MECHANICAL ENGINEERING ANNUAL REPORT 2011-2012

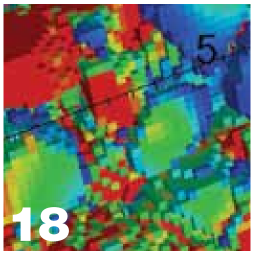
ME

MICHIGAN ENGINEERING

UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

Mechanical Engineering Annual Report 2011–2012

ON THE COVER AND INSIDE FRONT PAGE: Highly functionalized aramid building blocks are achieved in the form of 50 nm-diameter nanosheets from commercial Kevlar fibers that are being used by the Arruda group to form complex nanostructures with tailorable macroscopic properties through various chemical treatments. See page 32 for the full story.



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Message from the Chair

"As one of the nation's top mechanical engineering programs, the University of Michigan Department of Mechanical Engineering continually strives toward excellence on many fronts."

As one of the nation's top mechanical engineering programs, the University of Michigan (U-M) Department of Mechanical Engineering (ME) continually strives toward excellence on many fronts. I am delighted to share the highlights of our efforts, advances and impact over the past year with you in this 2011-12 annual report.

Construction of our department's new $46 million, 62,880-square-foot research complex is continuing on schedule, with completion expected by spring 2014. This new complex will enable transformative research activities, integrating core mechanical engineering with emerging areas, such as micro-, nano- and bio- systems.

In addition, we were thrilled to learn recently that the State of Michigan will provide $30 million for a major renovation of the existing G.G. Brown building. This is an approximately $47 million project focused on creating a modern, world-class instructional space for active teaching and learning in mechanical engineering.

Our faculty members are playing leadership roles and receiving recognition at the national and international levels. Professor Jyotirmoy Mazumder has been elected to the National Academy of Engineering, one of the highest professional honors accorded an engineer. Six of our junior faculty have garnered seven competitive young investigator awards in 2012, from the National Science Foundation, National Institutes of Health, Air Force Office of Scientific Research, Office of Naval Research and DARPA. Our colleagues have been invited to comment on important issues related to energy and the environment in national media. ME faculty continue to lead many multidisciplinary research activities. Recently we forged two new collaborations with industry partners BAIC Motor Corporation, Ltd., and FAW Group Corporation. The two resulting research centers will be housed at U-M and led by ME faculty.

Two new colleagues are joining our faculty at the start of the 2012-13 academic year: André Boehman, Professor of Mechanical Engineering, is a world leader in fuel processing and combustion research; Assistant Professor David Remy brings a wealth of new expertise in robotics, mechatronics and biomechanics. Several new faculty searches for the coming year are underway as well.

On the research front, our discoveries continue to impact both the scientific community and society. As you will read in the pages ahead, investigators have made breakthroughs in fundamental and applied research across many fields, from mechanics, acoustics, energy, transportation, manufacturing and robotics to bio- and nano-technologies. Multidisciplinary research centers in clean vehicles, advanced batteries, heat transfer at material interfaces and advanced manufacturing also are highlighted.

We continue to launch new education programs and opportunities for students in Ann Arbor and abroad—in classrooms, laboratories and remote health clinics, to name just a few of the learning environments. Our student teams—MRacing, Baja and the Solar Car Team—again excelled in the many competitions in which they participated.

We are proud of the achievements of our alumni and are grateful for their continued support of the Department in so very many ways. The examples included in this report are only a small sampling.

Thank you for your interest, and here is to a productive, fruitful year ahead.

Kon-Well Wang
Stephen P. Timoshenko Collegiate Professor and Chair, Department of Mechanical Engineering

Faculty Profile

4
Current NAE Members

71
Society Fellows

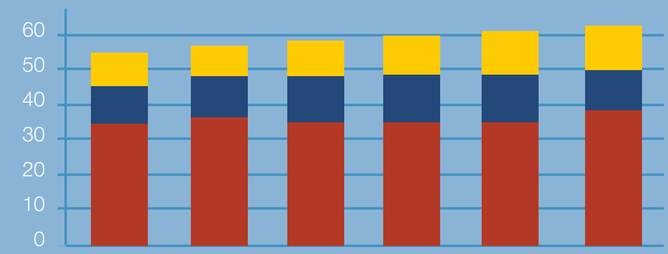
4
NSF PECASE or PFF Awards

29
NSF CAREER or PYI Awards

5
Current Journal Chief Editors

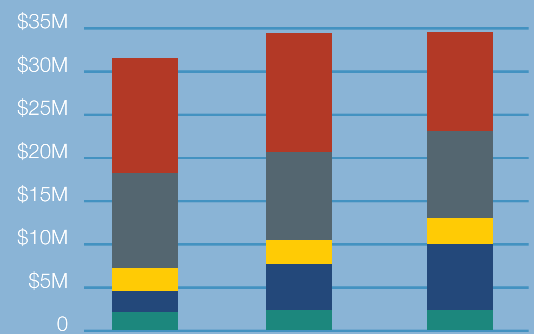
75
Current Journal Editorial Board or Assoc. Editor Appts.

Faculty Trends: Tenured and Tenure-Track



	FA07	FA08	FA09	FA10	FA11	FA12
Assistant	9	10	11	12	14	16
Associate	12	11	12	12	11	8
Professor	34	36	35	36	36	39
Total	55	57	58	60	61	63

Annual Research Expenditures

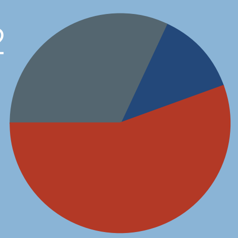


	09–10	10-11	11-12
NIH	1,996,237	2,168,238	2,153,049
DoE	2,390,860	5,407,039	7,797,900
NSF	2,701,330	3,104,779	3,278,770
DoD	10,992,316	9,796,979	9,853,599
All Other	13,792,756	14,092,339	11,804,193
Total	$31,873,498	$34,569,374	$34,887,511

Degrees Conferred

2011-12

BSE 209
MSE 120
PhD 47



Mazumder Elected to the National Academy of Engineering

JYOTI MAZUMDER

Professor **Jyoti Mazumder** has been elected to the National Academy of Engineering. He was recognized for his work in the area of "quantitative transport modeling for laser interaction and design and commercialization of direct metal deposition machines."

Mazumder is the Robert H. Lurie Professor of Mechanical Engineering and directs the Center for Laser-Aided Intelligent Manufacturing (CLAIM), where he and his research group study the plasma present in laser processing and attempt to understand the basic physics of the interaction between light photons and material electrons.

Election to the National Academy of Engineering is one of the highest professional honors accorded an engineer. Members have distinguished themselves in business or academic management, in technical positions, as university faculty and as leaders in government or private engineering organizations.

Fourth ME Professor Wins ASME William T. Ennor Award

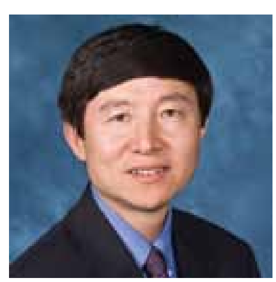
The American Society of Mechanical Engineers William T. Ennor Manufacturing Technology Award was established more than two decades ago. The award recognizes individuals or teams for developing or contributing significantly to innovative manufacturing technology as well as for its implementation. The innovation also must result in substantial economic and/or societal benefit. This is one of the most prestigious ASME awards in the field of manufacturing.

In 2012 ME Professor **S. Jack Hu** received the coveted award. Hu is the fourth U-M ME faculty member to be honored with the Ennor medal, joining fellow U-M ME colleagues and Ennor recipients **Yoram Koren** (1999), **Jyoti Mazumder** (2006) and **Jun Ni** (2009). Having four awardees on our faculty is an achievement that distinguishes the Department from among peer institutions.

Hu, the J. Reid and Polly Anderson Professor of Manufacturing Technology, received the award *"for pioneering the development of innovative methodologies for predicting and diagnosing quality variation in multistage assembly systems and methods for designing manufacturing system configurations and their implementation in automotive body assembly and battery manufacturing."*

YORAM KOREN

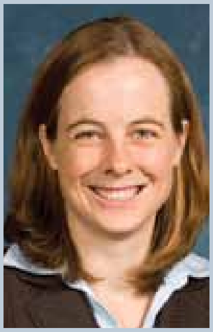
JYOTI MAZUMDER



JUN NI

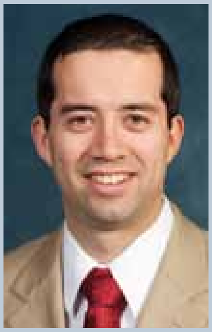
S. JACK HU

Six Faculty Win Seven Early-Career Awards in 2012


SAMANTHA DALY


JIANPING FU


JOHN HART


ERIC JOHNSEN


ALLEN LIU


PRAMOD SANGI REDDY

Assistant Professor **Samantha Daly** has won an **Air Force Office of Scientific Research Young Investigator Research Program award** for her proposed research, "A New Approach Towards Characterizing Microstructural Influence on Material Behavior Under Very High Cycle Fatigue." Her goal is to use new experimental approaches to examine local damage accumulation during very high cycle fatigue (VHCF), an increasingly common and costly problem in aerospace applications.

Aerospace components are being designed for increasingly longer lifetimes, usually in high-vibration, high-temperature applications. Accurately predicting when these components will fail is critically important. In order to understand what drives damage accumulation and eventual failure at the component level, quantitative experimental data linking accumulated local damage back to the microstructure is necessary. Currently no accurate, effective way exists to make this connection.

Daly's research approach addresses a fundamental gap in the understanding of fatigue failure in the VHCF regime. Through experiments across a range of applied loads and temperatures, she will conduct the first quantitative, full-field, *in-situ* comparisons between accumulated local damage, fatigue crack behavior, macroscopic response and underlying microstructure. She will pioneer the development of a new experimental approach and use it to examine the microstructural damage accumulation of titanium alloy Ti-6Al-2Sn-4Zr-2Mo. Results will be directly applicable to a wide range of materials of interest to the Air Force.

Assistant Professor **Jianping Fu** has received a **National Science Foundation (NSF) CAREER Award** from the NSF Division of Chemical, Bioengineering, Environmental, and Transport Systems for his proposal, "Biomechanical Phenotyping of Contractile Vascular Smooth Muscle Cells."

With the award, Fu will combine his expertise in both microfabrication and cell mechanics to investigate the biomechanical responses of vascular smooth muscle cells (VSMCs). VSMCs that reside within artery walls play a key role in diseases such as atherosclerosis and hypertension. While studies have characterized VSMC responses to mechanical stimuli, their precise mechanical characteristics remain largely unknown.

Fu's research will employ novel micromechanical tools to characterize the biomechanical properties and behavior of VSMCs in response to external forces. The insights gained into how VSMCs transduce such forces may ultimately lead to therapies to prevent or reverse pressure-induced vascular pathologies.

As part of Fu's CAREER award, he will develop a new interdisciplinary graduate course in biomechanics as well as an outreach program for K-12 students in the Ann Arbor and Ypsilanti school districts.

This 2012 CAREER award is the second NSF award received by Fu. In 2011 he received funding for his proposal, "Mesenchymal Stem Cells and the Synthetic Micro-environment: an Integrated Approach."

Assistant Professor **John Hart** is also a recipient of a **2012 NSF CAREER Award** for his proposal, "High-Speed Continuous Assembly of Nanoparticle Monolayers and Discrete Cluster Arrays."

Hart was granted the prestigious award to develop a manufacturing technology for high-speed evaporative self-assembly (ESA) of nanoparticles. Nanoparticle assemblies can be used in photonics, biological and chemical sensors, solar cells, batteries and

continued

in other applications. However, the throughput and variability of current manufacturing methods are inadequate for scale-up. Hart plans to develop a novel apparatus for continuous-feed ESA that will enable commercially relevant production rates. Hart's group will partner with other researchers and industry to build novel biosensors and glass coatings.

Hart's proposal also includes educational and outreach initiatives to increase the number of four-year university graduates with nanomanufacturing expertise. In collaboration with Oakland Community College, he will guide development of a course on nanomanufacturing processes and help create a lab module on self-assembly. Finally, he will work with artists and architects in order to promote awareness of nanoscale science and technology through artistic images. His own creative visualizations of small-scale structures have been featured in a wide variety of national and international publications, as well as on his Nanobliss website (www.nanobliss.com).

In addition, Hart received a **Young Investigator Program (YIP) Award** from the **Office of Naval Research** to explore mechanisms of load transfer within carbon nanotube (CNT) assemblies, such as yarns and sheets, and to create an experimental platform for tuning their mechanical properties.

Hierarchical ordering of CNTs can yield exceptional mechanical and multifunctional material properties, and there have been many recent, significant innovations in fabrication and commercialization of CNT-enhanced composites and fibers. Still, fundamental knowledge of individual and collective mechanical properties is lacking.

Hart plans to gain a quantitative understanding of the decoupled roles of CNT alignment, contact area, adhesion and packing density on material properties. Comprehensive characterization will enable direct interrogation of the relationships between the CNT behavior under load and mechanical properties of large-scale CNT assemblies. The research is highly relevant to the use of CNT composites for critical Navy missions, such as for lightweight, efficient structures that operate in extreme environments, embedded sensors and energy devices.

Assistant Professor **Eric Johnsen** has won an **Office of Naval Research Young Investigator Research Program award**. He was granted the award for his proposal, "A New Approach to Understanding and Predicting Cavitation Erosion using High-Fidelity Numerical Simulations."

Cavitation, or the formation of vapor bubbles due to pressure changes, occurs in external water flows such as along propellers, hulls and rudders, and also in internal water flows in pumps and other turbomachinery. Repeated collapse of these vapor bubbles generates high pressures and temperatures, ultimately leading to erosion of nearby solids.

Cavitation has been studied theoretically and experimentally for years, but its complexity requires the coupling of both solid and fluid mechanics. Bubble collapse occurs over a wide range of time and length scales, and Johnsen's research will use high-fidelity numerical simulations to visualize bubble collapse and the flow field everywhere at all times, something that has not yet been possible.

Johnsen's team suspects that shocks generated by bubble collapse dynamically interact with neighboring solids, an interaction that hasn't been studied previously. He expects to apply his research to guide the elaboration of reduced-order models to design components and materials that have improved efficiency, performance and lifespan while decreasing the costs of development, operation and maintenance.

Assistant Professor **Allen Liu** has been awarded a **National Institutes of Health (NIH) Director's New Innovator's Award** for his proposal, "Building Artificial Platelets."

Platelets are the "first responders" of the cellular world whenever an injury occurs to the body's vasculature, but they are continually in short supply in blood banks for a number of reasons, including a short shelf-life and susceptibility to contamination. Using biological components, Liu plans to develop artificial platelets that exhibit similar functionalities as their natural counterparts.

The artificial platelets, essentially lipid vesicles, will be formed through the process of microfluidic jetting, which is not unlike blowing a bubble. The platelets will be comprised of a combination of biological components that are well understood, including lipids and proteins. The synthetic molecules will mimic natural platelets' role in the clotting process. Liu envisions that such novel cellular devices will have a tremendous impact in medical settings around the world.

The competitive NIH Director's New Innovator's Award is designed to support exceptionally innovative projects that have the potential for unusually high impact.

Assistant Professor **Pramod Sangi Reddy** has received a **DARPA Young Faculty Award**. DARPA, or the Defense Advanced Research Projects Agency, supports early-career investigators to enable research pursuits related to the military's technology needs.

Of the 560 applications DARPA received for its Young Faculty Award program, Reddy was one of 51 who received funding. His proposal was entitled, "Nanoscale Engineering of Interfacial Thermal Transport in High-Electron Mobility Transistors (HEMTs) for Improved Reliability."

Reddy's focus is on finding new solutions for reducing the temperature rise in HEMTs during operation. Wideband III-V nitrides are viable for use in high-power transistor devices because of their unique transport characteristics, including high electron mobility and high thermal conductivity, but heat dissipation and subsequent temperature increases during operation pose an obstacle to improvements in performance and reliability.

Reddy plans to improve the reliability of HEMTs by leveraging his expertise in scanning thermal microscopy, nanoscale transport measurements and computational modeling of interfacial thermal transport. Towards this goal, he will quantitatively measure thermal fields and thermal conductivity at the nanoscale. From the insights obtained from these studies, he aims to lower device temperatures during operation through appropriate thermal engineering.

Meet New Faculty

ANDRÉ BOEHMAN

André Boehman, a world leader in fuels and combustion research, is joining the U-M faculty as professor of mechanical engineering. After receiving his PhD from Stanford and being a postdoc researcher at SRI International, Boehman started his academic career as an assistant professor of fuel science at the Pennsylvania State University in 1994. He was promoted to associate professor with tenure in 2000 and professor in 2006. Over the years, Boehman developed a strong research program at Penn State and built an outstanding record of high impact journal publications in energy and fuels engineering. He is a recipient of the 2009 John Johnson Award for Outstanding Diesel Engine Research and the 2009 Arch Colwell Award from the Society of Automotive Engineers. He has also demonstrated excellent leadership in serving the professional community, serving as Editor in Chief for *Fuel Processing Technology* and holding executive committee positions in national and international organizations. He is a Fellow of the Society of Automotive Engineers.

Fuel economy challenges in the automotive industry drive much of Boehman's future research plans. He has a strong interest in achieving 55% brake thermal efficiency in internal combustion engines. At U-M, Boehman will continue working with Volvo Group Truck Technology on its SuperTruck program, funded by the U.S. Department of Energy. He also plans to continue his work on characterization of the nanostructure and oxidative behavior of diesel soot as well as begin new, collaborative initiatives in high-efficiency combustion.

"I'm looking forward to working with the talented faculty, researchers and students in the U-M Auto Lab," he said. "The ME department is one of the premier departments in the country and does exceptional work in automotive engineering and many other areas."

C. DAVID REMY

C. David Remy joins the U-M faculty as assistant professor. His research is focused on the design, simulation and control of legged robots and other nonlinear systems. Specifically, he is interested in the effect and exploitation of natural dynamic motions, the role of different gaits and the possibility of force/torque controllable systems—both in conceptual models and hardware.

Remy draws inspiration from nature, biology and biomechanics and works to build and control better performing robotic devices. By designing the mechanics in a "smart" way that can be exploited by the controller, the mechanical structure of the robot generates much of the required motion by itself and needs little input from the actuator. Ideally, these robots will be faster and more powerful, efficient and versatile. "I'm hoping for cross-fertilization," he said, "where biomechanics helps robotics and robotics can help biomechanics, such as for physical rehabilitation," he said.

At U-M, Remy will teach undergraduate design and graduate dynamics courses. He is excited to be joining the Rehabilitation Robotics Cluster. "The ME department is going beyond classic robotics, and the research here is already highly interdisciplinary," he said. "There is research being conducted by a number of outstanding faculty that intersects nicely with my work. I'm looking forward to learning a lot—every single day."

Photo: A. Pfaffendorf

Remy earned his PhD from the Swiss Federal Institute of Technology and his master's from the University of Wisconsin-Madison.

New ME Research Complex Gains Ground

Construction on the new mechanical engineering research complex, a 62,880-square-foot addition to the existing G.G. Brown Memorial Laboratories building, is well underway and proceeding on schedule. The $46 million project is partially supported by $9.5 million from the National Institute of Standards and Technology (NIST).

The U-M ME department continues to actively define and shape the future of mechanical engineering; this new facility supports those efforts by enabling transformative research activities that will integrate core mechanical engineering with emerging new areas, such as micro-, nano- and biosystems, and result in landmark outcomes. When it is complete, this world-class research complex will stand three stories and contain lab modules and office space for professors, research staff and students.

The facility will be equipped with stringent temperature and humidity control and air filtration and will be dedicated to research in imaging and optics; biosystems; nanoengineering; micro-bioengineering; materials, mechanics and mechanical testing; microdynamics and nanostructures. Eight special ultra-low vibration chambers designed to meet NIST vibration specifications will be housed in a below-grade level of the building. With access to state-of-the-art laboratories, investigators will be better able to conduct research at unprecedented levels of precision and accuracy and make significant advances in various fields, such as energy, manufacturing, health care and biotechnology. Collaborative workspaces and shared equipment will encourage continued multidisciplinary partnerships on existing and new projects.

Enthusiasm for the research complex across the University runs high. The new building is expected to be completed in 2014.

+ more on the web

Construction updates, architectural renderings and a webcam with a real-time view of the project are available at www.engin.umich.edu/facilities/ggbrown-construction-project

ABOVE: **An architectural rendering of the new ME research complex.**
PHOTO: PERKINS + WILL AND INTEGRATED DESIGN SOLUTIONS, LLC

ME Growth Drives G.G. Brown Building Major Renovation

State Approves $30 Million in Funding

As construction continues on the new research complex addition to G.G. Brown Memorial Laboratories, the ME department is about to undertake another major project: a $47 million interior renovation of the existing building. The driving force is the tremendous growth in the Department.

The project will achieve several important goals for ME, including the ability to create a world class educational facility. We will consolidate undergraduate instructional design, fabrication and laboratory spaces so they are conducive to collaborative, cross-disciplinary work and develop innovative spaces for the “Design, Build, Test” pedagogic paradigm. Modernizing building infrastructure systems will improve energy efficiency. In addition, the project will create more accessible, efficient administrative and public spaces to better serve faculty, students, staff and visitors.

State-of-the-art academic spaces are a fundamental part of the renovation. These new spaces will be connected with an open staircase to promote visibility and interaction. Public areas will be refinished with new ceilings, flooring and paint and will be connected aesthetically to both the newly renovated spaces and the research complex addition.

The University has received $30 million for the renovation from the State of Michigan through a capital outlay bill, which Governor **Rick Snyder** signed in June 2012. The remaining costs will be funded by the College of Engineering and the U-M Office of the Provost.

Michigan Governor Rick Snyder

Mass excavation of the area where the new ME research complex will be is almost complete.

Two New Collaborative Research Centers to Call U-M ME Home

The University of Michigan's long-standing and highly regarded programs in automotive research have led to two new Collaborative Research Centers with industry partners in China: China FAW Group Corporation of Changchun and BAIC Motor Corporation, Ltd, of Beijing.

"U-M's outstanding and sustained automotive research programs, particularly in the areas of vehicle lightweighting and safety, were key factors in why these two visionary companies sought to establish collaborative research efforts here," said ME Professor **Greg Hulbert**. He and Dr. **Zheng-Dong Ma**, a research scientist also in ME, will co-lead the two centers with representatives from both companies.

A strategic cooperation agreement was signed between BAIC and U-M on September 19, 2012, in Beijing. This Collaborative Research Center will focus on weight reduction strategies and lightweight vehicle designs and technologies. It will provide a rich collaborative research environment for U-M faculty, students, visiting scholars from BAIC and visiting students from Chinese universities.

On September 20, in Shanghai, Michigan Governor Rick Snyder joined U-M and FAW representatives for the signing of a strategic framework agreement between FAW and the University. The focus of this Collaborative Research Center is on lightweight vehicle design and vehicle safety. It is anticipated that 15 to 20 U-M faculty, students, FAW visiting scholars and visiting students from Chinese universities will be involved with the Center. The scope of the agreement is proposed initially for five years, with the opportunity to expand the collaboration into other areas in Michigan.

GREG HULBERT

ZHEND-DONG MA

U-M ME Professor Volker Sick, Associate Vice President for Research, and Dr. Kang Li, Vice Chief Engineer and Executive President of the FAW R&D Center, sign a Strategic Framework Agreement, with Michigan Governor Rick Snyder as witness at the opening of the Michigan Center China on September 20, 2012, in Shanghai, China.

ME Faculty Instrumental in Advanced Manufacturing Initiatives

In June 2011 President Obama selected U-M as one of six universities to represent higher education in the Advanced Manufacturing Partnership (AMP). The AMP was designed to help the United States improve its economic competitiveness by spurring development and implementation of new technologies.

Although the US historically has been a leader in research and development, many discoveries have not been successfully "translated" into manufactured goods. The goal of the AMP was to develop recommendations for a national advanced manufacturing roadmap and improved infrastructure for research, development and commercialization.

ME professor **Sridhar Kota** played a critical role in the creation of AMP in his role as assistant director for advanced manufacturing in the White House Office of Science and Technology Policy (see related story below). ME Professor **S. Jack Hu** has been leading U-M in the collaborative AMP effort.

The AMP Steering Committee recently submitted a final report to President Obama. Both Hu and Kota served as advisors to the steering committee. The report's recommendations span three critical areas: enabling innovation, securing the talent pipeline and improving the business climate.

Both Hu and Kota were instrumental developing the recommendation for the creation of a national network of manufacturing innovation institutes (MIIs), which the President announced in March 2012. The MIIs will serve as a hub to accelerate the maturation of emerging technologies. The first pilot institute was just announced, and the President has proposed $1 billion to fund the additional institutes over the coming year.

Kota Working to Enhance US Competitiveness

Mechanical Engineering professor **Sridhar Kota**'s service to the White House Office of Science and Technology Policy (OSTP) as assistant director for advanced manufacturing may have ended, but his work promoting advanced manufacturing and devising strategies to improve U.S. competitiveness continues.

Nationally, Kota played an instrumental role in launching Manufacturing Innovation Institutes (MIIs) to mature emerging technologies and their manufacturing readiness through translational research (see related story above). The MIIs will accelerate maturation of emerging technologies through investments in relevant manufacturing technologies with widespread application.

Kota also serves as advisor to the Clinton Global Initiative Advanced Manufacturing Working Group, which develops strategies for education and workforce training, sustainability and supporting local manufacturers.

In November 2011, Kota helped initiate the Connecting American Manufacturing program—a virtual marketplace that makes it easier for small- and medium-sized manufacturers (SMMs) to learn about US Department of Defense (DoD) opportunities and for the defense industry to locate US suppliers for its manufacturing needs.

President Clinton met CGI-America advisor Sridhar Kota and thanked him for his contribution.

As White House OSTP representative in Detroit for the Strong Cities, Strong Communities (SC2) initiative, Kota helped institute The Right Skills Now – Precision Manufacturing program at Wayne County Community College District. He is continuing his SC2 work through U-M and expanding the program to other community colleges in the region to build advanced manufacturing job skills.

Helping SMMs in the Midwest gain access to high-performance computer modeling and simulation tools also has been a priority for Kota. Such tools provide competitive advantages by reducing product development time and cost, yet they often are beyond the budgets and expertise of smaller companies. Kota helped spearhead the National Digital Engineering and Manufacturing Consortium, a public-private partnership including Boeing, GE, John Deere, Lockheed and P&G along with Purdue University and the Ohio Supercomputer Center. Purdue's ManufacturingHub.org provided the needed cyber infrastructure for a virtual community of resources and interactive simulation tools.

"It's critical to reach out to these smaller suppliers and manufacturers in a number of ways and bridge the gap between resources and opportunities," Kota said. "That trickles down and helps our economy and national security."

News Media Turn to ME Faculty for Fuel Efficiency Insights

When National Public Radio, *Scientific American* and *Popular Mechanics* were reporting recently on technological advances in automotive fuel efficiency, they turned to ME experts for input.

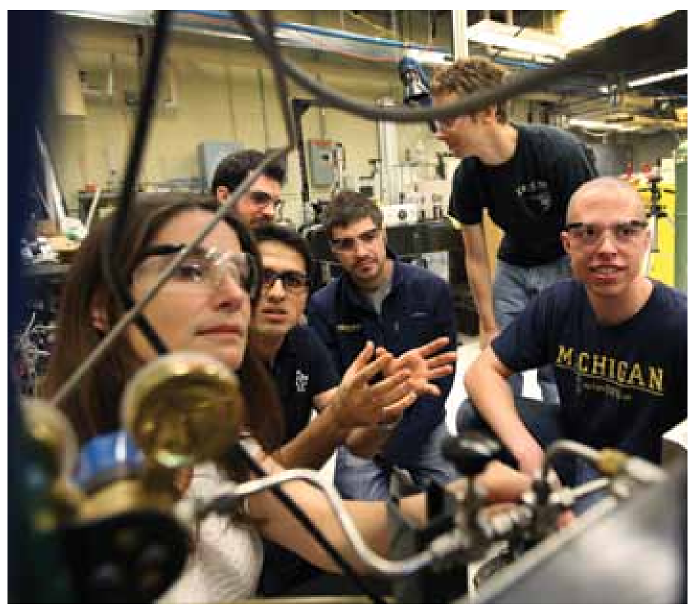
NPR reporter Sonari Glinton visited the U-M Automotive Research Center (ARC) to learn more about new fuel-efficient technologies being developed. Glinton toured the engine lab with Professor **Anna Stefanopoulou**, ARC director, and spoke with Professor **Margaret Wooldridge** for a report aired on NPR stations across the country. The report was the final segment in a special series focused on the Obama Administration's initiative to double fuel economy requirements to 55 mpg by 2025.

Stefanopoulou and Wooldridge discussed the engineering challenges to improving fuel economy and also about consumer expectations—including of creature comforts such as air conditioning and power windows—that automakers must consider. There are a few relatively inexpensive gas-powered cars that achieve more than 40 mpg, but a systematic approach to increase the fuel efficiency of all cars, on-average, without compromising luxury or increasing price is tricky and being feverishly pursued by automotive manufacturers.

Stefanopoulou is serving on the National Academies committee that advises on the Corporate Average Fuel Economy (CAFE) policy. The committee is assessing the cost, potential efficiency improvements and barriers to commercial deployment of technologies that might be employed from 2020 to 2030.

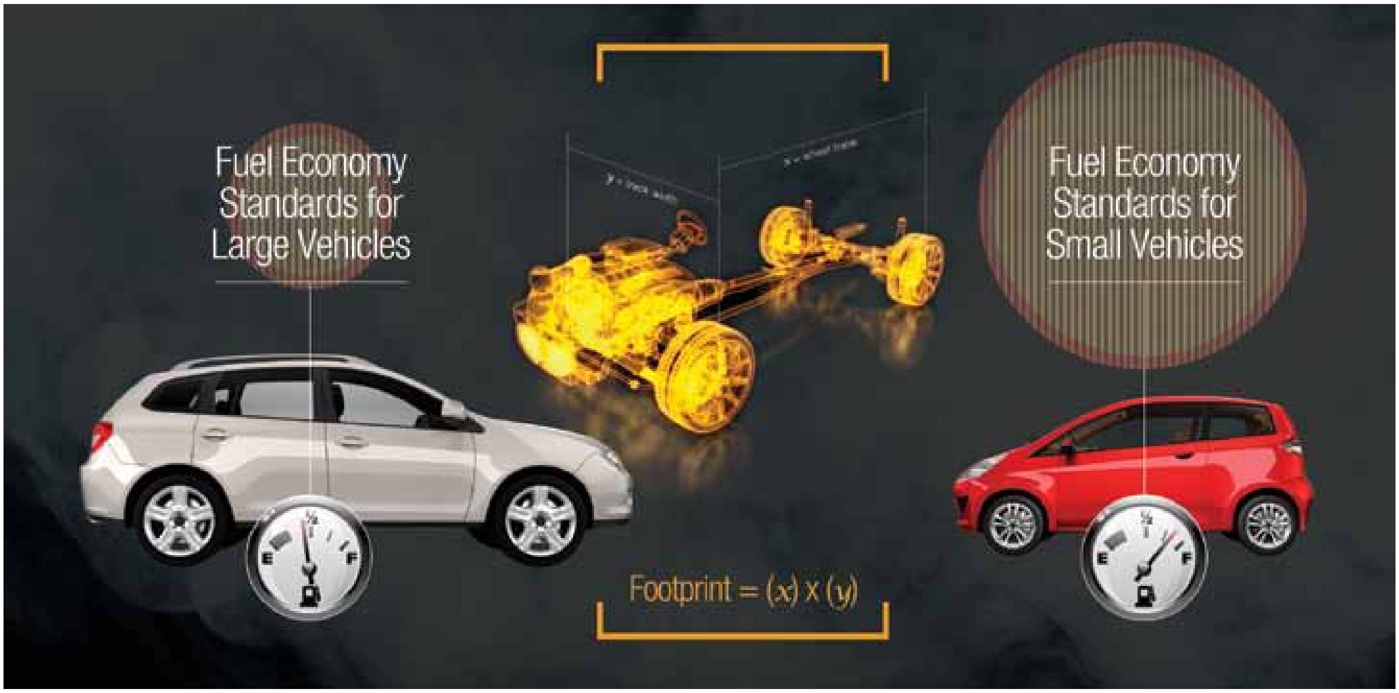
Scientific American also spoke with Wooldridge for an article entitled "Diesel Cars Make a Comeback in the U.S." In it, Wooldridge explained how diesel fuel and the way it's used enable vehicles to be more thermodynamically efficient, getting more power out of the same amount of fuel.

Both professors appreciate media coverage that highlights work in the ME department, especially when it has the potential to engage the public. "These articles reach and inform people far outside engineering and the sciences," said Wooldridge.



LEFT: Professor Anna Stefanopoulou (left) examines a V8 internal combustion engine with students Jacob Larimore and Xinfan Lin at the University of Michigan's Automotive Research Center. The researchers model engine performance to improve efficiency.

RIGHT: Professor Margaret Wooldridge (left) works with her graduate students (from left to right) Andrew Mansfield (background), Mohammad Fatourai (foreground), Dimitris Assanis, Steve Morris and Scott Wagnon on strategies to improve efficiencies and reduce energy use in the transportation and stationary power sectors.



New fuel economy standards will interact with decisions regarding how to set vehicle footprint. ME Professor Steve Skerlos and Dr. Katie Whitefoot have teased out these incentives and have measured their potential impact on fuel economy and carbon emissions.

Popular Mechanics interviewed ME Professor **Steve Skerlos** about a research article he co-authored, which sparked much discussion of the recently amended U.S. Corporate Average Fuel Economy (CAFE) standards and their effect on vehicle size.

The paper, "Design Incentives to Increase Vehicle Size Created from the U.S. Footprint-based Fuel Economy Standards," was published in the January 2012 issue of *Energy Policy*. While intuitively fuel economy standards are expected to decrease vehicle size, the findings suggest that the newly revised fuel economy standard might increase vehicle size.

CAFE regulations for vehicles produced from 2011 to 2016 are based on the vehicle's "footprint," a measurement determined by the wheelbase multiplied by track width. Vehicles with a larger footprint are not required to meet as stringent a standard as smaller vehicles.

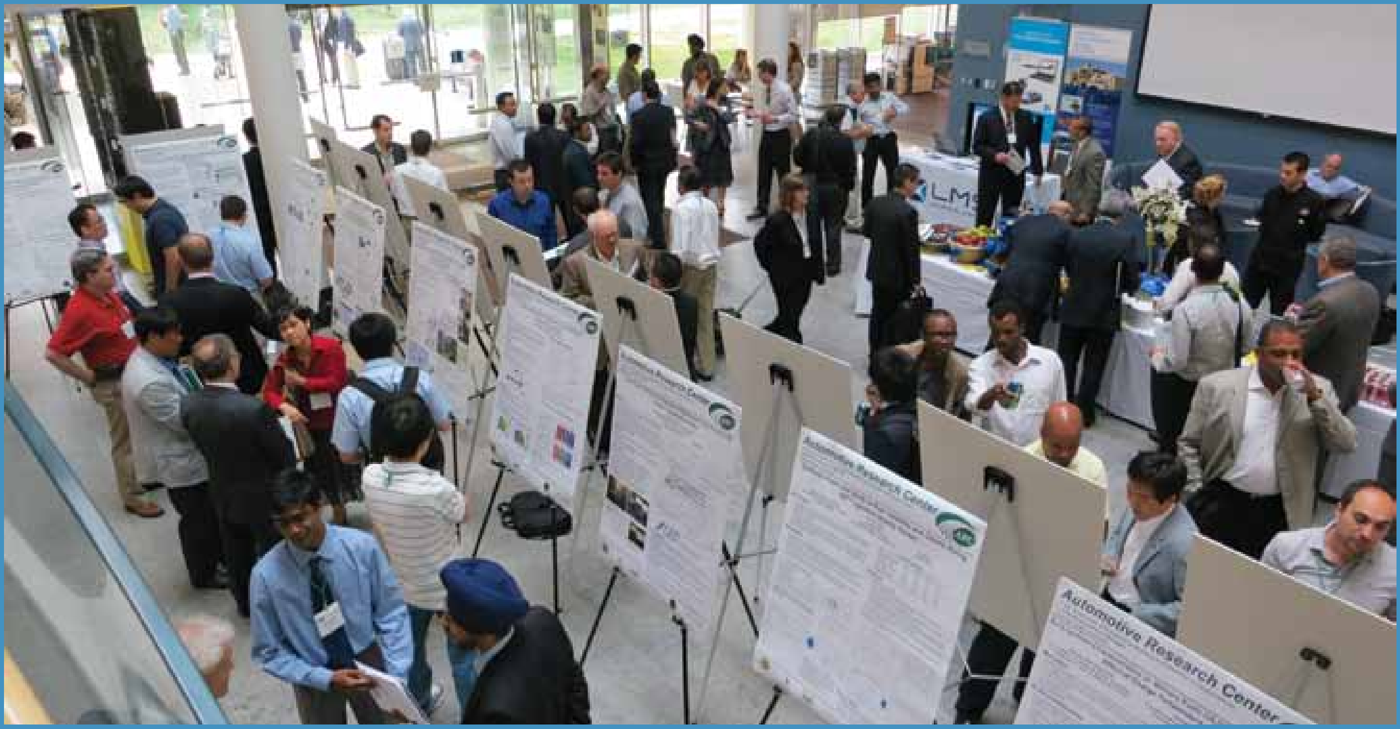
Skerlos and co-author Kate Whitefoot, senior program officer at the National Academy of Engineering, concluded that automotive manufacturers would have an incentive to increase the footprint of their vehicles under the new standards. Historically consumers have preferred bigger vehicles, which further boosts the auto industry's incentive to produce cars with larger footprints, even under new fuel economy regulations. In addition, larger cars may increase in size faster than smaller cars, raising questions regarding the impact of CAFE on traffic safety.

"These articles reach and inform people far outside engineering and the sciences."

Skerlos and Whitefoot propose several short-term measures that could help reduce the incentive: flattening the slope of the function that determines fuel economy targets and allowing modifications to the standards if it becomes clear environmental emissions targets won't be reached. Longer term, the authors recommend alternative policy options to address fuel-economy goals and traffic safety concerns.

"The revised CAFE standard is a positive step environmentally, but it is roughly a 20% smaller step forward than would be expected before our analysis—and has the potential for other unintended consequences in the domain of safety. We would like to see more research in the domain we are charting, particularly at the intersection of engineering design, performance modeling, market analysis and public policy," Skerlos said.

ARC Conference
Harnessing the Power of Future Mobility



Over 300 members of the automotive research community, representing academia, government and industry, converged on North Campus in May for the 18th annual conference of the Automotive Research Center (ARC).

Led by U-M, the ARC is a Center of Excellence for ground vehicle modeling and simulation, sponsored by the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC). The ARC focuses on basic scientific research in three areas: vehicle power and energy management, mobility and survivability of the complete vehicle system, including human operators.

The conference theme, "Powering Future Mobility," addressed the pressing need for sustainable mobility in an era of economic downturn and diverging requirements in commercial and military vehicle systems. "Cost-effective vehicle designs need to be analyzed, evaluated, integrated and validated using a range of experimental and simulation capabilities, even if those resources are distributed around the world," said **William Lim**, ARC program manager. "Such global concurrent engineering requires new methodologies."

The two-day event brought researchers together to highlight advances in modeling and simulation tools. In addition to over 20 technical presentations and two poster sessions, **Tulga Ersal**, U-M assistant research scientist, demonstrated novel technology developed at the ARC: Internet-distributed hardware-in-the-loop (ID-HIL) simulation. The system simulated a hybrid electric vehicle whose components were distributed across campus. "ID-HIL allowed them to operate together in real-time as if they were physically connected and enabled researchers to compare different power management strategies," said Ersal. "This technology opens up new possibilities for research collaborations."

A second case study demonstrated reliability-based design optimization tools that have been developed in the ARC with the University of Iowa. Ford engineers have used the tools to minimize weight and improve crashworthiness of a vehicle structure, and ME Associate Professor **Bogdan Epureanu** optimized the structural frame of a military vehicle to weigh as little as possible yet be able to withstand the heavy vibrations of combat operations.

"The ARC provides a unique platform for identifying the basic research questions that could create dual-use pathways despite diverging requirements between commercial and military systems," said Professor **Anna Stefanopoulou**, ARC director. "Our partnerships with industry and government have helped us build world-class research facilities to train students to tackle these complex systems issues."

PHONONS 2012

Sharing Knowledge of Phonon Physics

More than 200 researchers from academia, international research laboratories and industry convened in Ann Arbor for the 14th International Conference on Phonon Scattering in Condensed Matter (PHONONS 2012) in July. The conference, hosted this year by U-M and chaired by ME Associate Professor **Kevin Pipe**, is the premier international forum for theoretical, computational and experimental work in phonon physics and related phenomena.

As photons are the fundamental units for electromagnetic waves, phonons are the fundamental units for vibrations. Because phonon-phonon and phonon-electron interactions govern important transport properties for a material, electrical mobility and thermal conductivity (see related story on page 16), phonon physics impact numerous areas of scientific and technological inquiry, including electronic devices, heat transfer and thermoelectric energy conversion. In particular, the use of nanostructures to engineer phonon scattering has recently emerged as an important topic.

Daily sessions over the five-day conference included five plenary talks, 18 invited talks, more than 100 contributed talks and a poster session. Topics included phonon scattering in nanoscale structures and MEMS, coherent phonons and ultrafast acoustics, acoustic solitons, electron-phonon interactions, phonon microscopy and imaging, Raman scattering, neutron and x-ray inelastic scattering, phonons in disordered materials, phonon transport at interfaces, surface acoustic waves, phononic crystals and metamaterials, optomechanics, thermal phonon transport, and phonons in electronic devices.

Pipe actively reached out to graduate students, postdoctoral fellows and young faculty worldwide to encourage early-stage researchers to participate in the conference and give presentations.

The high-profile conference drew prominent experts from 23 countries in North America, South America, Europe, Africa and Asia. “Their participation and enthusiasm reinforces U-M’s role as a leading scholarly institution among investigators working at the forefront of phonon research,” said Pipe.

CIRP Conference

Focusing on Customer-Driven Assembly

Over 100 researchers from around the world gathered in Ann Arbor in May for the 4th International Academy for Production Engineering (CIRP) Conference on Assembly Technologies and Systems. This year’s conference theme was “Responsive, customer-driven, adaptive assembly.” The event brought together active researchers in assembly technologies and systems to exchange ideas and explore future research directions. Assembly research is critical to maintaining manufacturing competitiveness and developing successful products.

ME professors **S. Jack Hu** and **Yoram Koren** served as co-chairs of the conference, which included tours of ME research laboratories and a presentation by General Motors. Forty-five technical papers were presented in six topical areas: Assembly Processes and Technologies, Reconfigurable Assembly Systems, Assembly System Planning, Ideas, Assembly Quality and Man-made Collaboration. Dr. Daniel Whitney of Massachusetts Institute of Technology shared his vision of assembly technologies in a keynote address that focused on the under-researched aspects of assembly design.

The relatively young conference continues to gain traction and attract additional attendees each time it’s held. “Feedback on the conference was very positive, and attendees were impressed with the organization and the quality of the papers presented,” said Hu.

Planning is underway for the next CIRP Conference on Assembly Technologies and Systems, to be held in Dresden, Germany, in May 2014.

A Multi-University Collaboration

Understanding heat transfer at interfaces

Understanding how heat travels between materials is critical to improving the performance, efficiency and reliability of many military and commercial systems. Thermoelectric refrigerators and power generators, heat sinks, power electronics, thermal barrier coatings and thermal interface materials all rely upon either maximizing or minimizing heat transfer.

Within these systems, thermal behavior at the macroscale is related to the physical and chemical structure at the nanoscale, particularly where different materials meet.

"In many ways we are now able to precisely control the physical and chemical structure at material interfaces, but predicting how changes to this low-level structure will affect thermal behavior is still a challenge," said **Kevin Pipe**, associate professor. "Better understanding will enable us to better engineer interfaces and potentially create radical enhancements in how an interface conducts or blocks heat flow."

Pipe heads an Air Force Office of Scientific Research Multidisciplinary University Research Initiative (MURI) to address this gap in understanding. Collaborators include investigators from the Materials Science and Engineering, Physics, Electrical and Computer Engineering, and Applied Physics departments at U-M and Stanford, Brown and Purdue universities. Together the MURI team has made a number of recent advances. Its work aims to develop a set of design rules for engineering interfaces with desired thermal properties.

While the photon is the fundamental unit by which electromagnetic waves (such as light) are transmitted, heat typically is carried in solids by acoustic waves, for which the fundamental vibrational unit is known as a phonon. Interfaces within materials can scatter phonons and consequently impede heat transfer; the more scattering an interface produces, the greater a thermal resistance it will have to heat flow.

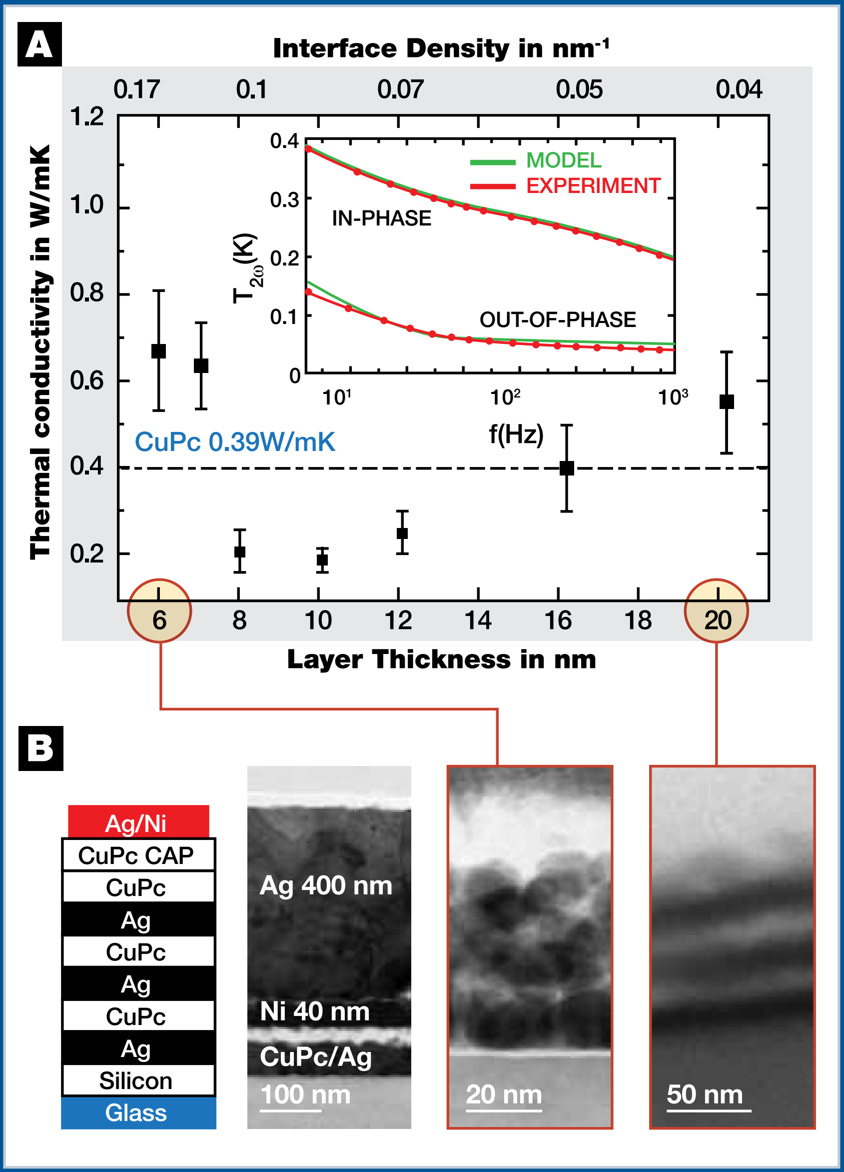
Pipe and colleagues have used sophisticated material deposition systems, simulations of molecular motion, and highly precise measurement tools to study the ways in which chemical bonds formed across an interface affect the efficiency at which heat is transferred. One of their measurement tools, for example, uses ultra-short laser pulses to generate high-frequency acoustic waves in a material. These waves scatter off a buried interface with an engineered nanoscale structure and are subsequently measured to determine how the interface affected their propagation.

Other measurement tools the group has developed include a high-speed thermal imaging system that can take snapshots of temperature with a time resolution of 800 picoseconds—approximately the time it takes light to travel nine inches—and a time-resolved x-ray diffraction system that can measure atomic motion with a time resolution better than 100 picoseconds.

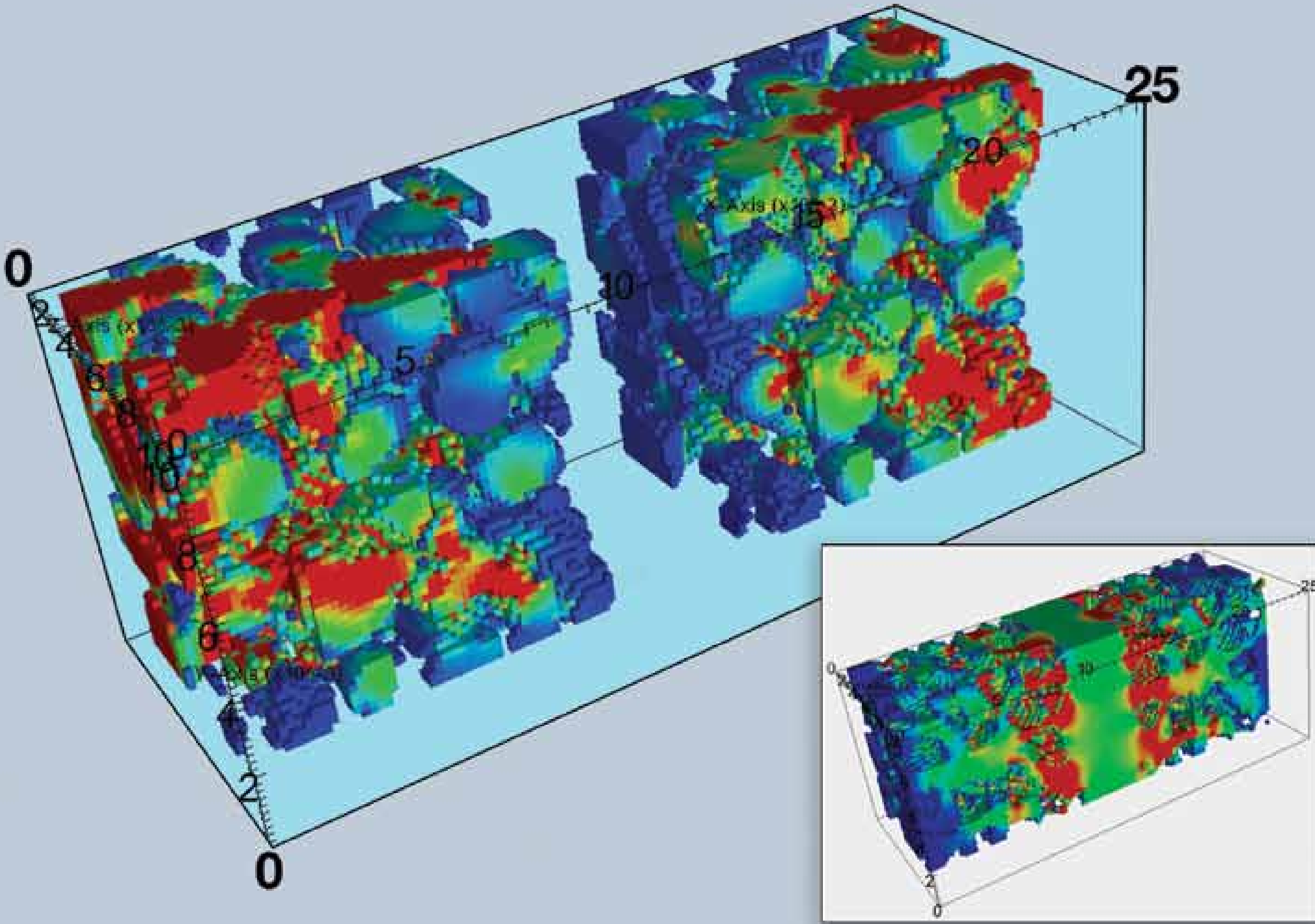
"While precision interfaces created in a laboratory setting are important for our ongoing fundamental studies because they have controllable structure," Pipe said, "eventually it will be important to look at interfaces as they currently exist in practical applications, where they are much more 'messy' and complex. That is where the understanding we are currently building can make a real difference."

More than two-dozen doctoral students and two post-doctoral researchers have been involved in the MURI project since its inception in 2009. The initiative runs through 2013.

"Better understanding will enable us to better engineer interfaces and potentially create radical enhancements in how an interface conducts or blocks heat flow."



Improving the thermal conductivity of a material is important for many applications (e.g., thermal epoxies). While a solution to this is often to mix in a material with high thermal conductivity such as silver (Ag), the team has shown that the interfacial thermal resistance between silver and common organic materials (here: copper phthalocyanine, CuPc) can strongly affect the thermal conductivity of the composite. As shown above, if the Ag/CuPc interfaces within a composite are mixed (above, for Ag thicknesses less than 8 nm) or if the Ag content is large (above, for Ag thicknesses greater than 16 nm), the thermal conductivity of the composite is improved beyond that of CuPc alone. In the intermediate range, however, the interfacial thermal resistance dominates, and the thermal conductivity of the composite is lowered below that of CuPc, even though Ag has a thermal conductivity more than a thousand times greater than that of CuPc. Figure credit: Y. Jin, A. Yadav, K. Sun, H. Sun, K. P. Pipe, and M. Shtein, *Appl. Phys. Lett.* 98, 093305 (2011).



Advanced Battery Coalition

Optimizing battery cycle life and performance

Vehicle electrification has the potential to significantly reduce pollution and conserve energy. At the GM/UM Advanced Battery Coalition for Drivetrains (ABCD) research center, teams are working to transform that potential into reality.

Research in the ABCD focuses on creating validated battery material, cell and pack models; speeding their insertion into advanced electrified drivetrains; and educating successive generations of individuals to execute resulting technology plans. “Converting a large portion of the transportation sector to electricity is critical to solving our energy and pollution problems. Advanced lithium ion battery study plays an important role here,” said Associate Professor **Wei Lu**, principal investigator and ABCD co-director.

One of the greatest challenges to vehicle electrification is battery life. By working across disciplines, Lu and his team have developed a critical understanding of battery fading mechanisms across multiple length and time scales. More specifically Lu and colleagues are exploring fading mechanisms related to everything from solid electrolyte interface (SEI) layer formation to mechanical stresses. Their research has provided the first integrated picture of the complicated battery fading process, and it is being fed into a control algorithm in order to optimize battery cycle life and performance.

“The degradation mechanisms are related to a number of electrochemical, thermal and mechanical processes,” Lu said. “By integrating modeling, simulation and experimental techniques, we developed a systematic and quantitative understanding of several key material properties and processes that contribute to degradation.”

The center has established state-of-art research facilities for lithium-ion cell characterization and testing. Researchers also have carried out systematic experimental investigation and validation supporting model development; characterized and developed fundamental understanding and modeling of SEI layer growth, manganese dissolution and fracture of electrodes; and revealed battery performance under external mechanical loadings. Other work includes micro- to cell-based electrode modeling and optimization; development of advanced comprehensive battery cycle and calendar life models; and control algorithms based on integrated physics-based element approach for prediction of battery life during charge/discharge cycles. The team developed an approach to generate realistic three-dimensional aggregation of carbon black and active material particles, and studied the transport and fracture behaviors of the network. With realistic particle network geometry constructed from experimental measurements and simulations, battery performance now can be predicted much more accurately.

"These studies have significantly advanced the fundamental understanding of battery fading."

battery models. "These studies have significantly advanced the fundamental understanding of battery fading," Lu said.

In a recent project, Lu and his team have shown quantitatively how coupled phase transition and lithium intercalation contribute to the stress evolution in electrode materials and the subsequent crack formation and loss of active materials during charge and discharge. The work has revealed how dissolution in both active and inert material phases contributes to the degradation of composite lithium-ion electrodes. The changes in effective transport properties result in a reduction in the electrochemical reaction rate and an increase in cell resistance, thereby reducing capacity.

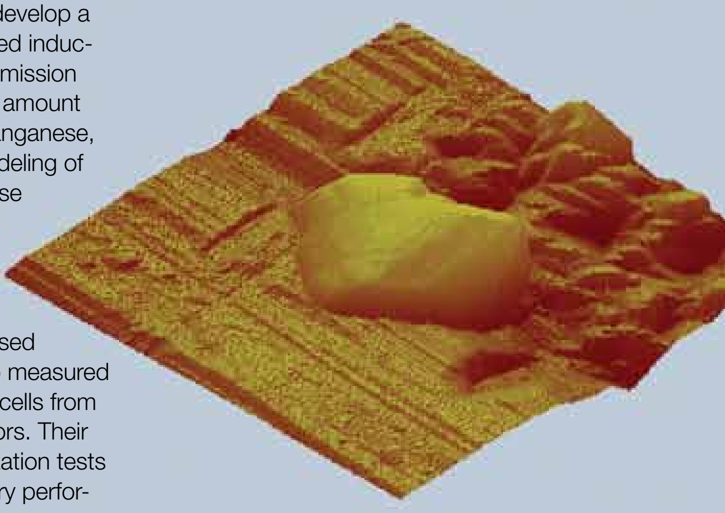
The molecular and continuum models developed by Lu and his team revealed SEI layer composition, formation and growth, and the effect of SEI porosity on battery impedance. These studies have led to a three-dimensional mechanical-thermal-electrochemical model and finite

In recent experimental work, the research team used x-ray photoelectron spectroscopy to investigate whether the SEI layer on an anode is stable at elevated temperatures. By looking at the configuration and thickness of the SEI layer stored at different temperatures, investigators found how high temperature affects the layer during storage and used the data to develop a predictive model. The team used inductively coupled plasma optical emission spectrometry to determine the amount of dissolved and deposited manganese, which validated the team's modeling of capacity fade due to manganese dissolution. They developed an advanced atomic force microscopy technique to measure local lithium diffusion, which was compared to and used in the modeling. The team also measured the temperature distribution in cells from resistance temperature detectors. Their hybrid pulse power characterization tests and models revealed the battery performance under various face pressures.

The virtual battery system that has been developed will significantly reduce the need for lengthy battery fading tests, which are required before a battery can be used in electrical vehicles. The system also provides important guidance for improved battery and battery system design, and it will lead to advanced control systems for optimized battery performance and battery life.

Lu emphasizes the importance of an integrated team effort to address battery fading. "This is a very challenging problem since it involves multiple disciplines. By looking at all the pieces, and then integrating them, the ABCD's talented team of faculty, staff and student researchers has provided a comprehensive and validated predictive tool," he said.

The ABCD's work has been supported by numerous donors, partners and collaborators, including General Motors, LG Chem, University of Colorado Colorado Springs, Oak Ridge and Argonne national laboratories, the U.S. Department of Energy and many others.



OPPOSITE PAGE: Electric current density distribution in a realistic three dimensional Li battery electrode at 43% state of charge. Red indicates high current density and blue indicates low current density. The inset shows the electric current density in the electrolyte.

TOP RIGHT: Atomic force microscope image shows volume change of a LMO particle due to Li intercalation.

Clean Vehicle Consortium
Collaboration speeds progress

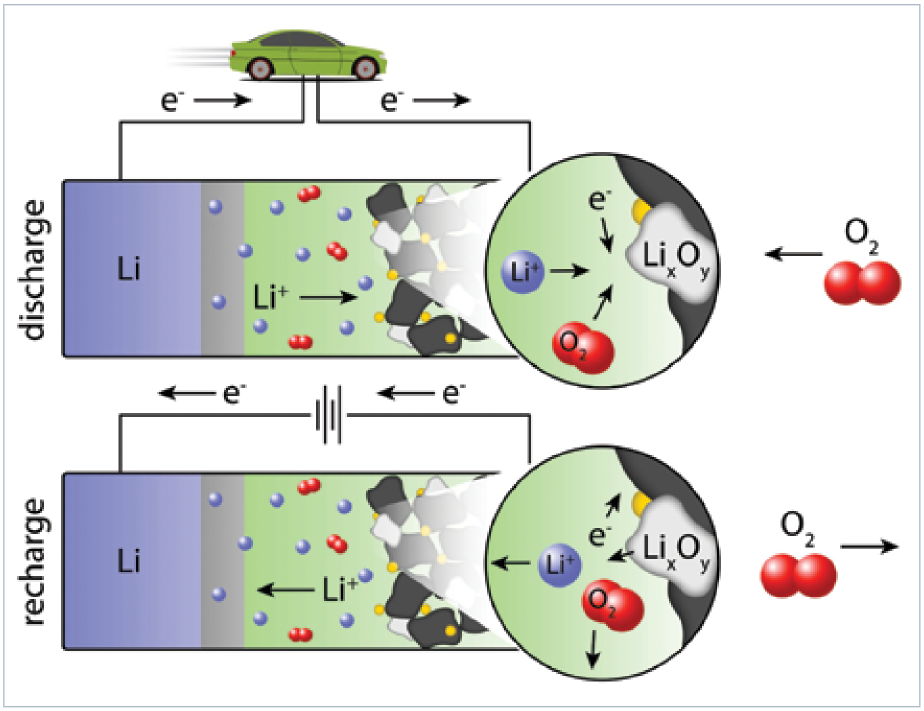
The U-M led Clean Vehicle Consortium (CVC), part of the $150 million U.S.-China Clean Energy Research Center, is on a mission: to speed dramatic advances in technologies to improve fuel efficiency and reduce oil consumption. The CVC has made strides in the past year, both in its six technical focal areas and its overarching goals.

Scientists and engineers from academia, national laboratories and industry partners in both countries work side by side in the CVC's six research thrusts, which include advanced batteries and energy conversion; advanced biofuels and clean combustion; vehicle electrification; advanced lightweight materials and structures; vehicle-grid integration and energy systems analysis.

"What distinguishes the CVC is not only the breadth and depth of work and our aim to conduct long-range rigorous, transformational research but to bring our discoveries and new technologies to market," said Professor **Huei Peng**, CVC U.S. director.

The CVC has made progress in several areas. Advanced batteries and energy conversion researchers, including ME Assistant Professor **Don Siegel**, have been developing molecular-level models of reactions that take place inside lithium air batteries. Investigators also are doing experimental work on prototype lithium ion batteries, measuring their physical and chemical behavior with use and age in order to improve performance and extend battery life.

Investigators from the U-M departments of Mechanical Engineering, Materials Science and Engineering and Physics along with researchers at Wuhan University of Technology are measuring physical and performance behavior of prototype thermoelectric materials. The team already has improved the figure of merit of these materials by 20%.



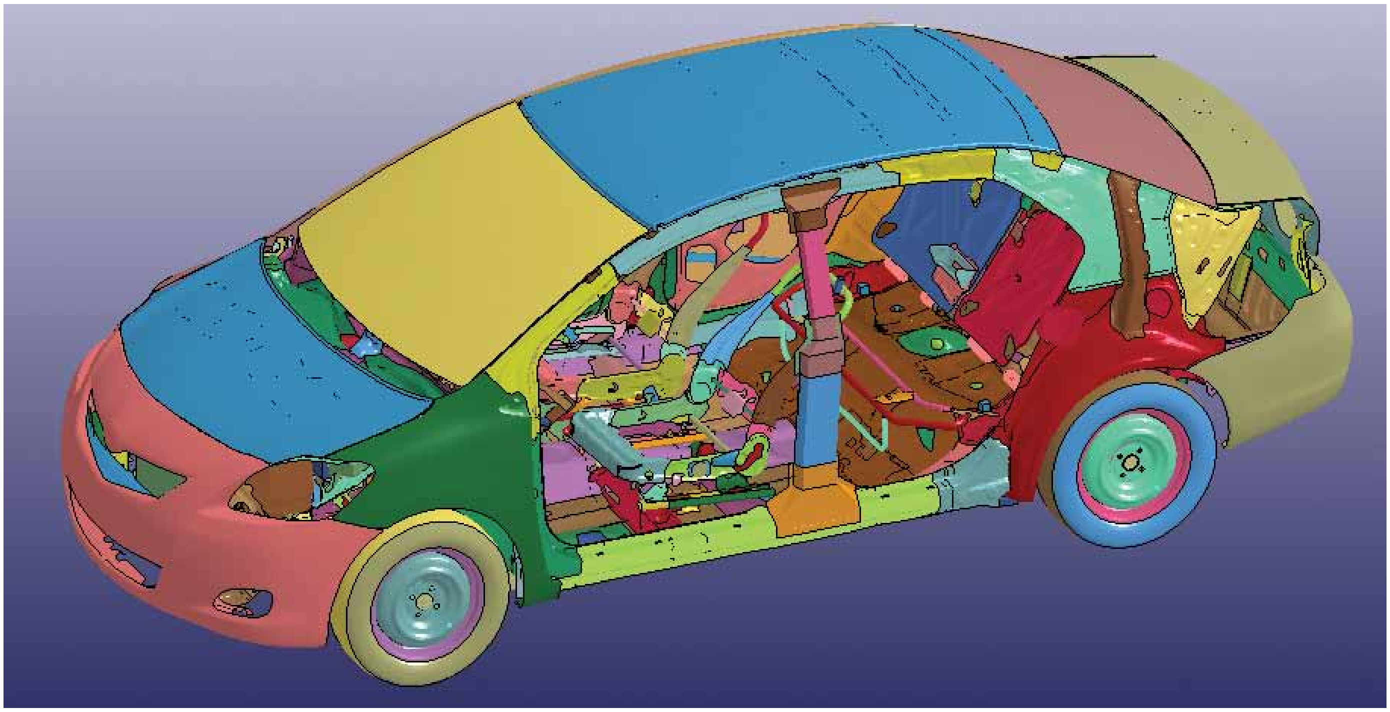
ABOVE: **Schematic of a lithium-oxygen cell under discharge and charging conditions. The precipitation and dissolution of the LixOy reaction product is illustrated in the magnified inset.**

"What that means today is that with these new technologies, it will be possible to produce a 500- to 1000-watt thermoelectric vehicle waste heat recovery device," Peng noted. Experimental work is ongoing and a 500-watt device currently is being tested and refined.

In the electrification thrust area, U.S. researchers have developed a highly efficient computational method that reduces simulation time by three orders of magnitude, or 1,000 times faster than current methods. Chinese researchers are testing production methods for amorphous silicon used to reduce iron loss in electric motors, and new motor designs now can be simulated quickly, with the most promising identified and moved to the prototyping stage right away.

Teams also have made progress in the modeling and manufacture of lightweight materials. The biggest barrier to widespread use of such materials as aluminum and carbon fiber is not the cost of the materials themselves, but manufacturing. The CVC is developing new joining methods, including riveting and welding, that are applicable to lightweight materials.

The collaboration evident in the past year's accomplishments is intrinsic to the CERC as a whole. "We were founded to contemplate the question, How can the world's two biggest energy consumers leverage each other's research investments so that efforts complement and augment each other and we don't waste money on duplication?" Peng explained.

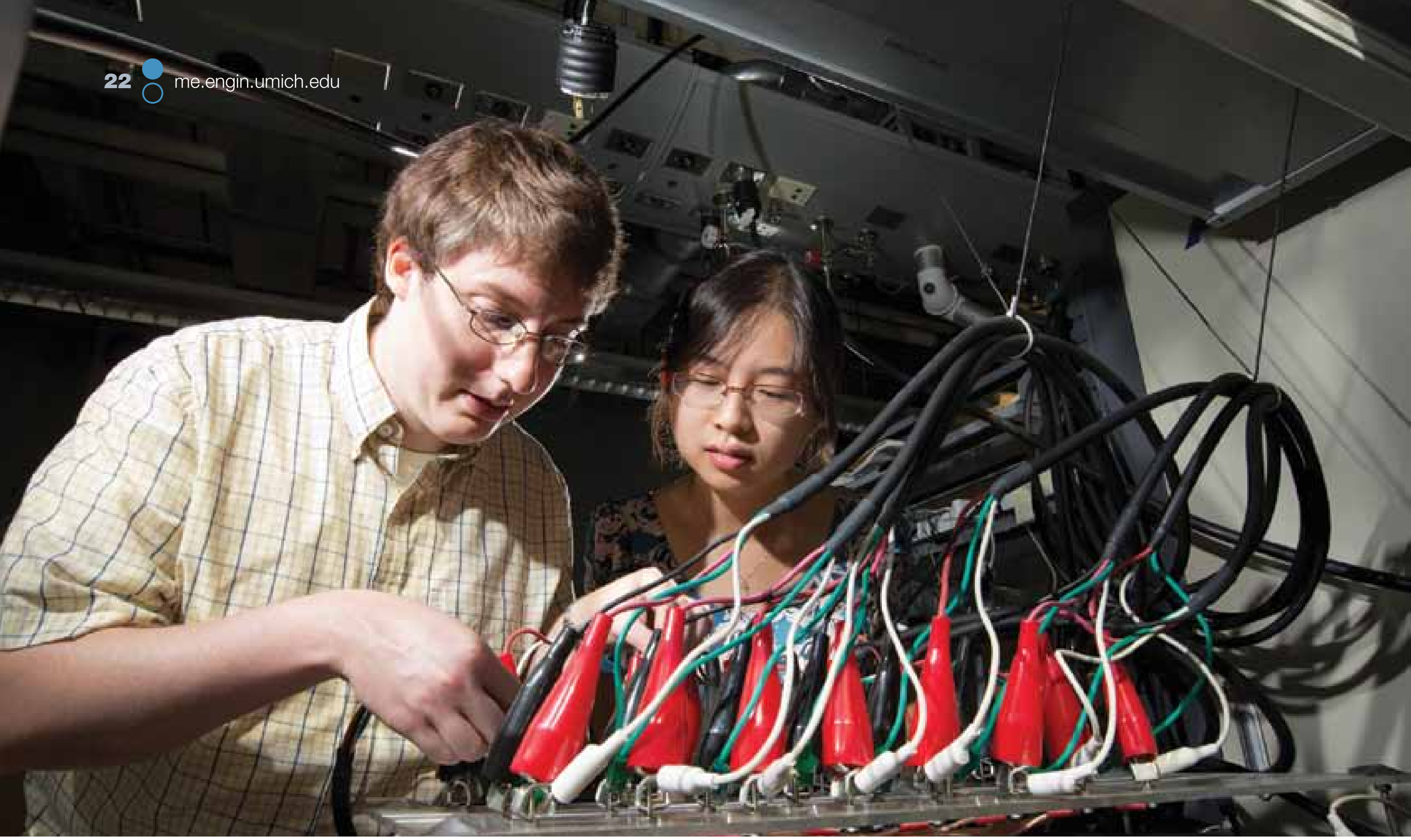


ABOVE: **A hypothetical B-pillar made of carbon fiber composite and steel integrated with a body-in-white finite element model of a mid-size passenger vehicle.** Image: Dr. Karim Hamza

The $150 million joint research and development consortium on clean energy technology is a flagship initiative started in 2009 and funded equally by the United States and China. Each country funds its own research projects. Money from U.S. sources supports U.S.-based research; funds from Chinese sources support China-based projects.

"Having shared goals is motivating," Peng said. "Vehicles consume about one-third of the energy used by society and produce a lot of greenhouse gas emissions. We're working together to produce cleaner vehicles and reduce our carbon footprint. We've made good initial progress, and I expect we will make a great deal more in the CERC's remaining three years."

"We were founded to contemplate the question, How can the world's two biggest energy consumers leverage each other's research investments so that efforts complement and augment each other and we don't waste money on duplication?"



Emerging Frontiers in Research and Innovation

Multidisciplinary research for vehicle-to-grid integration

Plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs) can reduce the use of petroleum and lower greenhouse gas emissions in comparison to conventional vehicles, but that's not all: they also can improve efficiency of the U.S. electrical grid.

ME Professor **Jeffrey Stein** is leading a multidisciplinary effort supported by the National Science Foundation Emerging Frontiers in Research and Innovation Program on infrastructure systems coupled by hybrid electric and electric vehicles: *"A Multi-Scale Design and Control Framework for Dynamically Coupled Sustainable and Resilient Infrastructures, with Application to Vehicle-to-Grid Integration."*

"Integrating the two systems—grid and vehicle—in smart ways can help our society leverage the synergies and provide both transportation and power in a more sustainable and resilient way," Stein said.

The research team includes investigators from Pennsylvania State University, the University of California, Berkeley, and the Missouri Institute of Science and Technology as well as industry partners. At U-M the group consists of investigators from several engineering departments as well as from School of Natural Resources and the Environment. Together, the group has produced several important findings over the past year.

One of the greatest advantages to EVs is their deferrable demand on the grid. As long as a vehicle is charged by the time the driver next needs it, electric companies can delay the load until times when overall grid demand is lower. "Deferrable loads offer electric utilities a huge advantage in terms of flexibility to distribute power. They reduce the need to tap ancillary generation services—that often cost and pollute more—to meet higher demand," Stein said.

The research team has developed and implemented a hierarchical control algorithm that effectively balances both charging need and electric service quality and cost. The algorithm enables 99.5% of PEVs to be fully charged while reducing energy costs and mitigating grid load fluctuations.

Researchers also have demonstrated the need to accurately characterize vehicle consumption profiles based upon naturalistic, real-world driving data. Their results showed significant differences in electricity demand and greenhouse gas emissions

> "Integrating the two systems—grid and vehicle—in smart ways can help our society leverage the synergies and provide both transportation and power in a more sustainable and resilient way."

when naturalistic, as opposed to average, consumption data are used in models.

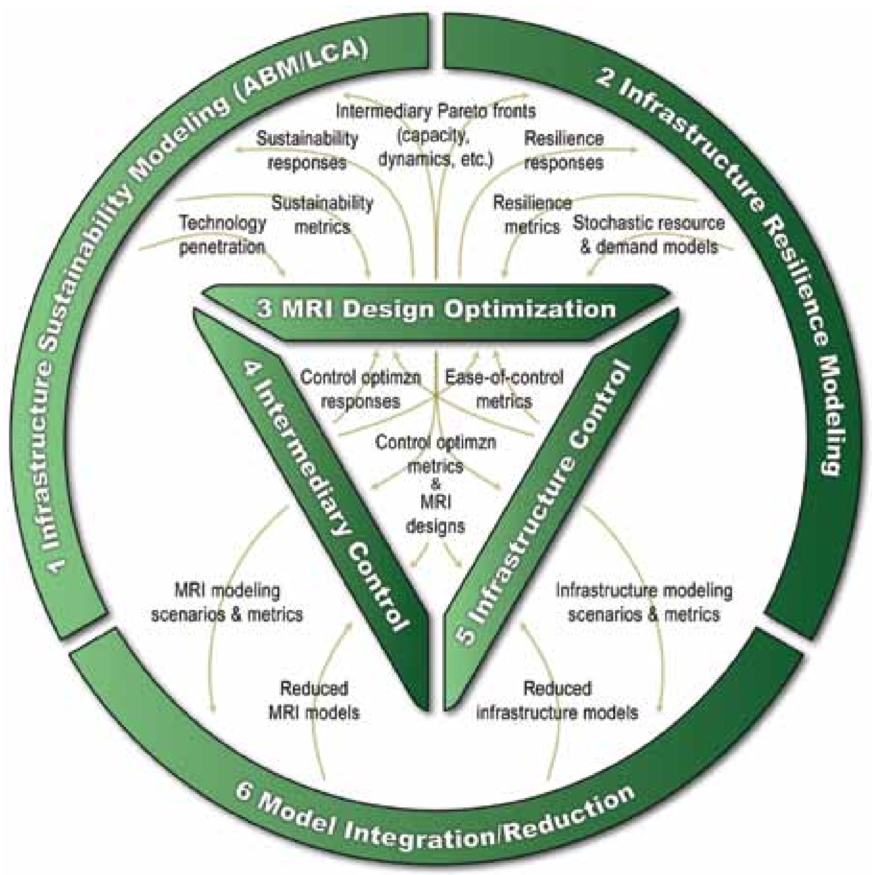
Using rigorous optimal control methods, investigators also found no significant differences in operation costs between two popular power management strategies. Costs were comparable across distances and gas-to-electricity price ratios, except when gas costs less than $1 per gallon, an unlikely scenario. The findings contrast with previous research in the field, providing the PEV community with new insights.

The team has developed a way to monitor the accuracy of predictions of short-term grid disruption (less than one minute) that could result from widespread PEV use. The new metric is believed to be the first of its kind.

Team members working on battery optimization have designed controllers that can determine the best way to use vehicles' gas engines and electric motors to save money as well as the best way to manage the grid for charging vehicle batteries. The controllers manage battery health, too, avoiding behavior that would prematurely age it. In a departure from previous work in the field, the novel models incorporate real driver data from studies conducted by the U-M Transportation Research Institute. Human behavior is an essential factor but hasn't been routinely integrated into previous models.

The work has shown some of the benefits of coupling the transportation and electric grid infrastructures as well as where potential problems arise. For example, in Michigan, a substantial amount of the base electricity load is produced from burning coal. Increasing the base load means burning more coal, which increases some polluting emissions.

"Future research requires careful assessment of as many codependent effects as possible," said Stein. "Towards this end we're working on an integrated case study to include the issues being explored by all of the researchers involved. The results should provide us all with a lot of new insights."



OPPOSITE PAGE, TOP: **PhD student Joel Forman and Xin Zhou are working on battery experiments that will help understand and control battery aging.**

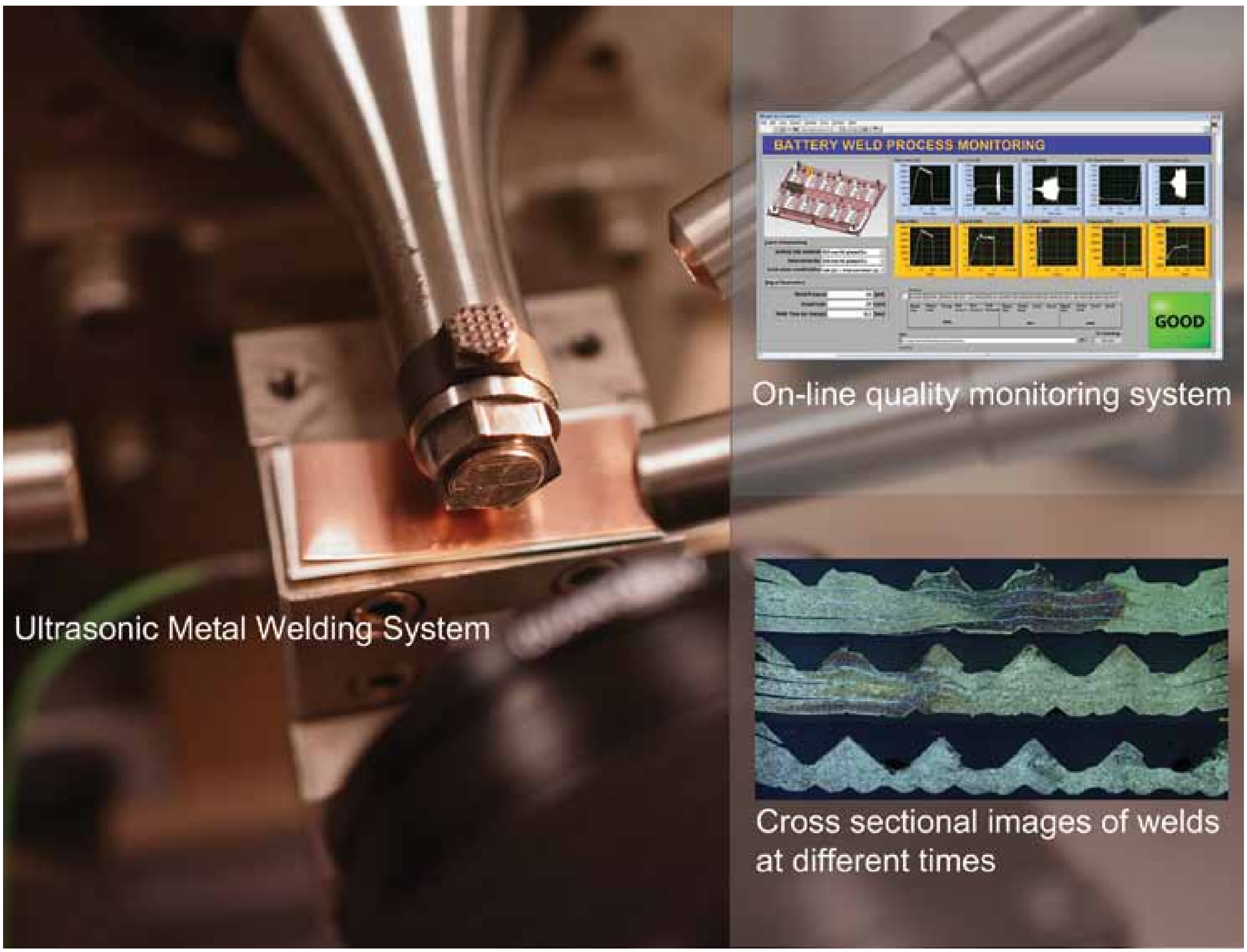
Going the Distance

Collaborative Research Laboratory transfers technology from lab to plant

Since its inception in 1998, the GM/U-M Collaborative Research Laboratory (CRL) in Advanced Vehicle Manufacturing has translated many of its lab innovations to solutions implemented on the factory floor.

The collaborative, multidisciplinary and solution-focused work in the CRL recently has led to a novel quality assurance system for monitoring the joining processes of lithium-ion batteries. The new technology, implemented in GM's Brownstown Battery Assembly Plant, monitors the 16 kWh lithium-ion battery system used in the Chevrolet Volt.

"Where the CRL really shines is in 'use-inspired basic research,'" said Professor



S. Jack Hu, referring to a research method described in *Pasteur's Quadrant*. Hu is the CRL's university co-director and J. Reid and Polly Anderson Professor of Manufacturing Technology. "We look at a need, a problem, and then we do the research to develop a fundamental understanding of the problem. From there we create solutions that are realistic and feasible to implement. It takes a rare combination of skills, and our strengths in this area have only grown over the years."

The quality assurance system developed in the U-M CRL monitors several important parameters of welds under process conditions. Welding is critical to the assembly of battery packs, and inappropriate weld conditions during the assembly process could result in less than optimal battery performance. That performance is paramount; the Volt carries an eight-year, 100,000-mile warranty on its battery system.

The CRL researchers also have developed an assembly system configurator that functions as a computer-aided tool for battery assembly system design and reconfiguration. An article about the work won a best paper award at the International Conference on Frontiers of Design and Manufacturing, held in China in June 2012.

Investigators from U-M and GM have been working together for many years on research of critical importance to GM's vehicle manufacturing operations, including key manufacturing processes and systems to support lightweight structures and vehicle electrification.

Hu and his students and collaborators also won the best paper award at the ASME Manufacturing Science and Engineering Conference, held at Notre Dame University in June 2012, for their innovation in high definition metrology-based process control.

"Where the CRL really shines is in 'use-inspired basic research.'"

"Our collaboration in general, and the new quality assurance system in particular, are wonderful examples of how new technologies can make their way from the laboratory environment to the factory floor and become part of a productive manufacturing system," said Hu.

OPPOSITE PAGE: An on-line quality monitoring system for ultrasonic welding in battery assembly.

Blind Deconvolution

Clarifying Sound in an Unpredictable Ocean Environment

Underwater sonar systems are used for a range of purposes, from detecting, identifying and localizing everything from pods of whales to enemy submarines. But sonar hydrophone arrays and signal processing techniques have to contend with a number of uncertainties: noise, echoes, reverberation and variations in time of the ocean environment. Other acoustic properties and ocean floor topography and materials typically are unknown as well.

"When you put a hydrophone array in the water and listen, you're faced with two sets of unknowns," said ME Professor **David Dowling.** "The first set is everything associated with the sound source. You don't know what it is, what sound it has made or where it is. The second set of unknowns is everything associated with the ocean, which is an environment that varies in time. So you can't readily identify the sound source or its location or the parameters of the environment that are distorting the sounds—you only have one set of measurements from your array."

Reconstructing an unknown signal from remote measurements made in an unknown and complicated wave-propagation environment is a common remote sensing problem known as blind deconvolution. It is a difficult problem in the ocean because sound may travel from its source to the receiving array along many unknown paths that include reflections from the ocean's surface and bottom. "In mathematical terms it's an ill-posed problem," Dowling said. "There are many possible pairings of source signal and travel paths that lead to the same set of final measurements."

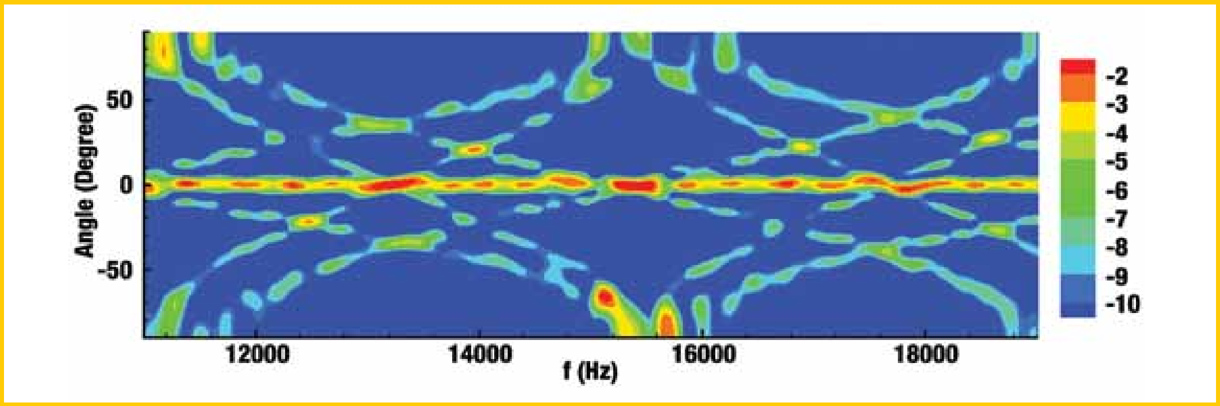
"It is possible to separate the source signal from the sound-path characteristics of the environment if you require the sound-path characteristics to satisfy commonly observed underwater sound propagation scenarios and assumptions," Dowling said.

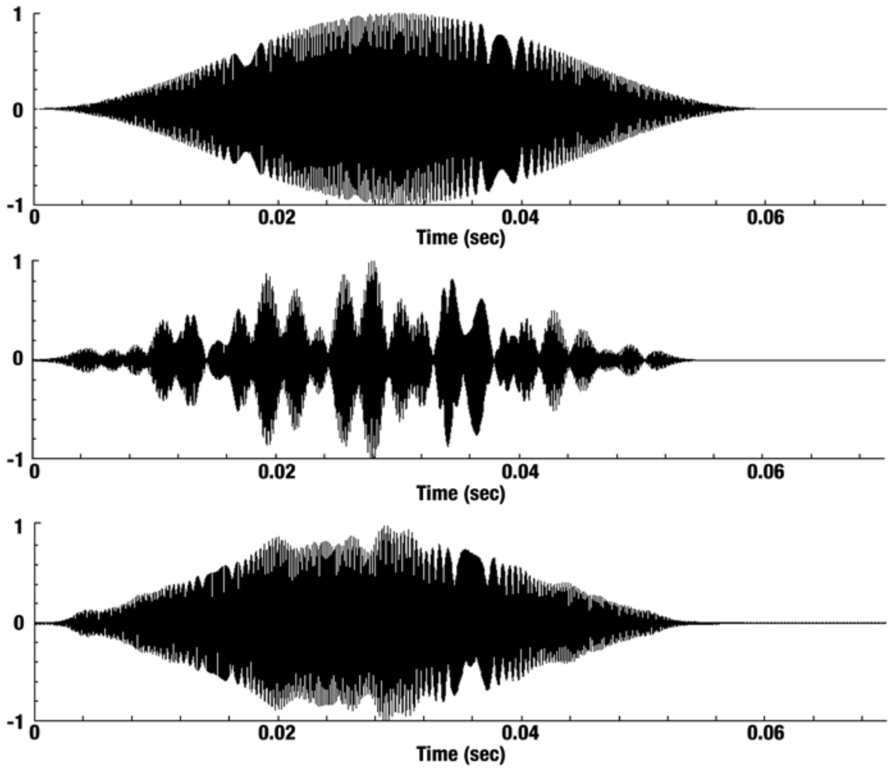
For example, just as light travels to the receiver's eye on ray paths, sound waves underwater may travel on rays when their frequency is high enough. "If I assume the sounds recorded at the elements of the array have to have traveled on multiple unknown ray paths from the source, including ones that have bounced off the ocean's surface or bottom, that assumption alone provides enough extra information to separate the source sound from the environment," he explained.

> "If we can validate our results with ocean-measured signals, this method could significantly change the way sonar engineers design hydrophone arrays."

Over the years researchers have taken varied approaches to blind deconvolution for different types of source signals and acoustic environments. In order to work, underwater blind deconvolution methods usually rely on statistical assumptions about the source signal or the sound-paths' characteristics. Dowling and his research group have developed a new blind deconvolution technique that differs from previous approaches.

Dowling's researchers take measured signals and analyze them based on an





algorithm they developed. The result is an estimate of the original waveform broadcast by the source and a set of transfer functions that characterize the sound-path structure of the environment between the source and each array element. His team has achieved cross correlation coefficients of between 92 and 96% between estimated and actual signals using real data from the ocean; in simulations, with high signal-to-noise ratio, the correlation rises to 99%. In other words, the approach is successful. In addition, the sound source location can be estimated from the set of transfer functions when a little environmental information at the array location is available.

Currently Dowling is working to determine how much time variability the technique can tolerate. Tides, surface waves, movements within the ocean caused by tidal surges against the continental shelf, weather above the surface and other factors cause ray paths to change. To account for the shifting ray paths, he and his group are partitioning signals into smaller duration pieces, on the order of tens of milliseconds. They apply the blind deconvolution technique to each piece to reconstruct the signal for that piece and then recombine them to recreate the original signal.

Dowling's blind deconvolution technique works across a range of frequencies and even has led him to discover a way to convert a high frequency signal into a low frequency signal, which greatly facilitates localization. Through a unique way of beamforming, his group has been able to take high frequency signals between 10 and 20 kiloHertz and process them as if they were 500 Hertz, or even lower.

"If we can validate our results with ocean-measured signals, this method could significantly change the way sonar engineers design hydrophone arrays," he said.

The U.S. Navy's Office of Naval Research supports Dowling's research on underwater acoustics and sound source localization.

OPPOSITE PAGE: Simulated received-sound direction map (in dB) from a vertical hydrophone array vs. acoustic frequency. Here the central horizontal structure at 0° is the signal and the slanted curving structures are unintentional interference produced by the unique beamforming algorithm. When averaged across frequency, the signal direction reinforces itself while the interference loses its prominence.

TOP: Sample blind deconvolution signal waveform shapes. The top plot shows the ideal signal, a tapered frequency sweep, that was broadcast by the source. The middle plot shows a sample received signal from a vertical recording array 2.2 km away from the source in an ocean environment 92 m deep; it has a cross correlation of 57% with the signal shown in the top plot. The bottom plot shows the signal reconstructed from the array measurements alone; it has a cross correlation of 98% with the signal shown in the top plot.

Fracture Mechanics and Adhesion
Spanning DNA analysis to automotive glazing

Professor **Michael Thouless** and his students have made a number of important contributions to the fundamental understanding of mechanical properties of materials, particularly in the areas of fracture and adhesion. From applications that span lightweight automobile structures to the analysis of DNA molecules, the uses and technologies to which his research results are applied are numerous.

Thouless and his students have been at the forefront of efforts to develop cohesive-zone models to analyze and predict the failure of bonded interfaces in lightweight materials. Design approaches for tough, lightweight materials are necessary for the widespread adoption of newer, lighter materials for energy-efficient applications in the transportation and energy-generation industries. However, the analytical models available to date have been limited in their applicability. Classical approaches to fracture analysis rely on an energy parameter—that is, toughness—as the failure criterion, and they require several assumptions to be made, including the pre-existence of relatively large cracks, relatively brittle interfaces, and materials that deform linearly and elastically.

"If these various assumptions are met, we can use classical fracture mechanics to predict the strength of an interface, but the assumptions are fairly limiting for many useful applications," said Thouless. "We need a different approach for regimes where fracture mechanics doesn't work."

In these regimes, an additional failure parameter—the cohesive strength of the interface—needs to be determined and included in the analysis. Thouless has developed cohesive-zone approaches that incorporate both the strength and energy parameters to provide a smooth transition between the different failure regimes. He also has developed experimental techniques to measure the two parameters.

Thouless' models have proven exceptionally accurate and were some of the first ever to characterize failure of adhesive joints that were dominated by plasticity (irreversible deformation)—an integral part of ensuring crashworthiness in automotive applications—rather than elastic (reversible) deformation. He has expanded the techniques so that the models include the fracture of bonded composites and ultrasonic welds, too.

Thouless' work also has suggested that efficient energy-absorbing composites can be designed by tuning the cohesive strength of interfaces to deflect cracks into tough, energy-absorbing interfaces. This is a significant departure from the conventional wisdom, which held that brittle, or non-energy absorbing, interfaces are required in order to deflect cracks.

Working in collaboration with scientists from Ford Motor Company, Thouless is currently investigating use of lightweight coated polymers that could one day take the place of glass in automobile windshields. But the coatings have to absorb ultraviolet radiation without yellowing and be hard enough to withstand scratching and chipping from dirt, pebbles and other objects. "We're trying to understand what failure mechanisms might be at work here and subsequently how we might design coatings to last the lifetimes of cars," he explained.

In collaboration with ME Professor **Ellen Arruda** and other colleagues in the College, Thouless is modeling the fracture and energy aspects of materials design for blast and ballistics protection (see related story on page 32). "The challenge here is that, at a fundamental level, you have to come to grips with what exactly you're designing against," he said. "We may know we need better armor or a better helmet, but how do you convert the blast into something you can dissipate as energy in a particular protective system?"

Currently, the group is investigating how to tailor a multi-layered composite to make this conversion and then design and fabricate the individual layers from nanocomposites to dissipate the energy efficiently through either visco-elasticity or fracture.

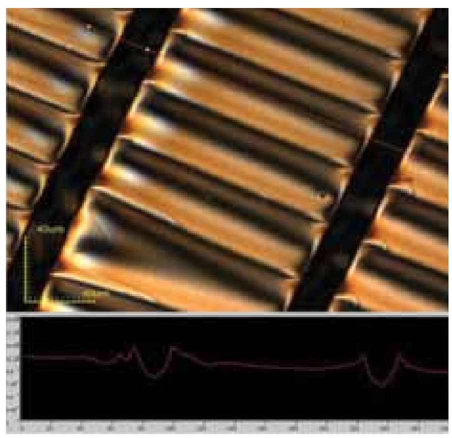
In collaboration with Professor **Shu Takayama** of Biomedical Engineering, Thouless has been applying his knowledge of the failure mechanisms of coatings and thin films at the nanoscale. The research

> “We need a different approach for regimes where fracture mechanics doesn’t work.”

group found by applying a tensile strain to a brittle thin-film—no more than a few nanometers thick—on a soft polymer substrate, investigators could create cracks. The surfaces of the cracks could then be coated with proteins to act as an extracellular matrix (ECM) to support cellular growth. This can serve as a miniature laboratory to provide valuable insights into nanoscale transport phenomena and cellular signaling mechanisms vis-à-vis the ECM.

If the thin, brittle film is sandwiched between two polymers, cracks tunnel through the film and form flexible nanochannels that can be open and shut, simply by controlling how much the polymer is stretched. The technique allows large biomacromolecular complexes to be introduced into the nanochannels and stretched extensively without damage caused by opening and closing the channels. The team has been able to insert a short segment of DNA and stretch it to 97% of its full length. The ability to manipulate large single molecules in this fashion could prove useful for biopolymer mapping applications in genetics and for epigenetics.

“Many people tend to think of fracture as a bad thing—after all, it represents a material failure,” said Thouless. “Sometimes it really is a nuisance to be avoided. But, other times, it can be exploited to play an important role in structure design, in dissipating energy or even in providing a step in a manufacturing process.”



OPPOSITE PAGE AND ABOVE: **When tension is applied to a system consisting of a thin gold film on an elastomeric (PDMS) substrate a series of periodic and parallel cracks channel across the surface (with concomitant buckling between the cracks). The huge modulus mismatch results in the cracks being driven deep into the soft substrate. A similar phenomenon of periodic cracking into the flesh of a tomato can be seen when rain swells the tomato after a summer drought, and causes the skin to split!** TOMATO PHOTO: MICHAEL THOULESS, RESEARCH IMAGES: J. HUANG

Improving Damping and Stiffness

New Meta-Materials and Structural Designs for Dynamic Applications

Lightweight materials that can dissipate energy while remaining stiff and strong are in high demand for any number of applications, including crash and blast protection and noise suppression in military and passenger vehicles as well as aircraft.

"But materials that offer a high degree of damping tend to be soft, so they're not good candidates for any of these applications," explained Professor **Greg Hulbert**. Hulbert is part of a collaboration that aims to design nanocomposite materials with microarchitectures that make them simultaneously stiff and also able to damp out energy. The team includes several College of Engineering faculty members and is funded by the Defense Advanced Research Projects Administration (DARPA).

The group has been developing materials that employ a stiff, three-dimensional microarchitecture of carbon nanotube (CNT) pillars and trusses, which are embedded in a nano-engineered polymer that has excellent damping properties (see related story on page 32). To determine the properties of the resulting composite materials, Hulbert simulates their response to dynamic loading. The results from his computational models are then used to tune, or modify, the microarchitecture by varying the spacing and curvature of the CNT pillars. This maximizes both damping and stiffness.

Hulbert's simulations have been validated by comparing them with data gleaned from mechanical testing. The new composite is predicted to have improved stiffness and damping properties over conventional engineering materials, such as rubber and steel.

The computational framework and simulations Hulbert has devised are guiding the analytical capabilities for, as well as optimal design of, new meta-materials with high stiffness, high damping and low weight. "The architectures we've come up with…I haven't seen anyone else with these kinds of geometries," he said. "We're heading toward creating unique materials that don't exist in standard form."

In a second project funded by DARPA, Hulbert and Research Scientist **Zheng-Dong Ma** are working to design structural systems that can mitigate the effects of high g-force shock loads. Such structural systems have wide application in ground and aerospace vehicles and watercraft.

In collaboration with Raytheon and Georgia Tech, Hulbert and Ma are using geometric amplification in conventional materials such as steel, aluminum and standard damping materials to improve the damping capacity of structural systems while, at the same time, maintaining structural stiffness. Geometric amplification refers to devices that can increase motion at specified design points, similar to a reversed lever. The systems under development also will have compact designs and be incorporated into existing structures or used to replace conventional load-bearing structural components.

The team's demonstration project included a prototype beam for an aircraft wing spar, a structural member that spans the length of a wing and bears much of the weight and loading. The prototype design was directly embedded into a pre-existing structural frame and could be adapted for varying target levels of stiffness and damping.

The work builds on previous research conducted at U-M by Dr. Ma and Professor **Noboru Kikuchi**. "We've been inspired by their designs," said Hulbert, "and, as a result, we've been able to come up with some very interesting concepts."

"The architectures we've come up with…I haven't seen anyone else with these kinds of geometries. We're heading toward creating unique materials and structures that don't exist in standard form."

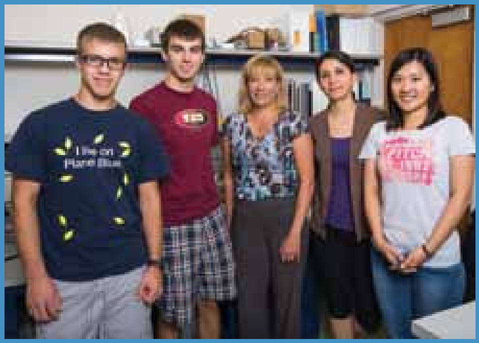
Achieving Material Toughness

High performance nano-building blocks for composites

Achieving material toughness, or the ability to deform without failing, is one of the greatest challenges in materials design. Professor **Ellen Arruda** and the research team in her laboratory are addressing the challenge head-on, investigating material structures and topologies at the nanoscale that confer, among other properties, toughness.

"Many applications—from trash bags to lightweight armor to protect soldiers—demand materials that are as tough as possible and that simultaneously can perform their intended functions in a practical way," said Arruda. Her research group is using high performance polymers as tiny building blocks to achieve and tailor these properties in nanocomposites for lightweight body armor.

Arruda and her team are working with poly-paraphenylene terephthalamide, commonly known as Kevlar™. With its strong molecular backbone, Kevlar fibers are stiff and strong along the fiber axis, but changing the material's geometry lessens its strength and stiffness. Its surface also is largely inert, so it doesn't bond well within a polymer matrix. Well-bonded interfaces are critical to composite stiffness and strength and only slightly less important to toughness. "But without at least moderate bonding, the resulting composites are not very exciting," she said.



L TO R: **Brandon Hazelton, Tyler Olsen, Ellen Arruda, Tanaz Rahimzadeh, Keqin Cao**

“This project is the perfect example of how researchers with a wide range of expertise and from multiple disciplines can come together around the long-standing problem of how you translate molecular structure into a property such as toughness.”

Arruda’s group has developed a method to dissolve and further process the Kevlar™ into aramid nanofibers (ANFs). These fibers are stiff, strong and heat resistant, and they have a significantly higher surface to volume ratio than the bulk material. The increased surface area means the material is more reactive and able to bond to other materials and form networks within a polymer matrix.

By varying the treatment process, researchers have been able to tailor and control the nanostructure of the ANF building blocks, the formation of networks and their macroscopic properties. The advances suggest a new versatile building block and chemical methodology that could be applicable to a large family of high performance polymer nanocomposites able to withstand extreme loading.

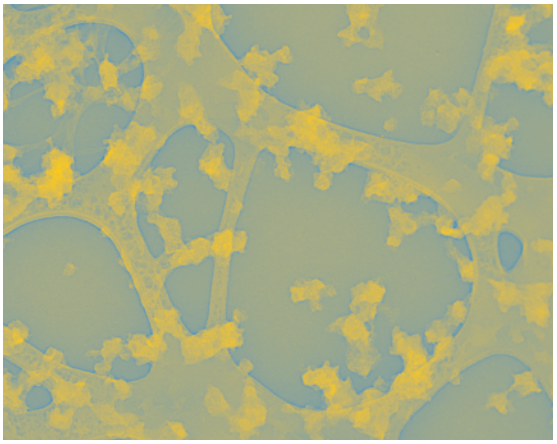
The research builds on Arruda’s work for the U.S. Navy’s Office of Naval Research on developing lightweight materials that are blast- and ballistic resistant. The materials under development potentially could be applied as clear coatings and interface layers to mitigate harmful effects of blast and to dissipate energy away from soldiers in combat situations.

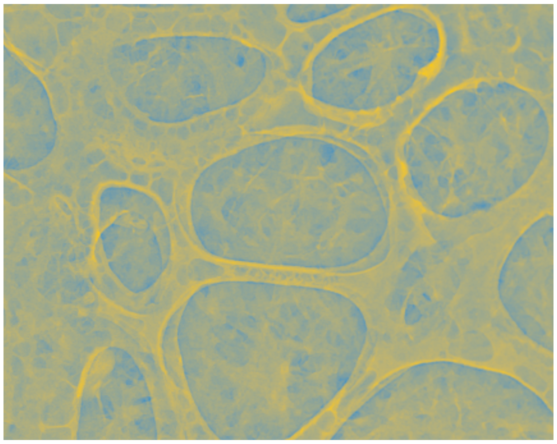
“Our goal is to improve the state of the art in body and vehicle armor technologies to reduce the effects of blasts and ballistics encounters,” Arruda said. The materials also could be used in automotive applications to improve vehicle crashworthiness and protect civilians from auto-related injuries.

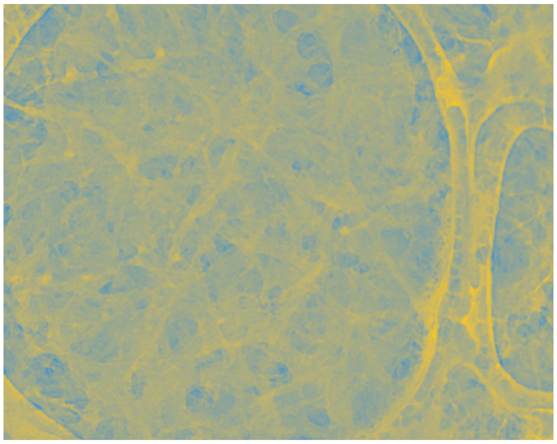
“One of the exciting things about using ANFs and the ability now to combine them with other materials means we can start realizing some of their exceptional properties and use them in more versatile ways,” said Arruda, “not only as fibers but in sheets and likely other geometries as well.”

The research has been presented at conferences in Europe and has generated a lot of interest and positive feedback. “This project is the perfect example of how researchers with a wide range of expertise and from multiple disciplines can come together around the long-standing problem of how you translate molecular structure into a property such as toughness,” Arruda said.

The research represents the efforts of a number of faculty members across the departments of Mechanical Engineering, Chemical Engineering and Aerospace Engineering as well as both graduate and undergraduate students.







OPPOSITE PAGE, BOTTOM: **PhD candidate Keqin Cao aligns a camera on her nanocomposite film specimen for simultaneous digital image correlation analysis of the deformation field during tension testing.**

RIGHT: **Kevlar nanocomposite building blocks imaged via transmission electron microscopy (top) nanosheets of approximately 50 nm diameters, (middle) 13 nm diameter nanofibers and (bottom) a cross-linked Kevlar™ nanofiber network.**

Novel Nanomanufacturing
Patterning graphene nanostructures

Graphene, a two-dimensional material comprised of a single layer of carbon, has unique electronic properties, particularly at the nanoscale. But to date no effective method for producing sub-10 nanometer scale graphene nanostructures over large areas exists. Assistant Professor **Xiaogan Liang** is working to change that.

"One of the most exciting and pressing needs when it comes to graphenes is to examine how nanolithographic technologies used in the semiconductor field can be adapted and refined. We can use similar ideas and technologies to pattern graphene sheets into nanostructures that we can engineer with specific electronic characteristics and functionalities," Liang said.

Conventional lithography has enabled good control of device layout for large-scale applications, such as the integrated circuits inside computers. But newly emerging nanomaterials differ markedly in structure from silicon and also in their compatibility with current lithography processes.

"The challenging questions for us are: How do we achieve a higher resolution with nanolithographic processes, and how do we develop a very specific and appropriate nanofabrication tool for making devices with these new materials? Those are the problems we want to solve," said Liang.

While working as a staff scientist at The Molecular Foundry at Lawrence Berkeley National Laboratory, Liang devised a solution. He invented a new nanofabrication method based on lithography to structure the surface of crystalline graphite and massively produce nanoscale graphene field effect transistors, or GFETs (see figure 1). Once the graphite substrates are patterned, they can be used repeatedly as a stamp to manufacture pristine graphene nanostructures.

Liang's method involves the application of voltage to the graphite stamp to create an electrostatic force that attaches graphene features to a target substrate. The desired structures can be exfoliated and printed. "In principle, the process is similar to laser printing, only here we use high voltage to create the electrostatic attraction between the GFET and the substrate," he said.

The technique Liang invented enabled patterning over a small area, adequate for investigational purposes but not commercial application. Now at U-M he is leading efforts to scale up fabrication to larger areas in a continuous fashion. Those improvements will open the door to a host of applications, including flexible electronic and optoelectronic devices such as thin films and many others.

In related work, Liang's group has developed a block copolymer self-assembly method to pattern nanostructures and create two-dimensional graphene nanomeshes and one-dimensional graphene nanoribbons (GNRs) (see figure 2). His method improves the resolution of current nanolithographic techniques.

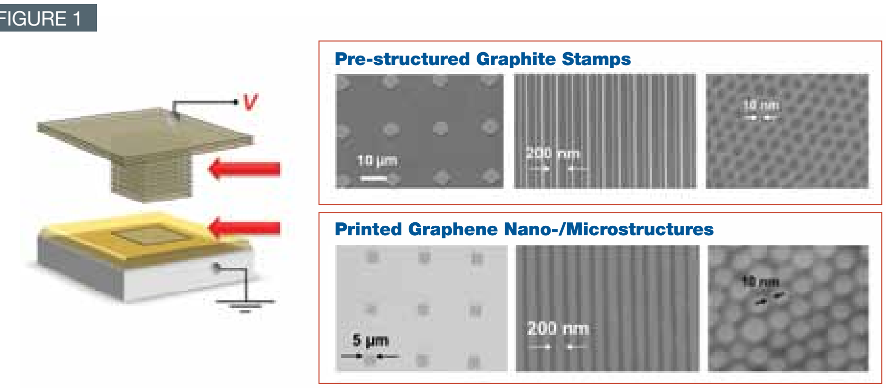
"Graphene is two-dimensional. If we can pattern it into one-dimensional nanoribbons, we can explore some new transport properties," he said. "In terms of the energy efficiency, these nanoribbons can be used as low dissipating channels for transporting electrons."

For the GNRs to transport electrons with little dissipation, however, the one-dimensional ribbons need to have atomically precise, smooth edges. Plasma etching, commonly used in semiconductor lithography, can leave rough edges and chemical contamination. Instead, students in Liang's laboratory are exploring new plasma-free processes based on new nanomechanical and chemical processes, aiming to achieve atomically smooth graphene nanostructures with controllable layouts.

Liang's group is applying its breakthroughs in nanolithography to an emerging and extremely promising area of applied physics and engineering: topological insulators, or TIs. These unique materials act as a conductor on their surface and an insulator or semiconductor in the interior. The surface state offers advantages when it comes to electron transport. "Electrons have the ability to tunnel through defects without any loss of energy," Liang said. "These are fascinating materials; they behave very differently from conventional semiconductors."

The potential applications for TIs include low-dissipation switch devices and other electronics, thermoelectric devices, magneto electronics, spintronics and

FIGURE 1



> "If our methods work, and we believe they will, we could one day realize the future of nanomanufacturing of functional device arrays of topological insulator nanostructures."

biological sensors. Fundamental research done to date has been performed only at extremely low temperatures, which are not feasible for practical applications. Such low temperature is required to suppress the residual bulky conductance in TIs.

The critical step now is to manifest the surface effects of TIs by increasing the surface to volume ratio. Liang and his group are looking at patterning nanostructures on the surfaces of TIs to increase surface transport and also depress the leakage path through the bulk.

The challenge will be to manufacture highly uniform TI nanostructures over large areas and with good ordering. "Currently, there is no way to do this," Liang said. "But if our methods work, and we believe they will, we could one day realize the future of nanomanufacturing of functional device arrays of topological insulator nanostructures."

FIGURE 2 **Graphene Hexagonal Mesh with 10 nm Ribbon-width**

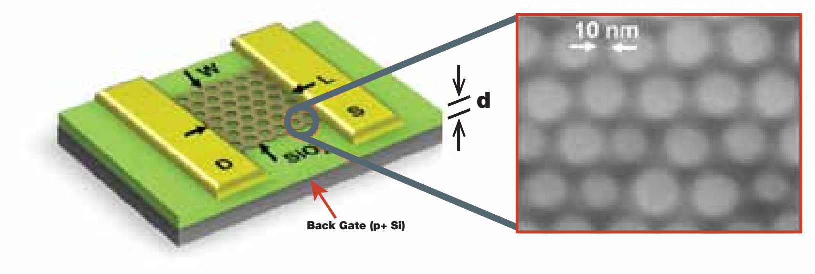
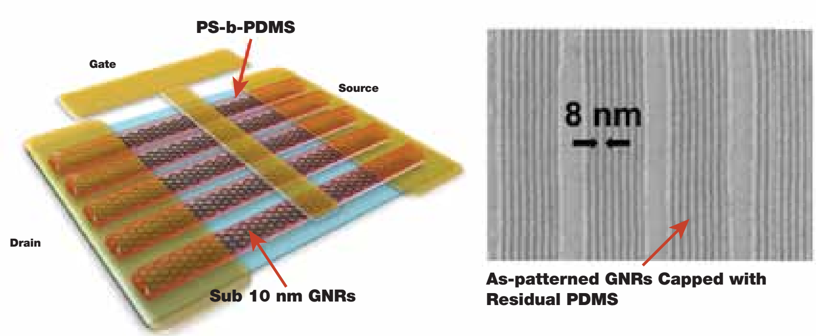


FIGURE 3 **Densely Aligned Graphene Nanoribbons (GNRs)**



OPPOSITE PAGE: Schematic illustration of electrostatic printing of functional graphene nanostructures (left inset); high-quality graphite surface lithographically structured with various micro- and nanostructures (upper inset); graphene nanostructures faithfully transfer-printed from structured graphite stamps (bottom inset).

TOP: Graphene-based field-effect transistor (GFET) made from graphene nanomeshes (GNMs) with sub-10 nm inter-mesh-hole spacing. A GNM can be regarded as a network of multiple graphene nanoribbons (GNRs) arranged into a percolating structure. The quantum confinement effect at the bottle neck regions of GNRs can open a bandgap for semiconductor-related applications. The inset SEM shows a GNM patterned by using block-copolymer self-assembly in combination with nanoimprint lithography, which could be further implemented as an upscalable nanomanufacturing process.

BOTTOM: Densely aligned sub-10 nm half-pitch graphene nanoribbons (GNRs) produced by using directed self-assembly of block-copolymers with cylindrical morphology (these are GNRs with the highest density and large-area uniformity to date) and fabricated FETs bearing such densely aligned GNRs. Such well-oriented nanoribbon arrays over wafer-scale areas can provide the higher scalability and uniformity for large-scale electronic and bio/chemical sensor applications.

Sensory Feedback

Using haptics to advance prosthetic control and sensation

In a multi-institution initiative funded by the National Science Foundation, Associate Professor **Brent Gillespie** is working to improve control for upper limb amputees using smart prosthetic devices.

"When it comes to prosthetics, haptic feedback often is overlooked," said Gillespie, who heads the Haptix Laboratory at U-M. "We have so much sensory feedback embedded in our bodies that we take it for granted. It's not until your fingers are cold while you're fumbling for the keys in your pocket that you realize how much you rely on the sense of touch."

The subtleties and complexities make designing experiments "surprisingly difficult," Gillespie said. "It's almost impossible to take away the sense of touch from a non-amputee, but at the same time, that sense is completely missing in individuals with missing limbs. Although a prosthetic device can return some functionality, the sense of touch is very difficult to replace."

The design paradigms for prosthetic devices have changed little since the mid-twentieth century. Devices typically rely on myoelectric control, or electrical signals derived from muscles in the residual limb. The signals can enable a terminal device to make simple movements such as opening or closing around an object. But the user must watch the gripper or listen for changes in the sound of its motor to ascertain the size of the aperture or whether too little or too much force is being applied to grip or lift a particular item. More

ABOVE: Encephelography and functional Near Red Spectroscopy are used to monitor the neural activity of Brandon Johnson, a member of the Haptix Lab, as he prepares to grasp and lift an object using a prototype smart prosthetic device. The instrumented terminal device that Brandon holds and motorized exoskeleton he wears about his elbow models the myoelectric control and sensory feedback being developed for use by upper limb amputees.

recently, some mechanical design changes have been made to prostheses, but the availability of sensory feedback—other than vision and audition—has remained a unique challenge.

Gillespie and collaborators from Drexel University, Rice University and the University of Houston are overcoming the obstacles. Together the team has developed a prototype interface system that provides sensory feedback through an exoskeleton worn on the user's residual limb. A force sensor on the terminal device relays feedback to a motor on the exoskeleton. When force develops as the user squeezes an object, he or she will feel an extension

Early brain imaging studies using electroencephalography (EEG) and functional near-infrared (fNIR) techniques have indicated that sensory feedback may indeed make the process of using a prosthetic device easier and more natural. Results suggest that cognitive demands on the brain are lower in users who receive such feedback than in those who don't.

"We believe by coupling myoelectric control with sensory feedback, users will be able to pay less attention to their device," said Gillespie. "For example, maybe they could lift a cup while conversing, whereas now they might have to stop what they're doing and watch the device as it takes ahold of

and then replace myoelectric signals with the EEG signals. The user imagines performing a particular behavior, such as lifting a cup, and the EEG signals can actuate the terminal device to carry it out. Sensory feedback could potentially enhance BMI strategies as well.

The number of new directions in related research is virtually unlimited, thanks to an innovative and multidisciplinary group at U-M. Gillespie works with colleagues both inside and outside the College of Engineering, including investigators from Plastic Surgery, Kinesiology, the U-M Orthotics and Prosthetics Center and other departments.

> "Some of the most forward-thinking work is happening right here at U-M....It's not simply about building an appliance that works; it's about developing an interface that requires a deep understanding of its human users."

moment at the elbow in direct proportion to the force generated at the terminal device. Other types of feedback the team is exploring include vibrotactile, skin stretch and squeezing cues. Studies have begun to delve into which type or combination is most effective.

Although the system requires the user to adapt to the idea that feedback received at the exoskeleton pertains to a distal, mechanized device, "It's not such a stretch since humans are very good at wielding tools. To borrow an example from philosopher Martin Heidegger, think about using a hammer: After a short period of time, you become less and less aware of holding the handle—the interface—and more attuned to what's happening at the head, where you're hitting the nail," Gillespie said.

the cup. And they might have to listen to the motor to sense how much force they're applying—the process can demand a lot of attention."

In addition to enhancing myoelectric control with sensory feedback, Gillespie and collaborators are working in the realm of brain-machine interfaces (BMI), looking at ways to increase the number of channels in targeted muscle reinnervation and to replace myoelectric control with EEG control. "The head cap we ask study participants to wear for purposes of monitoring is potentially useful as a control modality as well," Gillespie noted.

A decoder the team is developing can take the EEG signals, search for correlations between the signals and motor behavior

"Some of the most forward-thinking work is happening right here at U-M," said Gillespie. "That forces us to dive into fields not our own. It's not simply about building an appliance that works; it's about developing an interface that requires a deep understanding of its human users. Sensory feedback is going to be part of the game, and that makes this all the more exciting."

Personnel Tracking Systems

Ensuring the safety of soldiers and emergency responders

"The single greatest problem in rescuing downed firefighters is knowing where to find them."

Soldiers and emergency personnel face substantial risk in combat and disaster situations. Working inside burning or booby-trapped buildings, searching for victims among rubble or rescuing survivors all potentially put these individuals in harm's way.

"The single greatest problem in rescuing downed firefighters is knowing where to find them," said Research Professor **Johann Borenstein**, who heads the U-M Mobile Robotics Laboratory. His goal is to lower that risk through an innovative personnel tracking and position estimation system.

Known as personal dead reckoning, or PDR, the system measures the position and direction of an individual moving throughout a building relative to a known starting position. The system does not require any external references, such as GPS.

Co-developed by Borenstein and Assistant Research Scientist Lauro Ojeda, the PDR system is simple, comprised of a small sensor—an inertial measurement unit, or IMU—and a wearable computer to process sensor data. A radio modem transmits data regarding the subject's position and elevation to the monitoring individual. The combined sensor-radio pack is small enough to be mounted on the subject's boot and in the boot heel. It also can be attached to the side of a shoe so it can be easily detached and used by other individuals.

The PDR system is able to track diverse types of movement often used by emergency responders: walking, jumping, running, carrying or dragging heavy objects, crawling, retracing steps and moving in non-linear ways, such as walking around to the back of large equipment or

ABOVE: **During some of the experiments with the PDR system, a separately housed transmitter was used in order to test communication issues.**

OPPOSITE PAGE: **The PDR system comprises a removable IMU sensor in the heel of the boot and a computer/power/transmitter unit attached to the shaft of the boot.**

behind obstructions. It also can track users regardless of individual gait characteristics. It requires a seven-second initialization period prior to the mission, but no calibration for individual users is necessary.

Borenstein's research team has made the PDR system significantly more accurate than conventional IMU-based systems. Since the IMU is attached to the user's foot, error correction techniques can be applied that will not work elsewhere on the body. "Small errors from the IMU can be corrected with every step, when the instrumented foot is firmly on the ground and its true velocity at that moment is known to be zero," Borenstein explained.

For that reason, the system can eliminate undesirable "drift" from the IMU's accelerometers. Since, on footfall, the IMU's true velocity is zero, the system corrects accelerometers that indicate otherwise. Similarly, the system assumes corridors are straight and/or intersect at 90 degrees. If the system's gyro indicates otherwise, the system corrects it. The PDR also can be optimized for urban and other outdoor environments in addition to buildings.

In numerous tests, the PDR system has proven highly accurate. Position errors have been less than one percent of the distance traveled; directional errors have been near zero degrees in indoor walks of unlimited duration; and elevation estimates have been off by less than one meter.

Future work includes improving the system's performance when the user is crawling on hands and knees, a method often employed by firefighters to reduce exposure to heat and smoke. An effort also is underway to adapt the PDR system to tracking the location of autistic children who exhibit wandering behaviors.

Support for the PDR system has been provided by government agencies including the U.S. Department of Energy, the Department of Defense, Idaho National Laboratory, Oak Ridge National Laboratory as well as numerous nonprofit and private organizations, including MITRE, McQ, MDA Corporation, Robotic Research, Mercury Data Systems and the Center for Commercialization of Advanced Technologies.

A Rare Look

Shedding light on fuel ignition with novel experimental methods

Advanced combustion technologies have the potential to increase the efficiency of many types of engines, reduce polluting emissions and improve operational safety and combustion performance. But these technologies are limited today by the chemical kinetics of the fuels they use.

Low-temperature combustion strategies and lean premixed fuels in particular can dramatically increase device efficiency while reducing emissions. But applying the strategies to modern engine design presents several challenges. When combustion temperature is lowered, chemical reactions slow. Few experimental data exist that identify critical behavior as a function of temperature, pressure and composition at conditions consistent with modern engines. Yet this information is required to quantify reactivity, validate models and, ultimately, safely and efficiently design combustors for aviation, ground transportation and stationary power and heating applications.

Margaret Wooldridge, Arthur F. Thurnau Professor of Mechanical Engineering, is addressing these complex questions in the U-M Combustion Laboratory using a novel methodology she and her research team have developed to characterize fuel chemistry.

“We know a lot about ignition chemistry at high temperatures, but nowhere near as much at low temperatures,” said Wooldridge, who has developed a rapid compression facility (RCF) to compress test gas mixtures to pressures and temperatures found in internal combustion engines and other combustion systems.

While there are some other research groups using similar experimental methods, the RCF at the University of Michigan is a unique and decidedly powerful research tool. Wooldridge’s team has developed a method of high-speed gas sampling combined with gas analysis that it uses with RCF studies of ignition.

“We’re one of very few facilities in the world able to quantify intermediate species formed and consumed during ignition,” Wooldridge said, “and we do that in an extremely rigorous way. These are direct measurements of reaction pathways controlling combustion rates and the formation of air toxics.”

Darshan Karwat and Scott Wagnon, graduate students in Wooldridge’s research group, have quantified dozens of intermediate species formed during ignition. Their data highlight uncertainties and build confidences in the understanding of how fuels burn and how air toxics are formed. The new data are challenging targets for combustion chemistry of important fossil fuel standards, such as heptane, as well as biofuels such as butanol and biodiesel.

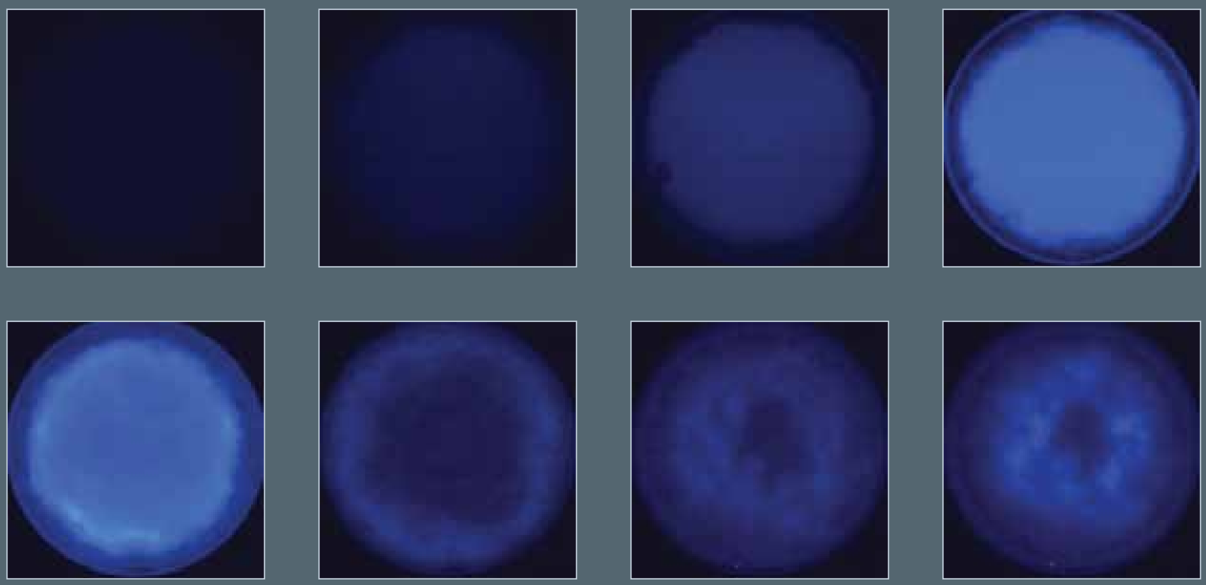
In work supported by the U.S. Department of Energy, Wooldridge and her research group have identified unexpected synergistic effects of biofuel and fossil fuel blends. “Whether you look at the transportation or stationary power sector, we won’t have enough feed stock to use biofuels exclusively. We need to understand the effects of different blends and how to optimize fuel composition. Controlling reaction rates becomes harder at lower temperatures, but operating at lower temperatures to gain improvements in efficiencies and minimize pollution is a need that can’t be ignored,” she said.

The Wooldridge group also has studied how diluents such as exhaust gases and steam, which are commonly employed to reduce pollutant emissions, affect low-temperature combustion chemistry. The diluents have thermophysical effects on combustion that are well recognized. However, Wooldridge’s research team has identified chemical effects of diluent composition that also are significant at low temperatures.

In another U.S. Department of Energy-supported project, Wooldridge is investigating the chemistry of high hydrogen content (HHC) fuels for gas turbines and stationary power applications. HHC fuels can be produced from a number of sources with some synthesis methods holding the promise of reducing carbon emissions of the power sector. However, variability in HHC fuel composition can be problematic. The Wooldridge group is working with ME Professor Hong Im to develop a domain map of the chemical behavior of HHC fuels at different temperature, pressure and composition conditions, as well as to characterize the sensitivity of the fuels to ignition and flame propagation, important safety concerns in combustor design.

“Hydrogen and HHC fuels have great properties, but there are significant practical challenges to using these fuels. HHC fuels are extraordinarily sensitive to local conditions in the combustion chamber, and there is a significant, unresolved difference between predicted and observed behavior of hydrogen combustion at conditions relevant to gas turbine combustors. We are trying to resolve the physical and chemical mechanisms at the heart of these discrepancies,” Woodridge explained.

OPPOSITE PAGE:
Still images from high-speed imaging of n-heptane ignition.



“We’re one of very few facilities in the world able to quantify intermediate species formed and consumed during ignition, and we do that in an extremely rigorous way. These are direct measurements of reaction pathways controlling combustion rates and the formation of air toxics.”

Combustion Science and Technology
Shrinking the carbon footprint of US manufacturers

Consumers may complain about the high costs of energy at the gas pump, but those costs pale in comparison to the expenses incurred by industry. Professor **Arvind Atreya** has been working with manufacturers to reduce their energy costs in a number of ways.

In a program funded by the U.S. Department of Energy, Atreya has been advising manufacturers in Michigan, Ohio and Indiana on how to lower their energy expenditures. The program is free to manufacturers. "They're very receptive to finding out about new methods that can save energy, cut costs and improve operations," Atreya said.

Thinking about energy savings and operational improvements has led Atreya down new research paths in his U-M laboratory, which focuses on combustion, fire, energy and the environment. He and his group have developed and demonstrated a transformational combustion technology for high-temperature furnaces to reduce energy use and the carbon footprint of U.S. manufacturers. This technology has been patented by U-M.

The large industrial furnaces used in the production of steel, aluminum and glass as well as for metal casting and petroleum

"The radiative flameless combustion approach would save manufacturers significant amounts of money in the United States and abroad if adopted."

refining consume tremendous amounts of fuel. "One of these furnaces might consume a quarter-million dollars of natural gas per day," said Atreya. "And right now they're no more than 50% efficient."

Currently, inside an industrial furnace, flames heat the furnace walls and the metal in turn is heated to its melting point not by the flames directly but by radiation from the furnace walls. "Right now, we're heating something other than the metal with flames and that something else radiates heat back to melt the metal. It's the same process for aluminum or steel or other metals, and it becomes very inefficient and very polluting," said Atreya.

The indirect process means that gas inside the furnace must be heated to, and remain at, temperatures significantly higher than the melting point of the material being processed. "There's nothing you can do with this gas—you can't let it cool or the metal will solidify again, so you have to exhaust it. Right now all that heat in the exhaust gas is wasted."

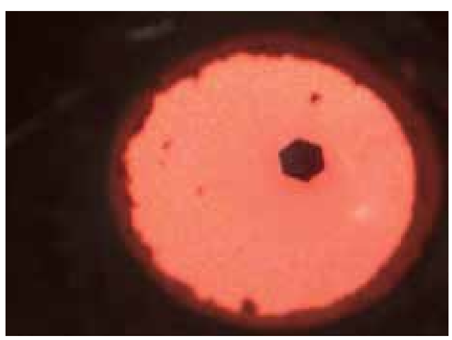
Atreya is approaching the problem with a two-fold solution: First, recirculate the exhaust energy back into the furnace with an internal and/or external flue gas recirculation device; second, enhance the radiation from the combustion process so that materials are heated directly by flames rather than indirectly.

Preheating the combustion air with recirculated exhaust gas, though, raises the flame temperature and pollutant formation. Atreya has addressed this problem as well by diluting and simultaneously preheating the air to particular temperatures that result in flameless combustion. This both improves efficiency and reduces pollutant formation. "We've found that pollution actually falls by a factor of 10," he said.

Atreya's solution works by creating a larger reaction zone inside the furnace without burning more fuel. As the temperature rises inside the furnace, radiation increases by the fourth power. "You're burning much more uniformly and homogenously and, because you have a larger reaction zone, you're radiating heat more efficiently to the material," he said.

Atreya has demonstrated the radiative flameless combustion (RFC) approach on a laboratory-scale furnace and was recently granted a patent. He also has developed real-time sensor technology for furnace monitoring since current flame sensors do not work for RFC.

The RFC approach reduces fuel consumption per unit of output by more than 50%. At the same time RFC improves furnace productivity, cuts pollutants and greenhouse gas emissions and improves product quality by eliminating the dross and other waste products that form inside



TOP: Flameless Combustion
BOTTOM: Flaming Combustion

furnaces. "It would save manufacturers significant amounts of money in the United States and abroad if adopted," he said.

The approach is an example of a practical and useful technology that was developed through a confluence of ideas, Atreya noted. However, a large number of fundamental problems remain to be solved. "We know it works but we don't exactly know why. The 'why' is important for better quantitative design and control, but the science has yet to be developed. My students and I are working on it," he said.

In another energy-related project, Atreya is looking at novel methods to generate fuel from woody biomass. His thermochemical approach would capture the pyrolysis products from wood in a narrow time and temperature range. These pyrolysis products would then be condensed, deoxygenated and refined.

"Once you have this liquefied bio-oil, you need to remove chemically-bound oxygen from it before you can send it to an oil refinery," said Atreya. He is currently investigating the use of novel regenerative catalysts to de-oxygenate the bio-oil prior to refining. "We've introduced real innovation; we're finding ways to generate fuels from renewable resources and we're learning how to do it very efficiently and all in one shot."

This method enables the biomass reactor to be transportable and autonomous such that it can be used in remote areas of the forest. "If the excess biomass is removed from the forest to generate green fuel, we will also significantly reduce the danger of forest fires," Atreya said. "The economics of doing this are compelling, and it creates numerous new jobs producing carbon-neutral transportation fuel."

“There are three things we want to improve in multi-vehicle systems: safety, particularly fatal accidents; congestion, which costs billions of dollars annually in the United States; and energy consumption.”

Dynamics of Vehicle Flows:

Optimizing technologies to make traffic flow

The problem of traffic congestion is as old as the Model T. For decades now, researchers from many scientific and engineering disciplines have tried to tackle the problem using complex formulas and tools and by drawing analogies to other types of flows, such as fluid and gas. But, as ME Assistant Professor **Gabor Orosz** and colleagues wrote in a 2010 article in *Philosophical Transactions of The Royal Society A,* "it is becoming more and more obvious that traffic flows like no other flow in the Newtonian universe."

Orosz and his research group focus on modeling and analyzing the dynamics of vehicular traffic flows in order to understand precisely why and how traffic jams form, propagate and dissolve. Such knowledge is critical to the development of effective control strategies.

Unlike much automotive research that centers on particular components or individual vehicles, Orosz' work focuses on multi-vehicle dynamics. His research takes a systems approach and employs network theory to investigate vehicular traffic flows, including the effects of driver behavior.

"There are three things we want to improve in multi-vehicle systems: safety, particularly fatal accidents; congestion, which costs billions of dollars annually in the United States; and energy consumption. These are the big problems we target with our research," Orosz explained.

But working at the systems, rather than vehicular level, means added complexity when it comes to modeling, analysis, prediction and control. "Predicting the behavior of one vehicle can be complicated, but when you talk about hundreds or thousands of vehicles as well as their human drivers, the complexity is compounded. It's not enough to know what that one vehicle will do, because you don't know how the system will behave; you have to look at the interconnections among vehicles."

Technology that interconnects vehicles, such as autonomous or adaptive cruise control that enables drivers to follow another vehicle or stay in one's driving lane, for example, currently is available in passenger cars. Such systems rely on radar, a well-understood and widely adopted technology. Systems that employ radio transmitters are under development, but these increase the complexity significantly because of the network structure of connected vehicles.

To characterize the constraints of such technologies when employed at the systems level, Orosz is working with the U-M Transportation Research Institute (UMTRI). Data from an upcoming UMTRI study will help Orosz and colleagues identify the limits of present technologies so that the constraints can be considered when designing connected vehicle systems.

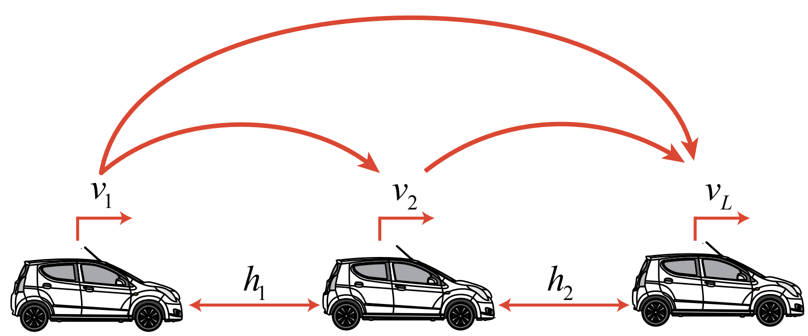
Given the size, not to mention sticker price, of vehicles today, Orosz and his team have built 1/8 scale ground robots to reproduce vehicle behavior. Based on data from the UMTRI study, he and his team can then continually modify the network of vehicles in order to develop effective controllers.

Although the connections among the robotic vehicles rely on laser range finders rather than the radar that current autonomous cruise control systems employ, "they're pretty realistic in terms of behaving the way real vehicles do—only at a much smaller scale and in a safe way," he said.

One of the challenges Orosz will continue to overcome with his research is how to interpret different types of motionand identify dynamic patterns.

In fact, Orosz and his team have discovered that collective motions, such as waves and patterns, reveal a lot about a system. Now he is working to classify different types of motions and, ultimately, how controllers could be employed in a multi-vehicle system to prevent them. "And you almost always want to prevent them; any kind of traffic pattern that is not simply a homogenous flow is usually bad."

Orosz and his collaborators are one of the few groups employing network theory to address the dynamics of traffic flows at the systems level. "With all of the resources at U-M," he said, "Ann Arbor really is the center of this research."



ABOVE: A platoon of connected vehicles. Apart from sensing the motion of the car in front, information about the motion of distant vehicles can be transmitted using wireless communication. Combining this technology with intelligent control design may allow one to avoid accidents and congestion.

Engineering Cornerstones

Integrating experimentation with theory and communication

For many students, ME 395 and 495, Laboratory I and II respectively, mark a turning point in their undergraduate education.

"I often see a transition from what I call being a technician to becoming a genuine engineer," said Professor **David Dowling**, who teaches ME 395.

That's because the courses are designed not only to emphasize the fundamentals of experimentation—including experimental design and uncertainty, safety and ethics—but technical communications as well.

"When students get to these lab classes they have to find the correct answers to problems, but they also have to produce a report that convinces someone who's likely to be skeptical of the correctness of their results, based on the theoretical underpinnings from their core ME courses. The courses force them not only to perform like an engineer, but to think like one," Dowling said.

Experiments in both courses are presented as technical scenarios that become more open-ended as the courses progress. Student teams assume the role of consulting firm and must conduct the required experiment and subsequently determine which data, related information and conclusions to include in the "client" report.

In ME 495 the experiments become more complex, typically spanning several weeks, and the required technical communications take multiple forms: written reports, posters and oral presentations. "The 495 curriculum often adopts some of the personality and expertise of the instructors of a particular term," said Professor **Bill Schultz**, who frequently teaches ME 495. Student work is evaluated on both technical and communications merit.

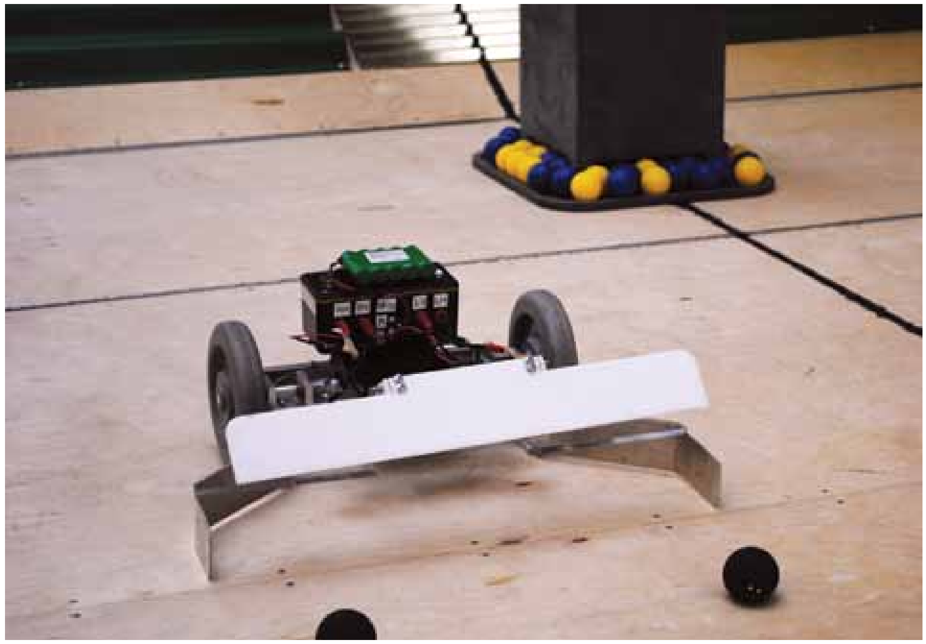
The process of communicating results is a valuable learning experience, if not a frustrating one at times. "At the start, many students aren't comfortable with the ambiguity that is inherent in the laboratory scenarios and that is an intended part of the courses, but that's how things work in industry. Engineers invariably deal with ambiguity," said Dowling.

Alumni agree the courses benefit their careers and provide a positive edge. "I often hear from graduates who say they're very thankful they took the classes," Dowling said, "even though they did not always appreciate their value at the time."

ME250 students compete in the Fall 2011 "Balltower" competition at the CoE Design Expo, while the staff and audience look on.

ME Design and Manufacturing

Accelerating innovation



"MacroHard," built by students Alex Nagler, Alex Vigran, Nelson Worner and Jesse Staub, competes in the ME250 Balltower competition.

The ME department's core design curriculum is recognized nationally for its breadth and depth as well as the many hands-on experiences for students. In Design and Manufacturing I, II and III (ME 250, 350 and 450 respectively), students learn to take an idea and shepherd it through prototyping and testing. From concept to build, they gain the knowledge and skills to turn concepts into manufacturable products and functional physical systems.

DESIGN, MATERIALS AND MANUFACTURING

In Design and Manufacturing I, course lectures center on three themes: the design process, materials and manufacturing. Students learn to visualize concepts in numerous ways and communicate their ideas to others. In the machine shop, they experience firsthand the capabilities and limitations of different manufacturing processes, including traditional machining, waterjet and laser cutting, rapid prototyping and assembly.

The course culminates in a "Balltower" competition at the College's Design Expo. Student teams compete using a remote-controlled machine built during the semester. The team whose machine acquires the most ping-pong and squash balls from features on the two-by-eight-foot "arena" wins. In 2011-12, the arena took on an added degree of difficulty with new features conceived by course leader Assistant Professor **John Hart** and modeled after the North Campus bell tower, wave field and buildings.

MODEL-BASED SYSTEM DESIGN

Design and Manufacturing II introduces the model-based design of mechanical and electromechanical systems. Lectures focus on system analysis and synthesis, mechanical elements and mechatronics, or the synergetic integration of mechanical disciplines, electronics, controls and computers. In past semesters, student projects have included golf-club swinging machines, catapults and an inverted pendulum. In 2011-12, student teams tackled a new challenge: a mobile backpack carrier for a wheelchair.

"Through these projects, students are introduced to sensors, actuators and controllers and learn how to integrate them into high-performing mechanical systems. It turns out to be one of their favorite subject areas in the 350 course," said Assistant Professor **Shorya Awtar**, course leader.

SOPHISTICATED PROTOTYPES FOR INDUSTRY SPONSORS

Design and Manufacturing III offers students a complete capstone design and manufacturing experience through an open-ended, real-world engineering project. Projects come from industry partners and university research labs and involve the design, fabrication and testing of a new device, machine or system based on customer needs.

These sponsored projects have become increasingly more mechatronic in nature, requiring system-level integration of mechanical design, sensors, actuators and controls. To address this need, the Department has invested in creating a world-class mechatronics instructional lab facility equipped with state-of-the-art instrumentation. In recent years, the Department has hired a lecturer, **Mike Umbriac**, and an engineer, **Toby Donajkowski**, to support the ME 250, 350 and 450 classes.

continued

ME250 Fall 2011 First Place team, "The Original Three" (Corey Zwegers, Tim Bello, Kelsey Arens, Michael Erickson), with course instructors Prof. John Hart and Mike Umbriac, Jean Chu (GSI), and representatives from prize sponsor Harris Corporation.

Successful projects have included interactive inverted pendulum and ball-on-plate balancing exhibits for the Ann Arbor Hand-On Museum and a minimally invasive skin biopsy device. During 2011-12, students developed a tool to align satellites prior to launch for Lockheed Martin, an anti-whiplash headrest for Johnson Controls Inc., and a surgical assist device for use in awake-craniotomies at University Hospital. Course projects have led to startup companies, too. FlexDex LLC, for example, designs affordable tools for enhanced dexterity and intuitive control in minimally invasive surgery.

"The added instruction in mechatronics really pushes the industry projects in ME 450 to a whole new level," said **Gordon Krauss**, course coordinator. "Having been exposed to mechatronics in their sophomore and junior year (in ME 250 and 350) as well as the rest of the Design and Manufacturing curriculum, students are quite ready to deliver solutions beyond what would be expected of your typical mechanical engineer."

Design for Global Health

It's not every day that undergraduate students have the chance to improve health care in the developing world. ME alumnus **Keval Patel** (BSE '12) and several classmates had this opportunity, however, thanks to an innovative Design for Global Health experience conceived of and coordinated by ME Assistant Professor **Kathleen Sienko** in collaboration with Dr. **Aileen Huang-Saad** of the Biomedical Engineering department.

"The experience gives students a unique opportunity to address major global health challenges both through clinical immersion and collaborative hands-on design," Sienko said. The program's four cornerstones include co-creation with the end-user community, experiential learning, intercultural training, and in-depth exposure to a specific thematic area.

Patel was part of a student team that visited Ghana during the 2011-12 academic year to investigate maternal health. The experience began with background reading and observation on the obstetrics ward of U-M's University Hospital. Next, the team traveled to Ghana for an eight-week clinical immersion at Komfo Anokye Teaching Hospital (KATH) in Kumasi. From there, the team traveled among rural communities in northern Ghana and then spent two weeks at the Korle Bu Teaching Hospital in Accra (KBTH).

"Our observations helped us develop a far greater sense of the condition of healthcare in the region and the needs pressing healthcare providers," Patel said. In addition to observing physicians in the clinic and health care workers at rural sites, the team performed a needs assessment, recording the challenges noted while observing.

Upon returning to U-M, the team analyzed the needs assessment and, in collaboration with physicians in Ghana and at U-M, selected one particular challenge: devising alternative methods for infant delivery.

RIGHT: **Professor Sienko stops en route from Kumasi to Accra to watch as a young woman sells her wares by the roadside.**

ABOVE: **View of the small village behind the woman, left.**

"The input from Ghanaian physicians and our clinical observations really helped show us what challenges were truly important to physicians on the ground," Patel said. Alternative methods are required because of the often-poor road conditions that exist between outlying villages and health facilities as well as a shortage of trained care providers in rural areas. These factors can mean life-threatening delays when complications such as ectopic pregnancy and prolonged labor arise.

The team developed potential solutions through the senior capstone design course, ME 450. With ongoing input from and evaluation by physicians in both countries, the team ultimately developed an alternative to forceps, which require extensive training to avoid injury to the infant. The concept employs a nylon sock applied to the baby's head using a compliant plastic applicator. The individual assisting in the delivery then uses the sock to help extract the baby. "Our concept would allow a lesser trained provider to still be able to perform a life-saving delivery during an emergency," Patel said.

The Global Health Design experience has been recognized as a model for medical technology co-creation in resource-limited settings. In 2011 and 2012 it received funding from multinational medical device companies to support similar programs in China in minimally invasive surgery, cardiac surgery and cancer treatments. Sienko also has piloted the first U-M - African engineering student clinical observation team in collaboration with the University of Ghana and Makerere University at KBTH.

Also in 2011, five U-M graduates founded a company to commercialize several devices they developed in the Global Health Design program.

Students who choose to complete two semesters of design in ME 450 and ENGR 455 typically enroll in the Multidisciplinary Design Minor Global Health Design Specialization.

+ more on the web

For more information on the Specialization:
http://sitemaker.umich.edu/specialization/Home

Engineering Collaboration

ME faculty forge relationships in Ghana

The complexity of engineering research today demands both multidisciplinary and global approaches to identifying and implementing solutions. In a new initiative supported by the U-M Rackham Graduate School, the Mechanical Engineering department and the College of Engineering, three ME faculty have initiated relationships with universities in Ghana. The goal is to establish long-term research and education collaborations and further strengthen the global dimension of the U-M ME doctoral program.

Some of the participants of the UM-KNUST STEM-Africa Conference in Kumasi, Ghana, May 2012.

"We want to reinforce and build upon our existing relationships with two institutions in Ghana—Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi and University of Ghana (UG) in Legon—that already have been productive and insightful for everyone involved," said Professor **Elijah Kannatey-Asibu**, who is leading the effort.

The three-year grant enables three ME faculty per year to visit Ghana. Three to four PhD students each year also will be supported during one- to two-month internships in Ghana. Similarly, Ghanaian faculty will visit U-M to facilitate research collaborations and joint education proposals. Research focus areas include global health, energy, manufacturing and other areas of mechanical engineering.

In August 2011, Kannatey-Asibu and two ME co-investigators, assistant professors **Nikos Chronis** and **Kathleen Sienko**, returned from a four-day fact-finding visit to both Ghanaian universities. Kannatey-Asibu discussed collaborations in the area of materials and manufacturing, including a project on using recycled plastics and natural fiber composites for low-cost wind turbines.

Chronis and Sienko met with biomedical engineering colleagues and visited Komfo Anokye Teaching Hospital to explore joint projects. Chronis is developing point-of-care biochips for HIV monitoring in resource-limited settings that don't require hospital or clinic accessibility. The technology will enable monitoring of the effectiveness of an individual's antiretroviral therapy and identify HIV-positive patients who would benefit from such treatment. Chronis met with doctors and local health-care workers and is hoping to test a prototype within the coming two to three years.

Sienko has been working with Komfo Anokye Teaching Hospital since 2008. She has led two groups of Global Intercultural Experience for Undergraduates (GIEU) students and three cohorts of Global Health Design Specialization students to Ghana (see related story on page 49). Her work focuses on creating a framework for appropriate engineering design in healthcare in resource limited settings.

Three PhD students are completing two-month internships in Ghana in the summer of 2012. Ibrahim Mohedas is studying the diagnosis of pre-eclampsia, a hypertensive disorder during pregnancy, in rural settings and developed user requirements for an improved blood pressure device for use by community healthcare workers. Amir Sabet (BSE BME '09, MSE BME '10) is exploring the engineering design process for medical devices and technologies in resource-limited settings, and Serge Gregory (MS ME '06) is investigating solar thermal electric plants and micro-turbines to provide power to rural villages.

During the 2012-13 academic year, there are opportunities for other ME faculty to spend up to four days in Ghana, and additional U-M ME doctoral students can spend up to two months in Ghana. Three Ghanaian faculty members also are expected to visit Ann Arbor.

Previously, Kannatey-Asibu led three U-M GIEU student-teams to Ghana to address plastic recycling issues. He has co-organized several conferences between U-M and African institutions to help foster collaboration among scientific researchers. He organized and co-chaired sessions on manufacturing innovation and sustainable energy and design at a U-M - KNUST conference in May 2012. He also represented U-M at the Pan-African University Workshop on Curriculum Development in Nairobi, Kenya, in 2011. He has been involved in shaping the engineering curricula at the university, which was only recently established by the African Union.

+ more on the web

For more information on Global Engagement of Doctoral Education and related activities: http://sitemaker.umich.edu/me-ghana/Home

International Engineering Summer School

Participation in popular study abroad program in Berlin triples

The International Engineering Summer School (IESS) at TU Berlin, now in its seventh year, has again drawn a record number of U-M Engineering undergraduates to study and live in Germany's capital. IESS participation has steadily grown from 10 in the inaugural class in 2006 to 32 in 2012. The program has been popular among all classes and welcomes students from all College of Engineering departments. Seven of the 32 participants in 2012 were Mechanical Engineering students.

"TU Berlin Professor Frank Behrendt, the IESS co-founder, and his team worked tirelessly and with above-and-beyond enthusiasm to accommodate the increased number of students who wanted to come to Berlin," said Professor **Volker Sick**. Sick conceived of and developed the IESS in close collaboration with Behrendt.

The IESS continues to benefit from the support received from automotive engineering firm IAV GmbH and IAV, Inc. As a result the program has been able to offer a broader portfolio of projects as well as reduced fees to students. Participants in the summer 2012 session chose from one of three research projects. Teams investigated the production of alternative energy via fluidized-bed wood gasification, fluid mechanical design to achieve drag reduction, or efficient programming of a microcontroller to build a musical tuner. The next IESS will include two additional projects, one on advanced internal combustion engine studies and one on sustainable energy concepts.

A significant number of the IESS participants use the summer experience to fulfill several requirements for the International Minor. This minor, the first offered by the College of Engineering, was co-developed in 2008 by Sick and Dr. **Amy Conger**, who serves as the College's director of International Programs. It quickly has become the most popular minor for engineering students with some 200 students currently enrolled and more than 100 graduates.

Sick, who has served the College of Engineering as faculty advisor to International Programs since 2007, is starting a new appointment as Associate Vice President for Research for Natural Sciences and Engineering in September 2012. He will continue co-teaching the IESS.

IESS participants visit the Sans Souci castle in Potsdam near Berlin.

U-M - SJTU Joint Institute
Cementing a strong foundation

Since it was founded in 2006, the University of Michigan - Shanghai Jiao Tong University Joint Institute (U-M - SJTU JI) has made strides toward its mission to build a global partnership and world-class institute for engineering education in Shanghai. Its many successes to date have led to a number of milestones in 2011-12 that further strengthen its foundation and enable future growth.

"Both sides reviewed all that has been done over the past six years, and everyone was quite happy with how the JI has been developing," said ME Professor **Jun Ni**, who currently serves as dean of the JI and who was instrumental in its founding. As a result, the two universities signed a 10-year master collaboration agreement in June 2012. "Both institutions were enthusiastic about committing to the JI for an additional 10 years," he added.

The U-M - SJTU Joint Research Collaborative is now in its third year, with another group of projects recently funded. Since its inception, several ME faculty, including professors **Volker Sick**, **Albert Shih** and **Don Siegel**, have been recipients of research support for collaborative projects with SJTU faculty.

Close to 100 undergraduate students from SJTU arrived in Ann Arbor for the fall 2012 semester, joining some 80 seniors who currently are studying in Michigan. The U-M also granted admission to more than 90 graduate students, primarily through the College of Engineering. In addition, more than 40 U-M students are studying in Shanghai. Nine U-M faculty, from both within and outside the College, taught courses at the JI during the 2012 summer semester.

The JI has produced over 600 graduates to date. Over 80% have pursued graduate study in China and the United States (10% and 70%, respectively). Among the students who came to study in the United States, almost all have been admitted by top U.S. schools. "This is a remarkably impressive record of graduate placements," Ni said.

In addition, the scope and scale of JI programs continue to expand. "We're working simultaneously to bring new disciplines into the JI and also trying to find ways for more U-M students to take advantage of such a unique opportunity."

One of the strategies for making JI study-abroad experiences possible for greater numbers of U-M students includes fundraising, and both universities have undertaken joint advancement activities. "It's important to both institutions to increase scholarship funds so that more U-M students can study in Shanghai and SJTU students can study in Ann Arbor," said Ni.

A number of other efforts to build capacity are underway, including new faculty and staff hires and facilities improvements. A new, 200,000-square-foot building for the JI has been approved and is scheduled to be completed in 2014.

The JI is receiving extremely positive feedback. In October 2011, JI administrators commissioned an external evaluation by a panel of expert reviewers. The panel determined that the caliber of JI students and faculty are comparable to those at top universities in the United States. China's Ministry of Education, which oversees over 3,000 Sino-international cooperative educational programs, also declared the JI a model to emulate. As a result, the Chinese government issued a case study of the JI, which has been provided to a number of colleges and universities throughout China so that they can adapt some of the JI's best practices and features to create and improve their own programs.

"The JI truly is a model educational partnership. That was our vision when we founded the JI in 2006, and it's our vision today," said Ni. "We were pleased to have our work validated by both the expert reviewers and the Chinese government. With the new 10-year collaboration agreement, we can continue moving forward to make that vision a reality."

U-M-SJTU Joint Institute administrators in Shanghai during the signing ceremony of a 10-year partnership agreement.

BLUElab

Engineering for Global Impact

Student members of BLUElab, Better Living Using Engineering, are finding innovative solutions to real-world problems locally and across the globe. Project teams focus on developing sustainable technologies that can have a lasting impact environmentally, culturally and economically.

BLUElab projects are as diverse as the organization's membership, comprised of over 100 students across all College of Engineering departments and disciplines outside of engineering as well. "Students campus-wide are encouraged to pursue their passions in sustainability and create projects that improve living conditions and lives," said Professor **Steve Skerlos**, the organization's co-founder and faculty advisor.

WOVEN WIND WINS PEOPLE'S CHOICE AWARD

A BLUElab team is continuing its initiative to generate a low-cost source of electricity to a small town in the mountains of Guatemala. For this pilot program, students have built a small wind turbine crafted of inexpensive, locally sourced materials. Local women generate personal income by weaving fabric for the turbine blades. This project was a 2012 Dell Social Innovation Challenge People's Choice Winner and earned a $1,000 prize.

TURNING WASTE AND SCRAPS INTO SAFE FUEL

Another BLUElab team has been working on installing an anaerobic digestion system in Liberia. The team's biodigester takes animal and human waste and food scraps and combines them with bacteria, which convert the mix into biogas comprised of between 60% and 70% methane. The biogas then can be used to produce electricity and odorless fertilizer, to heat water and to prepare food. Biogas is a healthier and more sustainable source of cooking fuel than wood.

COLLECTING AND PURIFYING WATER

BLUElab students have partnered with Nicaraguan-based blueEnergy, a non-governmental organization working with the United Nations, to build and implement a rainwater collection and purification system in the Bluefields region of the country. The team is using low-cost, indigenous materials to build the system and to provide clean water and sanitation services to one of the poorest, most isolated regions in the Western hemisphere.

LASTING IMPACT

This year a new student team formed to provide solar heating to rural homes, also in Guatemala. Several other projects are ongoing, too. "BLUElab members are continually conceiving of diverse new projects—all with the potential for real and positive impact for individuals," said Skerlos.

Closer to home, BLUElab has continued its successful campus job fair and well-attended Sustainability Speaker Series.

+ more on the web

For more information, visit http://bluelab.engin.umich.edu/

ABOVE LEFT: **Students outside of Freetown, Liberia learn about the operation of a new system installed at their school that converts animal waste into bioenergy.**

ABOVE RIGHT: **Project Leaders of the Guatemalan Solar Team examine a solar panel (near Santa Cruz, Guatemala).**

Formula SAE

MRacing Extends Successful Streak

The University of Michigan Formula SAE® team, MRacing, recently returned from another successful run at Formula Student Germany 2012 where it placed tenth overall, second in acceleration and fourth in endurance.

MRacing and its vehicle, MR-12, were well prepared after the Formula SAE Michigan race in May 2012, in which they placed 5th, giving MRacing its eighth consecutive top 10 finish.

"This consistently high placement is incredibly rare among all teams," said **Brian Fallin**, 2012 MRacing co-captain. He attributes the "record hot streak" to a number of positive changes: the recent expansion of the Wilson Student Team Project Center, an increase in membership and even more support from both alumni and sponsors. As competition stiffens and vehicles become more expensive to build each year, that support is much welcomed and appreciated.

"We're really standing on the shoulders of giants. Team alumni support us as informal advisors and help transfer knowledge to new members. The University's alumni base and location in southeastern Michigan are key to helping us find sponsors in the automotive industry. This year we had two companies approach us and go on to become platinum sponsors," Fallin said.

The continued success of MRacing has increased the team's stature on campus and helped recruit committed new participants. With a nearly 30 percent increase in membership over the past year, the team now has added capacity to focus on important mechanical details, testing and its aggressive build schedule. "Manufacturing the car takes a lot of foresight, planning and lead time," Fallin said.

That experience is excellent preparation for landing a job in industry. Since 2009, the team's seniors have all been employed or had job offers by graduation. "Our participation in MRacing and Formula SAE in general has radically benefited each of us," Fallin said. "I know, at least for me, it's given me the opportunity to choose my future."

Reed Sullivan, 2013 captain and a ME junior, plans to continue the winning streak. "Our team goal is to finish top three in both competitions we attend next year."

+ more on the web

For more information, visit the team website at http://mracing.engin.umich.edu/

Reed Sullivan races MR-12 during the Formula Student Germany endurance event at the Hockenheimring.

U-M Solar Car Team

A record-breaking win

Through intense weather and an exceptionally challenging route, the U-M Solar Car Team and its vehicle, Quantum, prevailed, winning the 2012 American Solar Challenge with the largest margin of victory in the history of the race. The eight-day competition for solar-powered vehicles covers 1,650 miles, from Rochester, New York, to St. Paul, Minnesota. Quantum crossed the finish line just shy of 45 hours, a full 10 hours ahead of the closest vehicle. Quantum's time broke the existing record, set by U-M's 2008 car, Continuum. The win also was the U-M team's fourth consecutive title.

Quantum is the lightest vehicle in the team's history and weighs 200 pounds less than its 2009 predecessor, Infinium. It's also 30% more aerodynamic, which proved beneficial when the racers encountered heavy rain on the race's second day. Many teams were severely affected, and Quantum acquired hours' of lead-time.

Although inclement weather poses serious challenges, the team had made it a priority to test the vehicle—and give drivers

plenty of experience—in wet, rainy conditions. "The car performed well despite the adverse weather conditions, and that can be attributed in large part to the skill of our drivers. We made sure they had a lot of experience in the rain," said **A.J. Trublowski**, 2012 lead strategist and ME senior.

The route itself also proved a challenge as it took racers through more developed, urban areas than in previous years. Heavy traffic, busy roads and harried commuters made navigation more difficult, although passing through more cities and towns increased interactions with supporters along the way.

In the fall 2011, the U-M team finished third in the World Solar Challenge, a 1,800-mile race across the grueling Australian outback.

More than 100 students from across campus are part of the U-M Solar Car Team, including 15 members of the ME department.

+ more on the web

For more information:
http://solarcar.engin.umich.edu/
@umsolarcarteam

TOP: Andrew Huang (ME) tightens a hub nut after changing a tire during the Ann Arbor stage stop of the 2012 American Solar Challenge, while teammates Evan Fletcher and Sarah Spitzer look on.

BOTTOM: The team celebrates its fourth consecutive and seventh total national championship with a chorus of "The Victors" at the American Solar Challenge finish line in St. Paul.

Experience Energizes Baja Racing

With the energy and experience of many returning teammates, the Society of Automotive Engineers (SAE) Michigan Baja Racing Team remained a competitive force throughout the 2011-12 race season.

The team was motivated to work during summer 2011 so it could begin the design and manufacturing process as early as possible. Seasoned team members helped push Michigan Baja to complete its vehicle a full week earlier than in recent years. The extra week paid off. “We had time for significantly more testing, which helped us discover and fix unforeseen problems,” said **Calvin O’Brien**, the team’s technical director and an ME senior.

Michigan Baja competed in all three races during the year, “a challenge in itself and one not accepted by many teams,” added O’Brien. The team also managed to bring a second car to events in Alabama and Oregon. “We were one of the only teams able to bring two vehicles to the first competition of the year. That helped new members get to experience the excitement of driving in the endurance race as well as the stress of doing mid-race repairs.”

The team placed ninth overall out of 175 teams. Members attribute much of their success to having that extra time for testing—and a place to do it. Michigan Baja worked with the College of Engineering and North Campus Facilities and Grounds groups to locate a suitable test track with terrain similar to what they’d face during competition.

Testing and data will continue to play a critical role in the coming year’s vehicle. The team hopes to procure a data acquisition system that will allow it to more accurately determine loading. “With this new information, we should be able to further lighten and strengthen the car,” said O’Brien, “because our goal for next year is to win.”

TOP: **ME senior Calvin O’Brien at the Auburn, Alabama, competition’s endurance race. The team finished twelfth.**

2012 Korybalski Lecture Brings Cristina Amon to Campus

Cristina Amon, a renowned scholar, committed educator and gifted institutional leader, delivered the fifth annual Korybalski Distinguished Lecture in Mechanical Engineering. Amon currently serves as dean of University of Toronto's Faculty of Applied Science & Engineering. Her May 2012 address focused on *"Emerging Trends, Opportunities and Responsibilities for Engineering Education."*

Amon's lecture expanded upon the challenges identified in recent reports by the National Academy of Engineering (NAE). The NAE's *Engineer of 2020* urges the profession to anticipate and adapt to a changing engineering practice, and it encourages engineering schools to attract exceptional students and explore new teaching and training approaches. In her talk, Amon articulated the importance of diversity and system thinking in engineering education and stressed the value of instilling professional, transferable skills such as leadership, entrepreneurship and problem solving from a global perspective. In her own work, she aims to integrate education, research and engineering practice. She is dedicated to promoting women and minorities in engineering and has developed several successful outreach initiatives.

After receiving her mechanical engineering undergraduate degree from Simón Bolívar University in Venezuela, Amon spent two years in engineering practice and teaching then continued her education at the Massachusetts Institute of Technology, where she earned a master's and doctoral degree. Prior to her appointment at the University of Toronto, she was the Raymond J. Lane Distinguished Professor and Director of the Institute for Complex Engineered Systems at Carnegie Mellon University.

Amon's research pioneered the development of computational fluid dynamics for formulating and solving thermal design problems subject to multidisciplinary competing constraints, and she devised a multi-stage concurrent thermal design methodology. Her work has advanced the scientific foundation of heat transfer enhancement and made significant contributions to concurrent thermal designs, innovation in electronics cooling and transient thermal management of wearable computers.

Dean Cristina Amon and Michael Korybalski

Amon's talk was a part of the annual lectureship endowed by one of our distinguished alumni, **Michael Korybalski**, chair of the ME External Advisory Board and former chief executive officer of Mechanical Dynamics. Each year, the lectureship brings prominent speakers to U-M in order to engage engineers across disciplines and inspire them to think about their role in solving societal problems.

Previous Korybalski lecturers have included **Marshall Jones**, an eminent researcher in laser technology; **Charles Vest**, president of the NAE and president emeritus of the Massachusetts Institute of Technology; **Roger McCarthy**, chairman emeritus and retired chief executive of Exponent, Inc.; and **Larry Burns**, retired vice president of research and development and planning for General Motors.

> The lectureship brings prominent speakers to U-M in order to engage engineers across disciplines and inspire them to think about their role in solving societal problems.

Alumni Remember Their U-M ME Experience

Our ME alumni are a distinguished group. Graduates are making discoveries, conceiving of and creating new technologies, and improving society as scholars, engineers, public servants, global volunteers, innovators and entrepreneurs. Below, several reflect on how their U-M experience helped shape their careers and accomplishments.

MARSHALL JONES (BSE ME '65)

The transition to the University of Michigan Mechanical Engineering department from a two-year college was a major one for Marshall Jones (BS ME '65). A self-described "farm boy" raised on a duck ranch on Long Island, New York, he was the only African-American undergraduate in the College of Engineering at the time.

"Being at U-M was a totally different experience for me, and [right from the start] I felt like I belonged there," Jones said.

For one, he excelled academically. "The things I was learning in ME were truly my cup of tea. I was definitely a design-oriented person; I was able to see things in three dimensions and understand how they work," he said.

Jones also excelled as an athlete. He won the U-M campus wrestling championship and was invited to try out for the team, but declined in order to focus fully on his studies.

The decision paid off. "My ME undergrad education was tough but excellent," says one of the world's foremost experts on laser materials processing and member of the National Academy of Engineering. Since 1974, he has worked for GE Global Research, where he currently serves as principal engineer in Manufacturing & Materials Technologies.

Jones is passionate about education, and he has volunteered in a number of capacities to encourage young people to pursue STEM (science, technology, engineering, math) careers. He also has taught at the college level. "I found that I was modeling my teaching approach on what I had experienced in the U-M ME program," he said. "It worked for me, and I knew it would work for others."

But that hasn't been the only benefit of his U-M experience: "Throughout my career, folks have taken notice that my undergrad engineering education was from U-M. I have no doubt they know how strong the U-M ME program was, and still is."

STEPHANIE LACROSSE (BSE ME '97, MSME '99)

Since earning her master's degree in Mechanical Engineering from U-M, Stephanie LaCrosse's career has taken her from a mechanical and electrical engineer at Ford Motor Company to Hyundai, where she was in charge of technical planning for the United States, and to Nissan to manage concept vehicles and head the advanced planning group. Her entrepreneurial spirit, also nurtured at U-M, led to her launch several start-ups including the popular consumer car review website, Honk.com.

At U-M, LaCrosse had the opportunity to work closely with her faculty mentor, leading to a teaching assistantship and valuable research experiences in the Lay Automotive Lab. Teaching gave her a new perspective: from a focus on her own classes to helping others and seeing the many ways people learn. The camaraderie in the lab, where LaCrosse and colleagues worked on improving engine efficiency long before "clean energy" and hybrid vehicles had gained traction, boosted her confidence. As faculty and guests toured the lab and students presented their work, she realized their efforts could—and would—have an impact. "It felt like what we were doing mattered."

LaCrosse says the experiences gave her far more than valuable work and professional experience; they taught her a methodology for solving problems and an appreciation for innovative approaches that can be translated and applied to any field or challenge. "My U-M mechanical engineering degree has really given me an edge in knowing how to think through problems."

MICHAEL LEAMY (MSME '95, PHD '98)

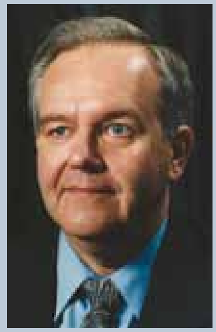
Michael Leamy, an associate professor at Georgia Institute of Technology, applied only to one graduate program: U-M Mechanical Engineering. At Michigan, Leamy studied under and learned from top researchers in Mechanical Engineering, particularly in vibrations engineering and computational mechanics. He also made great friends from diverse backgrounds. "We did a lot of things outside of the classroom: intramural softball, hiking and a little road tripping."

After a teaching assistantship his first year, Leamy knew he wanted to pursue an academic career. "Both teaching and research

MARSHALL JONES

STEPHANIE LACROSSE

MICHAEL LEAMY



ROGER MCCARTHY

SHERI SHEPPARD

CHARLES VEST

are done at a very high level at Michigan with a great deal of integrity; it's hard not to get sucked in. Having a U-M degree also is highly respected in academic circles, and that helped me ultimately land a position at another great university."

ROGER MCCARTHY (BSE ME '72, AB PHILOSOPHY '72)

In a sense, you could say that Roger McCarthy (BSE ME '72, AB Philosophy '72) came to mechanical engineering late. McCarthy was a philosophy major in the School of Literature, Science, and the Arts and a junior when he first began taking mechanical engineering courses on the advice of a housemate. He was hooked. In his combined six years as an undergraduate, he never once missed a class.

"The reason was simple," he said, "Every day, day after day, I remember leaving each and every class feeling more valuable. I had this feeling every day, year and year out. With each class I understood more, and could do more, than I could that morning. For a 20-year-old this was heady stuff."

After two years of ME coursework, McCarthy recalls that the late Professor Emeritus Leland Quackenbush stopped him in the hall of the old West Engineering building one day. "He shoved a pile of forms in my hands and demanded I fill them out." McCarthy asked what they were. The professor explained they were an application for a National Science Foundation fellowship for doctoral study. "Not being particularly fast on the uptake I said, 'But I'm not sure I want a PhD.'" Still, McCarthy completed the application, won a fellowship and, after earning bachelor's degrees in both philosophy and mechanical engineering from U-M, went on to earn a PhD in ME at Massachusetts Institute of Technology.

In 1978, McCarthy joined Failure Analysis Associates, Inc., as an engineer. The company, now known as Exponent, Inc., investigates engineering failures. McCarthy took the company public and held the positions of chief executive and chairman. In 2004 he was elected to the prestigious National Academy of Engineering. Today, he is the founder and owner of McCarthy Engineering.

Reflecting on his storied career and many accomplishments, McCarthy credits his U-M ME experience. "It would be difficult to *overstate* the impact of U-M ME on my career path and my success," he said.

SHERI SHEPPARD (PHD '85)

Now a professor of mechanical engineering at Stanford University and co-director of the Center for Design Research, Sheri Sheppard chose the U-M ME graduate program for the quality—of the faculty, facilities and reputation—and the breadth of course offerings, from theoretical to practical. Her advisors, who had high expectations and always found time to talk and answer questions, had a strong influence on her, both then as a graduate student and now as a professor herself.

In the past decade, Sheppard has led several national studies on engineering identity and engineering education.

CHARLES VEST (MSME '64, PHD '67)

Charles Vest, president of the National Academy of Engineering and president emeritus of Massachusetts Institute of Technology, was hardly unfamiliar with U-M when he chose to pursue graduate work in mechanical engineering. His undergraduate mentor at West Virginia University urged him to apply; some of his undergraduate textbooks had been written by U-M faculty; and his father, Lewis Vest, had earned a doctorate in mathematics at the University.

While at U-M, Vest's research interests and academic work focused on heat transfer and fluid mechanics. The most important part of his graduate education, he says, was the opportunity to study with and be mentored and advised by excellent faculty, who taught Vest how to formulate and solve problems.

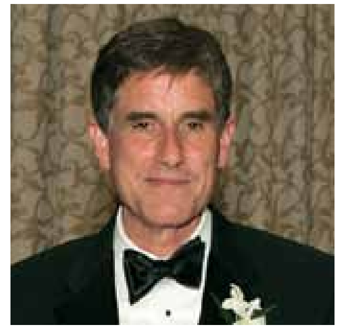
Alumnus Patrick V. Farrell Wins ME Department Alumni Merit Award

Patrick V. Farrell (BSE ME ’76, PhD ’82) is the recipient of the 2011 Department of Mechanical Engineering Alumni Merit Award. Alumni Merit awards are bestowed annually as part of Michigan Engineering Homecoming Weekend and recognize an alumnus/a who has demonstrated sustained and outstanding professional accomplishments.

Dr. Farrell received his BSE ME from the U-M, MSME from the University of California at Berkeley, and his PhD at the U-M. His research involved combustion, fluid mechanics and heat transfer, and applications of optical diagnostics to internal combustion engines. He remains active in Michigan Engineering, serving on the Dean’s Engineering Advisory Council.

Dr. Farrell joined Lehigh University as provost and vice president for academic affairs in 2009. As provost, he serves as the university’s chief academic officer. His responsibilities include leading efforts to attract, recruit and retain highly-talented individuals to Lehigh and working to ensure the success of the campus strategic plan over the next decade.

Before going to Lehigh, Dr. Farrell served as the provost and vice chancellor for academic affairs at the University of Wisconsin-Madison from 2006 until December 2008. During his time as provost at UW-Madison, he served as chief operating officer for the Madison campus and led the university’s two-year reaccreditation self-study initiative, which involved input from thousands of people on and off campus.



In addition, he was elected to the UW-Madison Teaching Academy, whose members developed methods colleagues could draw on to help each other improve and evaluate teaching. The resulting document is now used extensively at UW-Madison and other universities.

Among his honors, Dr. Farrell received the Benjamin Smith Reynolds Award for Excellence in Teaching at UW-Madison, and he recently received an Honorary Degree from City University London in recognition of his long-standing contributions to research and education in mechanical engineering. He is also a Fellow of the Society of Automotive Engineers and a member of the National Science Foundation’s Engineering Advisory Committee.

The ME department congratulates Dr. Farrell on this recognition of excellence and achievement.

ME External Advisory Board

Nearly twenty distinguished friends and alumni of the Department of Mechanical Engineering, from industry, academia and government, comprise the ME External Advisory Board (EAB). The EAB is a valuable resource to the ME chair and the Department as a whole in shaping and meeting strategic goals. The EAB members meet on campus twice every year to discuss departmental vision, strategies and issues and provide advice to the chair.

ME External Advisory Board members at their fall 2011 meeting. Left to right (standing): Doug Smith, Tom Shih, Chuck Gulash, Roberta Zald, Davor Hrovat, Alan Woodliff, Roger McCarthy, Michael Korybalski; (seated): David Cole, Kon-Well Wang, Walter Bryzik

Barber Receives the Jon and Beverly Holt Professorship in Engineering

ME Professor **James Barber** has been appointed the Jon and Beverly Holt Professorship in Engineering in recognition of outstanding career accomplishments and exemplary service and leadership.

Beverly Holt, Maria Comninou, James Barber and Jon Holt at Barber's Professorship lecture and ceremony.

Barber has an impeccable record as a scholar and educator. He has demonstrated a deep commitment to both teaching and mentoring. The textbooks he has written have been used by students across the globe. He has been recognized previously with the Arthur F. Thurnau Professorship at U-M, which rewards outstanding contributions to undergraduate education. He also received the American Society for Engineering Education Archie Higdon Distinguished Educator Award.

Barber is a leading authority in thermoelasticity and contact mechanics. He has made seminal research contributions and been recognized with some of the most prestigious honors in the discipline of solid mechanics, including the ASME Daniel C. Drucker Medal.

Skerlos Named Arthur F. Thurnau Professor

ME Professor **Steve Skerlos** has been named an Arthur F. Thurnau Professor in recognition of his outstanding contributions to undergraduate education. He will retain the title throughout his career at the University.

Each year U-M recognizes a select group of tenured faculty as Thurnau Professors. The individuals chosen all demonstrate a strong commitment to undergraduate education and to working with a diverse student body. They are innovative in their teaching approaches and have a demonstrable impact on students' intellectual development.

Several ME professors have received this prestigious honor: **James Barber**, **Noel Perkins**, **Ann Marie Sastry**, **Alan Wineman** and **Margaret Wooldridge**.

Skerlos served as ME Associate Chair for Graduate Education and heads the U-M Environmental and Sustainable Technologies Laboratory. He is the co-founder and faculty advisor of BLUElab (Better Living Using Engineering), which develops environmentally, culturally and economically sustainable solutions to development problems locally and abroad.

Thurnau professorships are named after alumnus Arthur F. Thurnau and supported by the Thurnau Charitable Trust, which was established through his will.

Flynn Wins Staff Service Award

Senior Accountant **Sarah Flynn** has won a 2012 Excellence in Staff Service Award. The College honored Flynn for her meticulous attention to detail, problem-solving skills and unswerving commitment to co-workers and customers alike.

In addition to sound fiscal management, Flynn is an outstanding collaborator and critical thinker. From the time she joined the Mechanical Engineering department in 2005, she took the initiative to review all charges on her accounts and investigate and remove unnecessary expenses. Her efforts have since resulted in significant salvaged funds and cost savings.

Flynn maintains, updates and monitors over 900 projects in the Mechanical Engineering project database, making her a valuable asset to contract and grant specialists. She also has analyzed endowment fund schedules and compiled a comprehensive endowment package, providing the Department a much-used tool for making investment and award decisions.

The Department congratulates Flynn for the much-deserved recognition.

ME Faculty Take University and College Leadership Positions

Research Professor **James Ashton-Miller** has been appointed Associate Vice President for Research - Research Policy and Compliance in the Office of the Vice President for Research (OVPR).

In his role, Ashton-Miller facilitates research policy development and selected compliance and integrity activities of the OVPR. In particular, he serves as the campus officer responsible for U-M efforts in the following areas: conflict of interest in research and technology transfer, human subjects review and approval, biosafety issues, research misconduct, research ethics training and stem cell research oversight.

Ashton-Miller joined the U-M faculty in 1983 and currently holds the title of Albert Schultz Collegiate Research Professor in Mechanical Engineering. His research interests include biomechanics, including mobility impairments in the elderly; birth-related injury; female stress urinary incontinence; spine biomechanics and athletic injuries.

Professor **Volker Sick** has been appointed Associate Vice President for Research - Natural Sciences and Engineering in the Office of the Vice President for Research (OVPR).

In this role, Sick supports the research efforts of faculty in the natural sciences and engineering disciplines. He also serves as OVPR liaison to the U-M Energy Institute, U-M Transportation Research Institute, Women in Science and Engineering and the Center for Statistical Consultation and Research as well as OVPR's representative on the Graham Environmental Sustainability Institute Executive Committee.

Sick's own research includes the development of laser-based and other optical measurement techniques to enable studies of mass and energy transfer at high pressures and high temperatures in mechanically restricted and vibrating environments. Sick has served on the U-M faculty since 1997. He is currently director of the W. E. Lay Automotive Laboratory

Professor **Panos Papalambros** has been named Executive Director of Michigan Interdisciplinary Professional Engineering (InterPro) and Academic Programs in the College of Engineering.

Papalambros is the Donald C. Graham Professor of Engineering and Professor of Mechanical Engineering. He joined the U-M ME faculty in 1979 and has served as ME department chair. As executive director of InterPro, he is responsible for strategically defining its mission and aligning its goals to continue to provide an outstanding academic program.

Papalambros' research interests include design optimization; large-scale system synthesis; automotive systems design, including hybrid vehicles; eco-design and product design. He is currently the Chief Editor of the *ASME Journal of Mechanical Design*.

Professor **Steve Skerlos** has been named Director of Sustainability Education Programs within the College of Engineering.

Skerlos, Arthur F. Thurnau Professor, joined the U-M ME faculty in 2000. His research centers on environmental and sustainable technology systems; life cycle product design optimization; pollution prevention technologies for manufacturing; metalworking fluid formulation and performance; supercritical fluid delivery of lubricants; and technology policy analysis.

As Director of Sustainability Education Programs, Skerlos acts as a liaison to connect students with sustainability opportunities within the College. He works to broaden campus-wide initiatives related to sustainability education, directs the program in Sustainable Engineering and the joint master's program in Engineering Sustainable Systems.

Faculty Awards & Recognition

EXTERNAL AWARDS

ELLEN ARRUDA
American Orthopaedic Society for Sports Medicine (AOSSM) Excellence in Research Award, 2012

JAMES ASHTON-MILLER
Best Paper Award Cabaud Memorial Award, 2011

SHORYA AWTAR
ASME Leonardo da Vinci Award, 2011

SME Outstanding Young Manufacturing Engineer Award, 2011

ASME Freudenstein/General Motors Young Investigator Award, 2011

SAE Ralph R. Teetor Educational Award, 2012

JAMES BARBER
Text and Academic Authors Association (TAA) , 2012

DIANN BREI
ASME Dedicated Service Award, 2011

SAMANTHA DALY
ASME Orr Early Career Award, 2011

Hetenyi Award from Society of Experimental Mechanics, 2012

AFOSR Young Investigator Research Program Award, 2012

JIANPING FU
NSF Career Award, 2012

VIKRAM GAVINI
NSF Faculty Early Career Development Award, 2011

Humboldt Foundation Research Fellowship, 2012

JOHN HART
AFOSR Young Investigator Research Program Award, 2011

ONR Young Investigator Award, 2012

NSF Faculty Early Career Development Award, 2012

JACK HU
ASME Mfg Science & Engr Conference Best Paper Award, 2012

ASME William T. Ennor Manufacturing Technology Award, 2012

ERIC JOHNSEN
ONR Young Investigator Award, 2012

NOBORU KIKUCHI
USACM Computational Structural Mechanics Award, 2011

SRIDHAR KOTA
ASME Freudenstein/General Motors Young Investigator Award, 2011

TAE-KYUNG LEE
Donald Julius Groen Award - Institution of Mechanical Engineers, 2011

ALLEN LIU
NIH New Innovators Award, 2012

JYOTI MAZUMDER
National Academy of Engineering, 2012

JAMES MOYNE
Semiconductor Equip and Materials Int'l (SEMI) Outstanding Achievement Award, 2011

JWO PAN
SAE Arch T. Colwell Merit Award, 2011

SAE Arch T. Colwell Merit Award, 2012

ASEE Archie Higdon Distinguished Educator Award, 2012

PANOS PAPALAMBROS
IJRM Best Paper Award, 2011

NOEL PERKINS
ASME N. O. Myklestad Award, 2011

KAZU SAITOU
Achievement Award - Design and Systems Division of the Japan Society of Mech. Engrs., 2011

PRAMOD SANGI REDDY
DARPA Young Faculty Award, 2012

ANN MARIE SASTRY
ASME Frank Kreith Energy Award, 2011

ALBERT SHIH
ASME Mfg Science & Engr Conference Best Paper Award, 2012

VOLKER SICK
SAE International Leadership Citation, 2012

JEFF STEIN
ASME DSCD Michael J. Rabins Leadership Award, 2012

BRUCE TAI
ASME Mfg Science & Engr Conference Best Paper Award, 2012

MICHAEL THOULESS
Overseas at Churchill College Fellow, 2011

DAWN TILBURY
SWE Distinguished Engineering Educator Award, 2012

GALIP ULSOY
TÜBİTAK Special Award, 2012

KON-WELL WANG
SPIE Smart Structures & Materials Lifetime Achievement Award, 2011

HUI WANG
ASME Mfg Science & Engr Conference Best Paper Award, 2012

MARGARET WOOLDRIDGE
ASME George Westinghouse Silver Medal, 2011

NEW FELLOWS

DIANN BREI
ASME Fellow, 2011

DAVE DOWLING
ASME Fellow, 2011

American Physical Society Fellow, 2012

JACK HU
CIRP Fellow, 2012

HONG IM
ASME Fellow, 2012

MASSOUD KAVIANY
American Physical Society Fellow, 2011

JUN NI
Int'l Society for Nanomanufacturing (ISNM) Fellow, 2012

WILLIAM SCHULTZ
American Physical Society Fellow, 2012

DAWN TILBURY
ASME Fellow, 2012

MICHAEL THOULESS
Institute of Materials, Minerals and Mining Fellow, 2012

KON-WELL WANG
American Association for the Advancement of Science Fellow, 2011

UM AWARDS

ELLEN ARRUDA
CoE Ted Kennedy Family Team Excellence Award, 2012

SHORYA AWTAR
ME Department Achievement Award, 2011

JAMES BARBER
Jon and Beverly Holt Professorship in Engineering, 2011

JOHANN BORENSTEIN
OVPR Research Faculty Recognition Award, 2011

DIANN BREI
CoE Ted Kennedy Family Team Excellence Award, 2011

NIKOS CHRONIS
ME Department Achievement Award, 2011

TIM GORDON
CoE Kenneth M. Reese Outstanding Research Scientist Award, 2012

JOHN HART
CoE 1938E Award, 2012

Robert Caddell Memorial Faculty/Student Achievement Award, 2011

WEI LU
Faculty Recognition Award, 2012

JONATHAN LUNTZ
CoE Ted Kennedy Family Team Excellence Award, 2011

SRIDHAR KOTA
ME Department Achievement Award, 2012

JYOTI MAZUMDER
Distinguished University Innovator Award, 2012

ALBERT SHIH
CoE George J. Huebner, Jr. Research Excellence Award, 2011

VOLKER SICK
CoE Education Excellence Award, 2012

Rackham Master's Mentoring Award, 2012

KATHLEEN SIENKO
CoE Raymond J. & Monica E. Schultz Outreach & Diversity Award, 2011

ME Department Achievement Award, 2012

Provost's 2012 Teaching Innovation Prize (TIP), 2012

University Undergraduate Teaching Award, 2012

continued

STEVE SKERLOS
Arthur J. Thurnau Professorship, 2012

CoE Neil Van Eenam Memorial Undergraduate Teaching Award, 2011

ANNA STEFANOPOULOU
CoE Research Excellence Award, 2012

MICHAEL THOULESS
CoE Trudy Huebner Service Excellence Award, 2011

SACUA Distinguished Faculty Governance Award, 2012

GALIP ULSOY
CoE Stephen S. Attwood Award, 2012

ANGELA VIOLI
Rackham Henry Russel Award, 2012

MARGARET WOOLDRIDGE
CoE Service Excellence Award, 2012

FACULTY PROMOTIONS

DIANN BREI
to Professor with Tenure

NIKOS CHRONIS
to Associate Professor with Tenure

KRISHNA GARIKAPATI
to Professor with Tenure

KATSUO KURABYASHI
to Professor with Tenure

STEVE SKERLOS
to Professor with Tenure

Student Awards

GRADUATE STUDENT AWARDS

JUSTIN BEROZ
NSF Fellowship, 2011

William Mirsky Memorial Fellowship, 2012

CHRISTOPHER BYNES
NSF Fellowship, 2012

KEQIN CAO
Alexander Azarkhin Scholarship, 2011

INDRANIL DALAL
Ivor K. McIvor Award, 2012

MATHIEU DAVIS
Young Investigator Award - International Society of Biomechanics, 2011

DAVID HIEMSTRA
William Mirsky Memorial Fellowship, 2012

JESSANDRA HOUGH
NSF Fellowship, 2012

BRIAN JUSTUSSON
1st Place in Army Research Laboratory Summer Student Research Symposium, 2011

ADAM KAMMERS
Azarkhin Scholarship, 2012

YOON KOO LEE
Graduate Distinguished Achievement Award, 2011

PETER LILLO
NSF Fellowship, 2012

DAVID LIPPS
Cabaud Memorial Award for Excellence in Research, 2011

KAITLYN MALLETT
NSF Fellowship, 2012

IBRAHIM MOHEDAS
NSF Fellowship, 2012

YOU KEUN OH
Cabaud Memorial Award for Excellence in Research, 2011

GAURAV PARMAR
NIST-ARRA Graduate Fellowship, 2011

SHRENIK SHAH
William Mirsky Memorial Fellowship, 2012

SIDDHARTH SOOD
NIST-ARRA Graduate Fellowship, 2011

GREGORY TEICHERT
NSF Fellowship, 2012

JOHNNY TSAI
Outstanding Student Instructor Award, 2011

STEVEN VOZAR
Distinquished Leadership Graduate Award, 2011

ETHAN WAMPLER
U-M International Institute Fellowship, 2011

HAI WANG
William Mirsky Memorial Fellowship, 2011

UNDERGRADUATE STUDENT AWARDS

SERGEI AVEDISOV
Lloyd H. Donnell Scholarship, 2012

KATIE BEVIER
R&B Tool Scholarship, 2011

CATHERINE BLAIR
R&B Tool Scholarship, 2011

KENDRA BORCHERS
R & B Machine Tool Company Scholarship, 2012

GREGORY CASS
Lubrizol Scholarship Award, 2011

DANIEL COX
Lloyd H. Donnell Scholarship, 2011

MICHAEL CZARNECKI
Robert M. Caddell Memorial UG Award, 2012

MICHAEL ERICKSON
R & B Machine Tool Company Scholarship, 2012

BRANDON EVANS
ME Academic Achievement Award, 2012

GRACE GU
ME Spirit Award, 2012

DONG GUAN
MESLB Transfer Student Award, 2011

JINGJIE HU
Robert M. Caddell Memorial UG Award, 2012

VAISHNAVI ILANKAMBAN
R & B Machine Tool Company Scholarship, 2012

YIQUN LIANG
Robert M. Caddell Memorial UG Award, 2011

BRENNAN MACDONALD
J.A. Bursley Prize, 2011

BRETT MERKEL
MESLB Impact Award, 2011

ME Spirit Award, 2011

BERNARD MURPHY
Robert M. Caddell Memorial UG Award, 2011

TYLER OLSEN
R & B Machine Tool Company Scholarship, 2012

JEFFREY PLOTT
Lubrizol Scholarship Award, 2011

KYLE SAFFORD
Outstanding Service Award, 2011

BRYAN SKULSKY
MESLB Future Leader Award, 2011

ADAM STEVENS
Robert M. Caddell Memorial UG Award, 2012

JACOB SUCHOSKI
R & B Machine Tool Company Scholarship, 2011

CRAIG TENBUSSCHEN
Cooley Writing Prize - Fiction, 2011

NATHAN VAN NORTWICK
MESLB Outstanding Service Award, 2011

EDWARD ZINGER
R & B Machine Tool Company Scholarship, 2011

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INSIDE BACK COVER IMAGE: ME new research complex construction site. See page 8 for details.
PHOTO: MARCIN SZCZEPANSKI, UNIVERSITY OF MICHIGAN, COE, MULTIMEDIA PRODUCER

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