An alchemist for the 21st century takes aim at the challenges of alternative energy through VCU's Institute for Sustainable Energy and Environment

Jena's prolific career sparked by a request to be a pen pal

By Joseph McClain

As a materials scientist, Puru Jena acknowledges his connection to the natural philosophers of centuries ago who worked to transmute common materials into precious ones, such as silver and gold.

"I call myself a modern-day alchemist," he says. Much of Jena's research focuses on the design and creation of new materials to address problems and challenges of life in the 21st century.

Jena, 80, is a Distinguished Professor in the Department of Physics in Virginia Commonwealth University's College of Humanities and Sciences. He also serves as the director for a new VCU university-level center, the Institute for Sustainable Energy and Environment, or ISEE.

A response to the call for collaborative, impactful research that addresses our global challenges, as set forth in the ambitious One VCU Research Strategic Priorities Plan, ISEE is a wide-ranging, transdisciplinary enterprise, addressing energy and environmental issues from multiple directions. A great deal of Jena's own work is applicable to sustainable energy and the environment. As modern-day alchemists, he and his collaborators have made a number of significant basic-science advancements in the quest to harness alternative energy sources, a precious resource in today's world.

"We all know that time is of the essence when it comes to creating a sustainable energy future," said VCU President Michael Rao. "It's vital that we dedicate education and resources to creating realistic and sustainable ways to harness energy. Dr. Jena's mission to train more students in scientific discovery, innovation and education is crucial to our environmental future and our global economy. We're fortunate to have him here at VCU."

President Rao continued, "VCU is recognized for transformative innovation and inventions that improve quality of life. ISEE's collaboration across disciplines and with organizations to unite and address the worldwide need for sustainable energy humanity now will benefit many generations to come."

Jena came to VCU in 1980, after receiving his doctorate from the University of California, Riverside, in 1970 and a decade of advancing through positions at a number of North American labs and universities. Before coming to the U.S., he received B.Sc. and M.Sc. degrees in physics at Utkal University in India. One day during his undergraduate studies, a faculty member approached him.

"A professor told me that a college in the USA is giving three scholarships to students at universities in India who have merit as well as poverty," Jena recalled.

The professor helped Jena assemble the application and paid for the postage. "I couldn't afford to buy the stamps," Jena added. "Then, one fine morning, the postman was looking for me.

There was this big envelope with blue and red marks on the boundary," he said. "I was just thrilled by seeing a letter in such a beautiful envelope."

The letter performed alchemy on Jena's life and career: It offered him a scholarship for his studies at Utkal University, underwritten by students at Salem College in Winston-Salem, N.C. One of the few requirements was that he correspond with students.

The first letter from Salem College to reach Jena was written by Vicky Auman, the president of the benefactor class. Auman and Jena became prolific correspondents and developed a close friendship.

"She is the one who suggested to me that I must come to the United States to do my graduate work," Jena said.

More than five decades later, Jena has authored nearly 650 papers including 14 edited books. His work has been cited more than 35,000 times, and his h-index is 92. His paper, "Penta-Graphene: A New Carbon Allotrope," published in 2015 in the Proceedings of the National Academy of Sciences, has been cited more than 1,000 times. In 1999, he was named a fellow of the American Physical Society.

He has presented over 550 invited talks in international conferences and academic institutions in 34 countries around the world and has organized over 60 international conferences. He has received nearly $18 million in funding from federal agencies such as the Department of Energy, Department of Defense, the National Science Foundation and NASA.

Prashant V. Kamat, the John A. Zahm Professor of Science at the University of Notre Dame, said Jena has made his mark within the sustainable-energy field, not only with his important contributions to the understanding of materials at the nanoscale, but also as an outstanding colleague and organizer-host of professional conferences. Kamat cited the International Symposium on Clusters and Nanomaterials (ISCAN), organized by Jena and held at VCU every four years since 1982, attracting leading scientists and young researchers from around the world to discuss the latest developments in materials and chemical physics.

"His enthusiasm, brilliance, humor and kindness made us comfortable to engage in scientific discussion in any gatherings," said Kamat, who also serves as editor-in-chief of the journal ACS Energy Letters*,* a leading journal that publishes the latest advances in energy research.

"Dr. Jena's extensive and storied career has greatly contributed to the theoretical understanding of nanomaterials, especially the concept of super-atoms, and you only have to look at his publication record to grasp the impact of his research on the entire field," said Angela Reynolds, Ph.D., the interim associate dean for research in the VCU College of Humanities and Sciences. "Even after nearly 50 years of scholarly study, Dr. Jena continues to produce innovative research, driven by his curiosity and enthusiasm."

The potential of Jena's theoretical work brought him into contact with Ivelina Metcheva, Ph.D., then head of Innovation Gateway and now assistant vice president for innovation at VCU TechTransfer and Ventures.

“Puru is a leader in his field of theoretical physics who looks years into the future to identify novel chemistries that could revolutionize multiple sectors, from agriculture to nano-processing and engineering,” Metcheva said. “He is helping put VCU and Virginia on the map as an innovation hub.” VCU secured a number of patents for Jena’s discoveries and he was inducted last year into the VCU chapter of the National Academy of Inventors.

Michael Mancini, Ph.D., who had worked as a tech transfer officer to provide VCU innovators and would-be entrepreneurs services focused on securing intellectual property rights for inventions and researchers, called Jena’s work “cutting edge.”

“It's very much on the theoretical side, just edging into what what is possible, physically,” said Mancini, now vice president of entrepreneurship and ecosystem development in Activation Capital, a Richmond firm specializing in technology startups. Such research is often better suited to a newer tech-transfer model based on partnerships, he added. “Let's find a company or a government organization, someone that has a real problem in the area that professors are working on, and bring them together.”

The classic alchemists sought to bring together common substances in their attempts to create precious ones — usually gold. They tried all manner of modifications to base metals — heat, pressure, soaking it — but, of course, always failed.

“The building blocks of materials are atoms,” Jena explained. “And the chemistry of atoms cannot be changed. So, that’s why the alchemists failed.”

However, modern-day alchemists such as Jena have an advantage over the old school, a group that included Isaac Newton himself: Jena and his collaborators work in nanoscale. Nanoscale is larger than atomic scale, but still pretty tiny.

Jena’s work takes place in an area that is less than 100,000 times the width of a human hair. Nanoscale and the even tinier sub-nanoscale occupy a kind of Goldilocks dimension, just the right size to allow materials scientists to manipulate the building blocks and use a large section of the periodic table of the elements as a palette to create new materials.

“If you look at the periodic table of elements, we have about 90 elements occurring in nature,” Jena said. “Everything that you see, or will ever see, will be made of this 90 elements — by themselves, or in combinations. That's how materials are made.”

But today, nanoscale science and engineering allows for the creation of materials that were unthinkable in the sphere of traditional combinations of elements. One example is super halogens. Jena said he read a flier about 10 years ago about the need for halogen-free electrolytes for lithium-ion batteries, which power our consumer electronics and electric cars.

“At that time, I knew what a battery is. But I had no idea beyond,” Jena said. “I had seen a battery in the store, and I know how to put it in my flashlight. I know how it works, but I did not know much about the composition and the structure.”

Batteries have three components. There is the cathode and anode, plus the electrolyte, which is a medium to pass ions between cathode and anode. (The direction depends on if the battery is charging or discharging.) When Jena loads his flashlight with D cells, those batteries likely

contain a potassium hydroxide electrolyte (assuming they are disposable alkaline batteries). Rechargeable lithium ion batteries require different electrolyte chemistry.

Jena asked a student to compile a list of lithium-ion battery electrolytes. The compounds on the list were heavy on halogens, a group on the periodic table that includes fluorine, chlorine, bromine and iodine. “Halogens are toxic,” he noted. “And they’re very reactive.”

The lab had already been working on what Jena was calling “super atoms.” He began thinking that perhaps he could engineer a super halogen: “I got the idea that perhaps we could apply this concept and see if we could design such an electrolyte. It would behave like chlorine, but it didn’t have to contain chlorine.”

Jena instructed his student to investigate the properties of the halogen salts that are being used for electrolytes. It turned out that the electron affinity — a measure of energy transfer — of halogen containing electrolytes was larger than that of chlorine but similar to some of Jena’s “super atoms.”

“And then I said, ‘Well, in that case, I know how to make a super halogen without ever using the halogen,’” he recalled.

His super halogen was a nearly spherical, figure with twenty plane faces – an icosahedronshape — a molecule containing one carbon atom, 11 boron atoms and 12 hydrogen atoms. Jena and his collaborators published work describing their super halogen in Angewandte Chemie International Edition. It attracted international notice and numerous citations.

“We wrote a paper that we have found a halogen-free electrolyte without ever knowing how a battery is made, just using quantum mechanics,” he said.

Jena’s accomplishments in modern-day alchemy extend beyond super halogens to span a wide expanse of nanotechnology, such as his work with various forms of carbon. With Professor Joel Therrien at the University of Massachusetts in Lowell and Dr. Hong Fang at VCU, he discovered a mechanically stable carbon material that is metallic as well as ferromagnetic. They dubbed it “U-carbon.”

Science magazine covered the announcement of U-carbon at an international conference and described attendees as buzzing with excitement. U-carbon, it reported, is ”harder than stainless steel, about as conductive, and as reflective as a polished aluminum mirror,” and predicted its use in lightweight coatings, medical products, and novel electronic devices. (Jena’s TEDx talk describes the many faces of carbon.)

Among all his discoveries, Jena says his “pet project” is hydrogen storage. Hydrogen shows great promise as a replacement for fossil fuels for cars, and Jena has been working on hydrogen problems for decades.

“In 2003, President George W. Bush announced the hydrogen initiative,” Jena said. “He wanted a hydrogen-based economy to replace fossil fuels. He said that a child born today will drive a car driven by clean hydrogen rather than by gasoline. Which means by 2020, we should have all the cars on the road using hydrogen. Of course, that didn’t happen.”

Five kilograms of hydrogen contains enough energy to drive a car about 300 miles at a stretch,

Jena said. “But to keep that amount of hydrogen, we need a tank that is probably 10 times bigger than the car,” he added. Current-technology storage such as liquefaction and pressurization offer a number of problems. Jena is working on a nanotech solution which involves using a substance that acts as a “sponge,” soaking up hydrogen.

“It absorbs the hydrogen, then you heat it up to extract the hydrogen. Then you fill it up again,” he said.

Jena has been at the forefront of hydrogen storage research for some time. The Department of Energy asked him to serve on a committee to consider the future of hydrogen fuel technology. “But as funding for hydrogen declined, so did interest,” he said.

The imperative to use alternative energy sources has rekindled interest — and research — on hydrogen. Discoveries centering on hydrogen storage and a lithium-battery electrolyte that’s chemically reactive as halogen, but without halogen’s toxicity, are right in the wheelhouse of the Institute for Sustainable Energy and Environment. The ISEE is a collaborative effort of VCU’s College of Engineering, the College of Humanities and Sciences and the L. Douglas Wilder School of Government and Public Affairs, and so its mission extends beyond modern alchemy.

Jena describes establishment of ISEE as the culmination of a personal 15-year dream. In 2007-2008, he served in the U.S. State Department as a Jefferson Science Fellow, advising the government on pending bilateral and multilateral agreements concerning science and technology. He was a member of the organizing committee of the Washington International Renewable Energy Conference (WIREC) 2008, led by the Department of State and Department of Agriculture.

Jena volunteered to lead the research and development collaboration arising from WIREC 2008. It took almost a year to assemble, and resulted in the involvement of 125 countries at the ministerial level. President Bush was among those who spoke to about 9,000 attendees – at the time, it was the largest conference of its kind. Jena then edited a conference report; an abridged version has appeared in a number of scientific and engineering bulletins and journals.

“That conference was to invite the ministers of energies from all the countries in the world to come to Washington to discuss what needs to be done to promote renewable energy globally,” Jena explained. “That conference had what I call four legs, and one of them was R&D: What is the R&D that we need to do to become completely renewable?”

“When I came back to Richmond, I talked to the university administration, saying that this is an area that's going to be extremely important,” Jena said. “There'll be a lot of federal resources that will be available to do research and development in this area. I think we should invest in an institute or a center to really work on this.”

“Addressing sustainable clean energy and the environment is a complex issue,” said Vice President P. Srirama Rao, Ph.D., whose office approved the ISEE as a university-level institute. “As the director of the Institute for Sustainable Energy and Environment, Puru Jena has taken on the enormous and ambitious goal to support clean energy and facilitate researchers in developing sustainable solutions and innovations that will help provide us with a cleaner, better future.

“This ambitious goal is at the core of our One VCU Research Strategic Priorities Plan: building

and supporting sustainable energy and environments -- and I couldn't think of someone more equipped to take this challenge head on than Dr. Jena," Rao added.

"Dr. Jena's focus on renewable energy -- long before it was fashionable to do so -- illustrate his visionary thinking and his commitment to combating climate change," said Catherine Ingrassia, Ph.D., interim dean of the VCU College of Humanities and Sciences. "By developing innovative and sustainable practices, Dr. Jena has pursued research and created the Institute for Sustainable Energy and Environment that will play a pivotal role in safeguarding the environment for future generations."

"Professor Jena is a world-renowned physicist whose pioneering work on the fundamental aspects of material science has moved the field forward and led to many exciting technological advances," said Fotis Sotiropoulos, Ph.D., VCU provost and senior vice president for academic affairs. "His passion for advancing environmental sustainability through cutting edge science and technology is positioning VCU to emerge as a leading institution in this area. I am immensely proud and humbled to lead academic affairs in an institution where I have the honor to call faculty of the caliber of Professor Jena my colleagues."

ISEE launched in late 2022. Jena said he would like it to become a global center, involving not only VCU faculty and students, but also incorporating expertise from all around the world through bilateral and multilateral collaborations.

"We want to establish a program in which we look at both energy and environment with a holistic view, not as an individual problem that you need to solve, because energy and environment are interrelated," he explained.

"And to solve this problem is highly complex," Jena added. "Not only do you have to have energy coming from all clean, sustainable sources, but you have to know how to store it, how to transport it cost-effectively and in a secure way." He cautions that the path from laboratory to market for renewable energy is not for the impatient, and there is a process that necessarily involves a number of players.

"From the fundamental science, we have to proceed to the development, where we bring in engineers and technologists to take the discovery from the bench to the device stage," Jena said. "And then we bring in the economists, to find out whether or not these processes are economically feasible."

And it's appropriate for VCU's Institute for Sustainable Energy and Environment to heed a version of the physician's "first, do no harm" motto.

"We need to bring in the environmentalists, to make sure that we are not harming the environment in the process of doing all these innovations," Jena said. "And we have to bring in people who could possibly suffer from it."

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