontier."

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NSF honors outstanding grad student researcher

Nuclear engineering and engineering physics graduate student Sam Garcia received a prestigious National Science Foundation Graduate Research Fellowship in 2022.

Garcia's research focuses on multiphysics modeling of nuclear microreactors. He looks at different designs for microreactors and creates simulations to see how they perform in different conditions.

"This is useful since we can take real-life experimental data that was done previously, the most notable being the systems for nuclear auxiliary power space-based microreactors, and try to model the exact same conditions to see if the outcomes match," Garcia says. "By using a code that is known to be quality-assured, we can validate the experimental results."

This work can enable researchers to use newer codes that allow for faster reactor modeling, which can reduce some of the research and development costs of reactor design.

"Additionally, having a working model of a reactor can help give estimates of its efficiencies, manufacturing capabilities and overall market performance," says Garcia, who is a member of Assistant Professor Ben Lindley's research group. "This is all in the pursuit to make nuclear an energy source that is mobile, safe and profitable."

Garcia, who earned his bachelor's degree in nuclear engineering from UW-Madison in 2021, says he appreciates that the fellowship promotes diversity and inclusion, which are reflected in the statistics of awardees.

"Any program or fellowship that promotes the growth of students in underrepresented communities is tantamount to promoting the growth of the field itself," he says. "To this end, I also feel that the EP department has done an excellent job facilitating my development as a scientist and engineer through a diverse community of students and faculty. With open doors, friendly communication and top-notch education, I am extremely proud and happy to be continuing my graduate studies here at UW-Madison."

The NSF fellowship recognizes and supports outstanding graduate students in STEM fields. Fellows receive three years of financial support through a $37,000 annual stipend and a $12,000 education allowance.

Submitted photo