McCormick

Northwestern Engineering

Chemical and Biological Engineering

Robert R. McCormick School of Engineering and Applied Science
Northwestern University

SPRING 2013

Researchers Make Strides Toward Selective Oxidation Catalysts

Oxide catalysts, typically formulated as powders, play an integral role in many chemical transformations, including cleaning wastewater, curbing tailpipe emissions, and synthesizing most consumer products.

Greener, more efficient chemical processes would benefit greatly from solid oxide catalysts that are choosier about their reactants, but achieving this has proven a challenge. Now researchers from Northwestern and Argonne National Laboratory have developed a straightforward and generalizable process for making reactant-selective oxide catalysts by encapsulating the particles in a sieve-like film that blocks unwanted reactants.

The process could find applications in energy, particularly the conversion of biomass into sugars and then fuels and other useful chemicals.

A paper detailing the research, "Shape-selective Sieving Layers on an Oxide Catalyst Surface," was published in October in the journal *Nature Chemistry*.

"The ability to conduct these reactions in a selective way opens doors to new applications in green chemistry and sustainability," especially for selective oxidation, said Justin Notestein, assistant professor of chemical and biological engineering at McCormick and the paper's corresponding author. "Unlike current processes, which may require enzymes or precious metals, our method relies only on harmless, inert oxides. These are powders you can hold in your hand."

In testing their method, the researchers focused on photocatalytic oxidations such as the conversion of benzyl alcohol into benzaldehydes, reactions that are notoriously unselective. The researchers coated a core particle of titanium dioxide, a harmless white pigment, with a nanometer-thick film of aluminum oxide. They used a synthesis method that resulted in a film pitted with "nanocavities," tiny holes less than two nanometers in diameter.

This sieve-like coating allowed only the smaller reactants in a mixture to slip through the holes and react with the titanium oxide; larger reactants were blocked. The result was much higher selectivity (up to 9:1) toward the less hindered reactants.

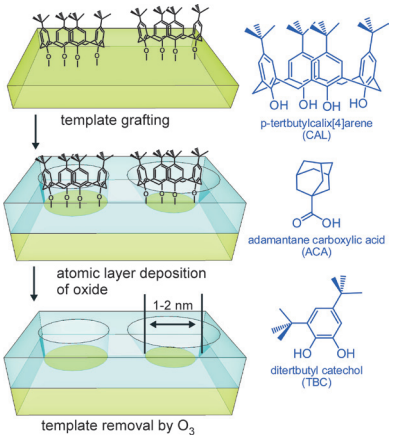
The process was conducted at room temperature and required only a low-power light source, whereas other catalysts may require precious metals or hazardous oxidants.

In addition to Notestein, other Northwestern authors of the paper included Richard P. Van Duyne, Charles E. and Emma H. Morrison Professor of Chemistry in the Weinberg College of Arts and Sciences; Peter C. Stair, professor and chair of Weinberg's chemistry department; postdoctoral researcher Christian P. Canlas; PhD candidate Natalie A. Ray; and undergraduate Nicolas A. Grosso-Giordano. From Argonne National Laboratory, authors included Junling Lu, Sungsik Kee, Jeffrey W. Elam, and Randall E. Winans.

The research was conducted in collaboration with the Institute for Atom-Efficient Chemical Transformations, a Department of Energy Energy Frontier Research Center that also includes members from Purdue University and the University of Wisconsin.

Nanocavity materials act like molecular-scale sieves to give selective reaction of one or another molecule in a mixture, potentially revolutionizing how complex reactions are carried out. These nanocavity materials are synthesized by 1) grafting a bulky template to an active catalyst, 2) partially coating the surface with another oxide, then 3) creating the molecule-sized nanocavities by removing the templates. Many templates (shown below at right) are available to modify the selectivity of the catalysts.

"Unlike current processes, which may require enzymes or precious metals, our method relies only on harmless, inert oxides. These are powders you can hold in your hand."
Justin Notestein



Breakthrough Nanoparticle Halts Multiple Sclerosis

NEW NANOTECHNOLOGY CAN BE USED FOR TYPE 1 DIABETES, FOOD ALLERGIES, AND ASTHMA

In a breakthrough for nanotechnology and multiple sclerosis, a biodegradable nanoparticle turns out to be the perfect vehicle to stealthily deliver an antigen that tricks the immune system into stopping its attack on myelin and halt a model of relapsing remitting multiple sclerosis (MS) in mice, according to new Northwestern Medicine research.

The new nanotechnology also can be applied to a variety of immune-mediated diseases including Type 1 diabetes, food allergies, and airway allergies such as asthma.

In MS, the immune system attacks the myelin membrane that insulates nerve cells in the brain, spinal cord, and optic nerve. When the insulation is destroyed, electrical signals can't be effectively conducted, resulting in symptoms that range from mild limb numbness to paralysis or blindness. About 80 percent of MS patients are diagnosed with the relapsing remitting form of the disease.

The Northwestern nanotechnology does not suppress the entire immune system as do current therapies for MS, which make patients more susceptible to everyday infections and higher rates of cancer. Rather, when the nanoparticles are attached to myelin antigens and injected into the mice, the immune system is reset to normal. The immune system stops recognizing myelin as an alien invader and halts its attack on it.

"This is a highly significant breakthrough in translational immunotherapy," said Stephen Miller, a corresponding author of the study and the Judy Gugenheim Research Professor of Microbiology-Immunology at Northwestern's Feinberg School of Medicine. "The beauty of this new technology is it can be used in many immune-related diseases. We simply change the antigen that's delivered."

"The holy grail is to develop a therapy that is specific to the pathological immune response, in this case the body attacking myelin," Miller added. "Our approach resets the immune system so it no longer attacks myelin but leaves the function of the normal immune system intact."

The nanoparticle, made from an easily produced and already FDA-approved substance, was developed by Lonnie Shea, professor of chemical and biological engineering at McCormick.

"This is a major breakthrough in nanotechnology, showing you can use it to regulate the immune system," said Shea, also a corresponding author. The paper was published in November in the journal *Nature Biotechnology.*

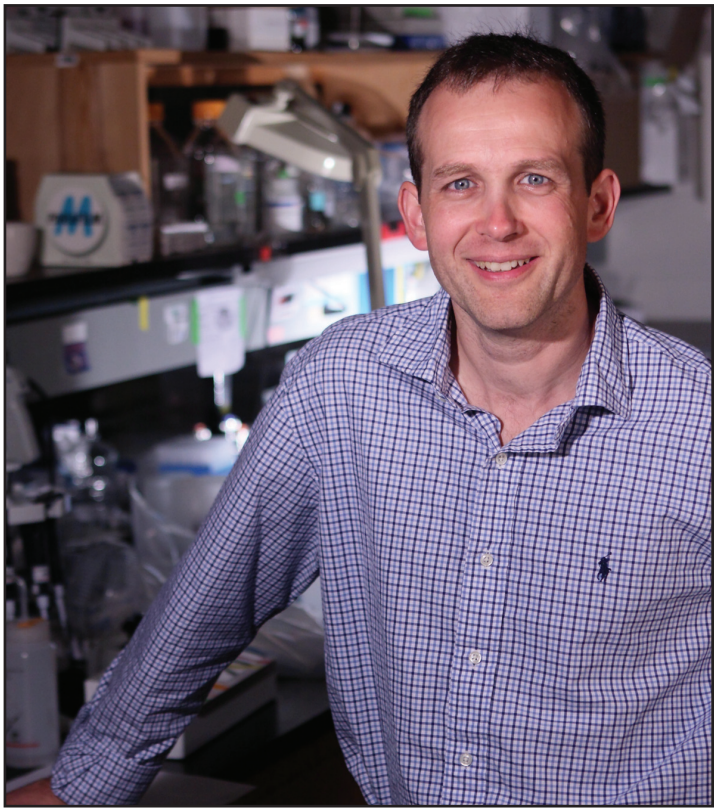
Miller and Shea are also members of the Robert H. Lurie Comprehensive Cancer Center of Northwestern. In addition, Shea is a member of the Institute for BioNanotechnology in Medicine and the Chemistry of Life Processes Institute.

Clinical trial for MS tests same approach — with key difference

The study's method is the same approach now being tested in multiple sclerosis patients in a phase I/II clinical trial — with one key difference. The trial uses a patient's own white blood cells — a costly and labor intensive procedure — to deliver the antigen. The purpose of the new study was to see if nanoparticles could be as effective as the white blood cells as delivery vehicles. They were.

The big nanoparticle advantage for immunotherapy

Nanoparticles have many advantages; they can be readily produced in a laboratory and standardized for manufacturing. They would make the potential therapy cheaper and more accessible to a general population. In addition, these nanoparticles are made of a polymer called Poly(lactide-co-glycolide) (PLG), which consists of lactic acid and glycolic acid, both natural metabolites in the human body. PLG is most commonly used for biodegradable sutures.



"This is a major breakthrough in nanotechnology, showing you can use it to regulate the immune system."
Lonnie Shea

The fact that PLG is already FDA approved for other applications should facilitate translating the research to patients, Shea noted. Miller and Shea tested nanoparticles of various sizes and discovered that 500 nanometers was most effective at modulating the immune response.

"We administered these particles to animals who have a disease very similar to relapsing remitting multiple sclerosis and stopped it in its tracks," Miller said. "We prevented any future relapses for up to 100 days, which is the equivalent of several years in the life of an MS patient."

Shea and Miller also are currently testing the nanoparticles to treat Type 1 diabetes and airway diseases such as asthma.

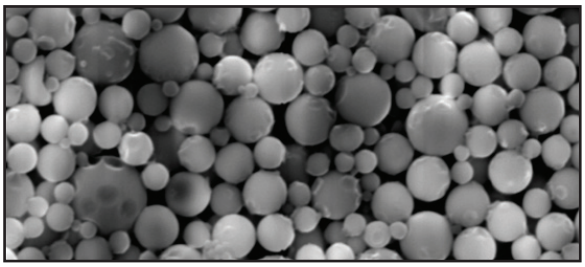
Nanoparticles fool immune system

In the study, researchers attached myelin antigens to the nanoparticles and injected them intravenously into the mice. The particles entered the spleen, which filters the blood and helps the body dispose of aging and dying blood cells. There, the particles were engulfed by macrophages, a type of immune cell, which then displayed the antigens on their cell surface. The immune system viewed the nanoparticles as ordinary dying blood cells and nothing to be concerned about. This created immune tolerance to the antigen by directly inhibiting the activity of myelin-responsive T cells and by increasing the numbers of regulatory T cells, which further calmed the autoimmune response.

"The beauty of this new technology is it can be used in many immune-related diseases. We simply change the antigen that's delivered." *Stephen Miller*

"The key here is that this antigen/particle-based approach to induction of tolerance is selective and targeted. Unlike generalized immunosuppression, which is the current therapy used for autoimmune diseases, this new process does not shut down the whole immune system," said Christine Kelley, National Institute of Biomedical Imaging and Bioengineering director of the division of Discovery Science and Technology at the National Institutes of Health, which supported the research. "This collaborative effort between expertise in immunology and bioengineering is a terrific example of the tremendous advances that can be made with scientifically convergent approaches to biomedical problems."

"We are proud to share our expertise in therapeutics development with Dr. Stephen Miller's stellar team of academic scientists," said Scott Johnson, CEO, president, and founder of the Myelin Repair Foundation. "The idea to couple antigens to nanoparticles was conceived in discussions between Dr. Miller's laboratory, the Myelin Repair Foundation's drug discovery advisory board, and Dr. Michael Pleiss, a member of the Myelin Repair Foundation's internal research team, and we combined our efforts to focus on patient-oriented, clinically relevant research with broad implications for all autoimmune diseases. Our unique research model is designed to foster and extract the innovation from the academic science that we fund and transition these technologies to commercialization. The overarching goal is to ensure this important therapeutic pathway has its best chance to reach patients, with MS and all autoimmune diseases."



Nanoparticles (shown above) developed by McCormick researchers could aid in the treatment of multiple sclerosis.

The research is supported by a grant from the Myelin Repair Foundation, grants NS026543 and EB013198 from the National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health and Juvenile Diabetes Research Foundation Grant 17-2011-343.

Two Chemical and Biological Engineering Professors Named AAAS Fellows

Two faculty members from the Department of Chemical and Biological Engineering have been elected fellows of the American Association for the Advancement of Science (AAAS), the world's largest general scientific society.

The professors were nominated for meritorious efforts to advance science or its applications. New fellows were honored in February at the 2013 AAAS Annual Meeting in Boston.

Luís A. Nunes Amaral, professor of chemical and biological engineering, was selected for distinguished contributions to the theoretical and computational study of complex systems, particularly for the development of a cartographic framework for characterizing large networks.

John M. Torkelson, Walter P. Murphy Professor of Chemical and Biological Engineering, was chosen for outstanding contributions to the field of polymer science and engineering and for formulating core principles underlying dynamics in confined polymer systems and nanoparticle-polymer interactions.

Four other Northwestern faculty members were also elected members of the AAAS in February. They included two other McCormick faculty members — ***Michael J. Bedzyk***, professor of materials science and engineering, and ***Ajit C. Tamhane***, professor of industrial engineering and management sciences — as well as Franz M. Geiger, professor of chemistry, and Mercouri G. Kanatzidis, the Charles E. and Emma H. Morrison Professor of Chemistry, both of the Weinberg College of Arts and Sciences.

Luís Amaral

John Torkelson

AAAS is an international nonprofit organization dedicated to advancing science around the world. It publishes the journal *Science*, as well as newsletters, books, and reports. In 2012, AAAS elected 702 of its members as fellows.

Department News

GRADUATE STUDENT WINS FORESIGHT INSTITUTE'S DISTINGUISHED STUDENT AWARD

David A. Walker, a PhD candidate studying nanotechnology at McCormick, has been awarded the 2012 Distinguished Student Award by the Foresight Institute, a leading think tank that advances transformative technologies.

The Distinguished Student Award recognizes a student with notable work in the field of nanotechnology.

Walker is researching nanoscale electrostatic interactions and their ability to precisely assemble nano-objects to within a few nanometers. His adviser is Bartosz A. Grzybowski, Kenneth Burgess Professor of Chemical and Biological Engineering and director of the Non-Equilibrium Energy Research Center.

"I am interested in how electrostatic interactions can be implemented at the nanoscale," Walker said. "Nature has been using these forces for eons to assemble molecules and fold proteins while we, as scientists, are just beginning to implement their use in nano- and supramolecular-chemistry. Not just their ability to assemble nanoparticles, but their ability to regulate properties at a molecular level, is simply remarkable."

Walker has authored 11 articles and has had work published in nanotechnology and chemistry journals such as *Nature Nanotechnology*, *Nano Letters*, and *Angewandte Chemie Int. Ed.* He is also an NSF MRSEC Fellow, a Patrick and Shirley Ryan Fellow, a Harold Smith and Borrous Martin Fellow, and an honorary DoE NERC fellow.

Walker is the first Northwestern student to be granted the student award since its inception in 1997. Several Northwestern professors have received Foresight Institute recognitions, including Mark Ratner and Chad Mirkin, Fraser Stoddart, and George Schatz, who have received the professorial level Feynman Prize in previous years.

FACULTY NEWS

Jennifer Cole was selected to the prestigious NAE Frontiers of Engineering Education Symposium.

Mike Jewett was selected as a faculty member for Cold Spring Harbor Laboratory's inaugural course on synthetic biology. He was also a plenary speaker at the International Conference on Cell-free Bioproduction organized by the nine Fraunhofer Institutes in Germany, and he was appointed to the Scientific Advisory Board of gen9, a company building the first "fab" for synthetic biology. Finally, Jewett was selected as a participant in the National Academy of Engineering Frontiers of Engineering symposium.

The iGEM team advised by ***Mike Jewett***, ***Joshua Leonard***, and ***Keith Tyo*** was awarded a gold medal at the regional competition and advanced to the international competition at MIT.

Harold Kung was appointed an honorary professor at the Nanjing University of Technology in Nanjing, China.

Joshua Leonard received the Career Development Award from Northwestern's Prostate Cancer Specialized Program of Research Excellence (SPORE).

Research by ***Bill Miller*** appeared on the covers of the April issues of *Tissue Engineering* Part A and *Tissue Engineering* Part B. Co-authors included PhD graduate ***Swapna Panuganti*** and current PhD student ***Alaina Schlinker***, in collaboration with Paul Lindholm at Feinberg and Terry Papoutsakis at the University of Delaware.

Julio M. Ottino presented the 2012 TechniGraphicS Foundation Lecture at IIT Bombay, India, as well as the Distinguished Research Lecture in Chemical Engineering at Carnegie Mellon University. He also delivered an Eminent Lecture at the National Technical University of Singapore and a keynote lecture to their Board of Trustees.

Randy Snurr and graduate student ***Pritha Ghosh*** won the 7th Industrial Fluid Properties Simulation Challenge at AIChE 2012. Snurr also joined the editorial advisory board of the journal *Adsorption Science & Technology*.

Lonnie Shea was selected as the plenary speaker for the Engineering Fundamentals in Life Science Division (15d/e) of AIChE.

Keith Tyo received the ISEN Early Career Investigator Award for his proposal, "High Biofuel Conversion Yields through Degrading Byproduct Enzymes."

STUDENT NEWS

Senior ***Nicolas Grosso-Giordano*** was awarded first prize at the student poster competition at the national meeting of the American Institute of Chemical Engineers. His poster, "Towards Understanding Catalyst Diffusion in Biomass," was awarded first place in the Fuels, Petrochemicals, and Energy III division.

Cary Hayner, a graduate student in Harold Kung's group, was part of team that was the runner up in the Dow Sustainability Student Challenge. Their project worked to revolutionize anode performance of lithium-ion batteries in terms of both capacity and charging speed with little increase in cost. (For more about this project, see back page.)

Jennifer Kay and ***Rey Martin***, graduate students in Michael Jewett's lab, were awarded National Science Foundation fellowships.

Emily Leitsch, a graduate student working with John Torkelson, was awarded a Science, Mathematics & Research for Transformation (SMART) Scholarship from the Department of Defense.

Heather Mayes, a graduate student in Linda Broadbelt's group, was selected to participate in the 63rd Lindau Nobel Laureate Meeting.

Graduate student ***Alaina Schlinker***, a member of Bill Miller's group, was awarded a Dr. John N. Nicholson Fellowship.

Rachel Scholes, a junior, received an academic year Undergraduate Research Grant for her project with Neal Blair, "Plastic Marine Debris in Sediments at Lagartillo Reef, Costa Rica."

Chris Wilmer, a graduate student in Randy Snurr's group, was named to *Forbes*' "30 Under 30: Energy" list. Wilmer also won first prize in the poster competition of the American Chemical Society's Energy and Fuels Division at the August national meeting.

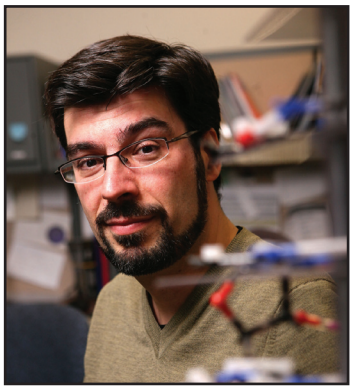
Fewer Resources May Explain Why Some Female Faculty Publish Less, Study Says

NEW STUDY UNCOVERS IMPACT OF GENDER-BIASED RESOURCE ALLOCATION ON FACULTY PRODUCTIVITY

A new Northwestern study of professors in STEM fields at top research universities across the country shows that bias against women is ingrained in the workforce, despite a societal desire to believe workplace equality exists.

The quantitative study of the complete publication records of more than 4,200 professors in seven STEM fields (science, technology, engineering, and mathematics) confirms that, for some disciplines, female faculty do publish fewer papers than male faculty but not for lack of talent or effort.

The researchers found the "productivity gap" varied depending on the discipline. In fields that require more resources, women publish less. This indicates the gap may exist because academic departments historically have not invested resources equally in female faculty from the start of their careers. Men are getting greater resources.



Luís Amaral

"If a woman starts her career at a lower point, it is impossible to catch up," said Luís Amaral, professor of chemical and biological engineering. "Women in academia are perceived as less productive, but this may be explained to a great extent by the fact that women are given fewer resources to succeed."

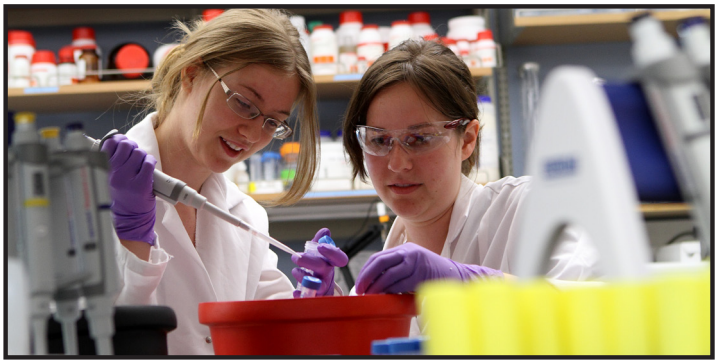
Amaral said he believes the results represent what is happening to all underrepresented groups in science and engineering, such as African-Americans and Hispanics, and possibly in workplaces outside academia, such as business, politics, and the legal profession.

Amaral and Teresa K. Woodruff led the study, which was published in December by the journal *PLOS ONE*. The findings have significant, field-specific policy implications for achieving diversity at the faculty level within the STEM disciplines.

"We are losing the potential of women — in science and engineering and many other fields — because of this biased difference," said Woodruff, the Thomas J. Watkins Memorial Professor of Obstetrics and Gynecology at the Feinberg School of Medicine. "I expect it would cost very little to bridge the gap and take bias out of the system. Our goal is to understand the productivity gap so we can intervene, change the culture, and create new policy."

Xiaohan Zeng, a graduate student in Amaral's lab and a co-first author of the paper, spent nearly three years amassing information on 437,787 publications authored by 4,292 professors in seven STEM fields — chemical engineering, chemistry, ecology, industrial engineering, material science, molecular biology, and psychology.

The research team built a database that sorted faculty by field. A wide variety of considerations needed to be factored in, such as the increase in publication rate over the last 40 years and the fact that senior faculty publish at a higher rate than junior faculty. The researchers only studied independent academic researchers — those who had survived the STEM pipeline and went on to become professors with their own labs.



Female professors in STEM fields face ingrained bias in the workplace, possibly because academic departments invest fewer resources in women, a Northwestern study suggests.

"These data enabled us to characterize the career-long scientific production of a sizable sample of faculty from seven disciplines, and to measure statistically significant differences that would have otherwise remained hidden," the authors wrote.

The researchers found that for a discipline such as industrial engineering, where research resource requirements are low, the gap essentially is absent. Male and female faculty published papers at similar rates. But for a discipline such as molecular biology, where resource requirements are very high, the gap is quite wide, with male faculty publishing at significantly higher rates than their female colleagues.

"We need rigorous mechanisms to help us not be unfair in the workplace," Amaral said. "We need facts to start studying these biases and get changes in the culture. You can't just trust people to say they don't have bias. We all do have unconscious bias."

The researchers used publicly available data in their study, but their methods can easily be used more broadly, including in the private sector, to investigate the effects of potential biases.

In the study, the research team also found that in disciplines where pursuing an academic position incurs greater career risk, such as in ecology, female faculty tend to have a greater fraction of higher impact publications than males. The greater the risk of career choice, the greater the impact gap, with women having more impactful papers.

This suggests female faculty in higher-risk careers publish papers of higher quality than their male colleagues.

"Women are self-selecting — they are not allowed to be as risky when choosing an academic career," Woodruff said. "You have to be really, really good to be a female in ecology. We are losing talented women in the STEM fields because they are choosing to go elsewhere."

The National Science Foundation supported the research.

The title of the *PLOS ONE* paper is "The Possible Role of Resource Requirements and Academic Career-Choice Risk on Gender Differences in Publication Rate and Impact."

In addition to Amaral, Woodruff, and Zeng, other authors of the paper are Jordi Duch (co-first author), Marta Sales-Pardo, Filippo Radicchi, and Shayna Otis.

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Student Startup Wins Big in Rice Business Plan Competition

SINODE SYSTEMS GAINS $911,000 IN CASH AND INVESTMENTS TO ADVANCE BATTERY TECHNOLOGY DEVELOPED BY HAROLD KUNG

SiNode Systems, a clean tech startup that commercialized battery technology developed in Harold Kung's lab, took first place in the Rice Business Plan Competition in April, walking away with more than $900,000 in cash and investments.

It was the second straight year that Northwestern teams — and, more specifically, teams pitching technology developed by professors from McCormick's Department of Chemical and Biological Engineering — won the competition.

SiNode, which got its start in Northwestern's NUvention: Energy course, bested 41 other teams from around the world in the world's richest and largest graduate-level business plan competition. In the three-day event, teams pitch business ideas to venture capitalist and industry experts seeking startups in which to invest.

"I am both delighted and excited for SiNode," said Kung, professor of chemical and biological engineering at McCormick. "Their success at the Rice Competition demonstrates the maturity of the students in understanding both the technology and the market, as well as their ability to develop a compelling vision of the future."

SiNode commercializes a lithium-ion battery anode that allows the battery to charge more quickly and hold a charge 10 times longer than current technology. The technology could greatly enhance battery life for smart phones and electric vehicles.

SiNode comprises graduate students from two Northwestern schools: Cary Hayner, of the Department of Chemical and Biological Engineering; Joshua Lau and Thomas Yu of the Department of Materials Science and Engineering; and Guy Peterson, Samir Mayekar, and Nishit Mehta of the Kellogg School of Management.

Two Northwestern startups, SiNode and BriteSeed, won nearly $1.2 million combined in the Rice Business Plan Competition. Among SiNode's members is Cary Hayner, a PhD candidate in chemical and biological engineering (above, at far left).

Hayner and Yu are PhD candidates in Kung's lab.

In all, 300 judges doled out $1.5 million in prizes and in-kind services at the 2013 Rice competition. Taking second place was another Northwestern NUvention team: BriteSeed, a medical startup that pitched a surgical tool to prevent unintended bleeding during surgery.

Last year, NuMat — a clean tech startup that pitched technology from the lab of Randall Snurr, professor of chemical and biological engineering — took first place.