Ian Robertson: On becoming an engine of materials research innovation

Materials play such a foundational role in advancing civilization that they are essentially the shorthand of human history, as defined by the Stone Age, Bronze Age and Iron Age. While those three distinct eras span millions of years, the modern materials challenges will be defined by accelerating the pace of innovation. The White House Materials Genome Initiative looks to unlock the power of materials by doubling the speed at which we discover, develop and manufacture new materials.

The University of Wisconsin-Madison College of Engineering will play a central role in this national initiative, with the summer 2013 announcement of the Wisconsin Materials Institute (WMI). This initiative will build on the impressive multidisciplinary strengths of UW-Madison not only in materials science, but in the computational tools and big data analytics we bring to the challenge.

Our 2013 annual report highlights some of the talented people and ideas behind UW-Madison materials science reputation. For example, Padma Gopalan, associate professor of materials science and engineering, is doing some impressive work on polymers self-assembly and how the resulting nanostructures can have useful properties in microelectronics, solar energy and medicine.

She also leads our National Science Foundation-funded Nanoelectronics Science and Engineering Center. Also featured is electrical engineer Luke Mawst, who is part of a team developing high-power semiconductor lasers that have implications for biomedical devices, environmental monitoring devices, inside avoidance systems and food packaging processes. Our third profile is of Dane Morgan, a materials science and engineering associate professor who leads the computational tools and big data analytics we bring to the challenge.

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Faculty, staff and students from across the UW-Madison campus conduct materials research in a variety of areas. Here, we introduce you to three engineers whose contributions are playing a major role in national efforts to advance materials.

**Q&A with LUKE MAWST**

Professor, electrical and computer engineering

Co-founder, Alfalight / Co-founder, Intraband

**Talk about your research. What, simply, do you study?**

The main thrust of my research is really looking at new semiconductor compounds and the application of those compounds into optoelectronic devices. Most people are familiar with the most common semiconductor material, silicon. But there’s a whole other class of materials for optoelectronics (like semiconductor lasers), materials that emit or detect light. They’re more complex materials, in a sense that we take multiple elements from the periodic table and combine them, things like gallium and arsenic, for example, to form gallium arsenide.

And then we can keep adding elements. We’re synthesizing materials with as many as five or six elements all combined together into a crystalline structure. These additional elements give us a lot of added flexibility to design the electronic and optical properties of the materials, which is advantageous for devices. We call them multinary materials.

**What are the key technical issues you focus on and how do you collaborate with others on campus to develop solutions?**

Some of our research occurs under the umbrella of the interdisciplinary, National Science Foundation-funded Materials Research Science and Engineering Center (MRSEC) at UW-Madison. It involves collaborations with Chemical Engineering Professor Tom Kuech, and Materials Science and Engineering Professor Sue Babcock and Associate Professors Dane Morgan and Marta Schlimak, as well as collaborations at Duke and Michigan. Under the MRSEC, we look at multinary compounds that have never been produced before, so there are challenges in combining these elements in a controllable manner such that we can produce a material system with the desired optical properties.

An example of the applications of these materials is in high-efficiency photovoltaics, or solar cells. We’ve been the first to successfully grow these five-element materials using metalorganic vapor phase epitaxy, or MOVPE. We’ve integrated the materials into solar cells in collaboration with our industrial partner, MicroLink Devices.

Industry also is working closely with us on virtual substrates. With commercially available substrates, you’re limited to a certain lattice constant, the atomic spacing, and that limits what materials you can grow on top and what devices you can make. Many devices require thick layers of materials with uniform composition. Here, we grow virtual substrates in a growth system called hydride vapor phase epitaxy, or HVPE, which allows us to grow very thick layers in tens of minutes. It’s potentially a low-cost growth technique for these virtual substrates.

**What impact, both technically and in application, do you think your work has for the state and the nation?**

One application is high-efficiency solar cells for renewable energy. There are efforts in the United States to develop these high-efficiency technologies. We’re working with Aju University to try to realize the highest-efficiency cells.

Another application is homeland security—for example, detection of dangerous toxic materials or explosives. Very high-power lasers in the mid-infrared range can be used in applications such as remote infrared sensing. Those detection schemes use lasers in the mid-infrared range, wavelengths from 3 to 10 microns. But there’s a lack of reliable high-output-power devices. I collaborate with Electrical and Computer Engineering Professor Dan Botez on quantum cascade lasers. The expertise we have in designing and developing very high-power semiconductor lasers, we rely on that now for producing these quantum cascade lasers, so we’re pushing the envelope and taking them to higher powers.

Tell us about what you find promising about the federal Materials Genese Initiative.

It will foster collaborations, very similar to what we’re doing, but at a much larger scale—coordination. These multi-university, industrial collaborations are key to driving the technology. We’re not experts on everything. We focus our research, say, on one aspect of materials development, but things like looking at reliability of devices, it’s hard for us to do that in a university setting, so we need collaborations with industry to do that, and that provides feedback for our materials research. The initiative may foster more of these interdisciplinary collaborations, and I think that’s key to moving materials technology and manufacturing forward.
Talk about your research. What, simply, do you study?

I use computational modeling to understand and predict materials properties for a wide range of applications. By solving the fundamental quantum mechanical equations that describe atomic interactions, I can predict how atoms will behave with very limited experimental input. In terms of applications, a major focus of my work is energy technologies, including fuel cells, batteries and nuclear materials, but I also work in the areas of high pressures and aqueous mineral geoscience and defect properties in semiconductors.

What are the key technical issues you focus on and how do you collaborate with others on campus to develop solutions?

The precise research challenges are specific to different applications, but a theme is the challenge of connecting the length scales of atoms—where I can make very precise predictions—with the much larger length scales of the technologies we use. This is often called the challenge of multiscale modeling. I generally bridge scales using thermodynamic and kinetic theories that are able to connect atomic processes—for example, the energy of a lithium atom in a crystal—to macroscale properties—for example, lithium battery voltages.

I collaborate with many of my UW-Madison colleagues to bring the interdisciplinary skills needed to solve complex problems. For example, I work with a wonderful team (Chemistry Professor Robert Hammers and Associate Professor Mahesh Mahanthappa, and Chemical Engineering Professor Tom Kuech) with skills in electrochemistry, coatings and polymer chemistry to try to understand how to improve the performance of lithium batteries. I am also part of the UW-Madison Materials Research Science and Engineering Center integrated computational group. Led by Materials Science and Engineering Associate Professor Iztok Subač, this group brings together modelers from all over campus with complimentary simulation skills.

What are some future opportunities or challenges in your research area?

Perhaps the most exciting opportunity to me right now is the recent advances in “first-principles” prediction, in which one can solve the fundamental quantum mechanical equations describing electrons and atoms to predict their properties without experiments. Such first-principles methods are now robust enough to take advantage of the full power of modern computers, which creates an unprecedented ability to generate valuable materials data. It is no exaggeration to say that for some properties, first-principles calculations can now produce, in only a few years, more data than has been obtained in all of human history. For example, I can predict the stability of compounds and their elastic constants at a rate of dozens a day on a big cluster of computers. However, a key challenge is to connect these first-principles predictions to materials understanding and design. Knowing an elastic constant does not in itself tell me how to make a lighter battery or safer nuclear fuel cladding, but such data can greatly accelerate the design process if we can use it effectively.

What impact, both technically and in application, do you think your work has for the state and the nation?

In Wisconsin, the United States and the world, we face an unprecedented energy challenge to use our carbon fuels more efficiently and develop non-carbon-emitting energy resources. Multiscale materials modeling, grounded in the ability to predict new properties from first-principles atomic calculations, can help us solve these challenges. In my group, we are searching for active catalysts for fuel cells, more radiation-resistant materials for nuclear reactors, and more stable electrodes for lithium batteries, all of which can help drive new energy technologies. We are also developing tools to automate steps that can accelerate materials research. For example, I am working with Associate Professor Paul Juras to integrate optimization methods, atomistic modeling and experimental data to enable the computer to automatically extract the complex structures of amorphous metals. This type of automation will enable researchers to solve materials science problems faster, thereby increasing the rate of development of new materials technologies.

Tell us about what you find promising about the federal Materials Genome Initiative.

The MGI is committed to enabling modern computation to dramatically accelerate development of new materials for advanced technologies. Perhaps not surprisingly, given my area of research, this focus of the MGI is something I very strongly support. In particular, the MGI is pushing people to create the necessary connections among experiments, simulation and data methods to make transformative advances in materials development. Such interdisciplinary integration is technically difficult and requires researchers to step out of their comfort zone, but holds enormous promise. In fact, the MGI is directly leading to this type of integration on our campus. I am co-director, with Chemical Engineering Professor Tom Kuech, of the Wisconsin Materials Institute (WMI), which was established in 2013 at UW-Madison as part of the university’s role as a partner institution in the MGI. In WMI, we are helping establish relationships among materials researchers, computer scientists, statisticians, mathematicians, bioinformatics experts and others to create integrated approaches to accelerate materials design.

I hope that MGI will help us create a more seamless coupling between experiments, modeling, data and intelligent algorithms. We have not yet arrived at the point where—as on Star Trek—I can just ask my computer to create a new material or device out of thin air. But in the spirit of the MGI, if we can integrate such methods as first-principles design, data mining and optimization algorithms, robot controlled experiments, and 3-D printing, perhaps we are not as far from Star Trek as we might think.
Gopalan joined UW-Madison 10 years ago, as a part of the functional organics cluster hire. She frequently collaborates with scientists across the spectrum, from physics and chemistry to, more recently, biomedical engineering. One current project is looking at how nanostructures help direct the differentiation of stem cells. “That crossover from chemistry all the way to medicine is truly exciting for me,” she says. “We are able to bring in traditional materials science surface characterization tools and very precise quantification tools that biologists don’t use right now. We create new materials platforms as templates to study stem cell behavior, but bring in tools to build a fundamental understanding of cause and effect.”

Gopalan is trained as a chemist, but her choice of materials science allows her to delve into many different scientific worlds. She has dozens of collaborations in her work with the Materials Research Science and Engineering Center (MRSEC) and the Nanoscale Science and Engineering Center (NSEC), which she currently directs. “There are no hard walls, there are no hard boundaries, and that’s what I love about what I do here,” she says.

The Materials Genome Initiative has the potential to be transformative, both nationally and at UW-Madison, Gopalan says—in much the way NSEC and MRSEC have changed the research culture of the campus. “The initiative will bring in computational modeling and theorists to work hand in hand with experimentalists like myself,” she says. “Much of the theory has lagged behind the experimental side, in terms of narrowing down the experimental parameters and creating a more predictive role.”

Bringing nature’s complexity to polymer synthesis

PADMA GOPALAN
Associate professor, materials science and engineering
Director, Nanoscale Science and Engineering Center

Padma Gopalan’s research focuses on designing, synthesizing and characterizing new types of polymers with the ability to self-assemble into a wide range of useful nanostructures. Yet one of her favorite nanostructures comes not from the lab but from nature, on the wings of a blue Morpho butterfly.

Seeing a blue Morpho, one would assume its deep-blue wing color is the result of pigmentation. In fact, the wings contain complex, tree-shaped nanostructures of silica that reflect light and wavelength to create the perfect blue color. Those elegant wings are self-assembled nanostructures in their purest form.

“It’s a never-ending quest for synthetic chemists like me to see how much of that type of nature we can re-create in the synthetic world,” says Gopalan, an associate professor of materials science and engineering. “The complexity is at a whole different level in nature compared to the synthetic systems we make.”

Gopalan’s research team works on synthesizing self-assembled nanostructures in polymeric materials anywhere in scale from 100-plus nanometers to sub-10 nanometers. These incredibly precise structures have applications in microelectronics, photonics, energy and biomanufacturing, but the key to their usefulness is control and replication across a larger scale.

“What we are looking for are the underlying rules of self-assembly,” Gopalan says. “How does the chemical structure influence the self-assembly, and how does the self-assembly influence the morphology and the macroscopic properties?”

Part of the fascination of Gopalan’s work is in the materials themselves, which are classes of block copolymers. These are comprised of chemical tandems that act like oil and water connected together, and the resulting thermodynamic factors govern the self-assembly process. “The information for self-assembly is already encoded in the chemical structure of the polymers we make,” she says.

That’s where the polymer design aspect comes into play in Gopalan’s lab. Can they mix in the right components, in the right portions, so that they self-assemble to produce valuable electronic, optical or magnetic properties? Gopalan has a number of patents through the Wisconsin Alumni Research Foundation, including a few that have recently been licensed by the semiconductor industry.
tuals of the future. “We’re only 50 miles away, and the university doesn’t really know who Oshkosh Corporation is,” says Tom Quigley (BSME ’94), vice president of engineering for the company’s fire and emergency division.

Quigley hopes to convince more Badgers to work at Pierce and live in Wisconsin for the long haul, not just as a stepping stone. He’d also like to partner with engineering students who can provide a fresh perspective on the design of Pierce products.

Pierce and Bower teamed up in 2012 to present some of Bower’s ideas that we’re looking for,” says Clouse. “They were trying to use a computer model to analyze the structure before they really understood the structure. That’s when I said, ‘Wait, back up.’”

Bower reinforced that workplace experience by taking the students up to Oshkosh for a project presentation to the engineering school’s dean. “They gave a presentation to about 15 of the engineers at Pierce, and then the engineers asked questions at them;” he says.

Ultimately, the consensus among Pierce engineers was that UW-Madison students are more than capable of delivering strong results and a highly professional project update presentation: “We’re trying to verify that, by partnering with the university, we would be able to get quality work,” Clouse says. “The team certainly exceeded my expectations for the project.”

Beyond the Bucky Wagon: Pierce seeks to strengthen ties with engineering students

and were forced to revisit some fundamentals. “Hand calculations were necessary for this project,” Clouse says. “They were trying to use a computer model to analyze the structure before they really understood the structure.”

The students had a counternarrative advantage in the design process, says Kathryn Clouse, the senior design engineer at Pierce who worked most directly with them. Because they didn’t have a sense of “what the industry is expecting to see,” they were able to be bolder with their ideas. “They said, ‘This isn’t necessary structurally. Can we take it out?’” Clouse says. Ultimately, we wound up having them leave some things in, but those are the types of ideas that we were looking for; and that’s something in our back pocket for the future.

The students, for their part, got a sense of what it’s like to do an engineering project in the workplace, and they were able to be bolder with their ideas. “They said, ‘This isn’t necessary structurally. Can we take it out?’” Clouse says. “Ultimately, we wound up having them leave some things in, but those are the types of ideas that we were looking for; and that’s something in our back pocket for the future.”

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Beyond the Bucky Wagon: Pierce seeks to strengthen ties with engineering students

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Geological engineers rock: Interdisciplinary alums solid in Industry

It’s a unique, interdisciplinary degree that prepares students to work in industries ranging from energy and environmental remediation to mining, excavation and construction.

At UW-Madison, geological engineering undergraduates receive not only rigorous training in mechanics and in fundamental engineering, but also a strong geoscience education. "What industry people tell me is that our geological engineers understand all of these things and are able to do them well," says Wisconsin Distinguished Professor Craig Benson, chair both of geological engineering and civil and environmental engineering. "They really like our geological engineers and want more of them."

Take, for example, Barr Engineering, a Minneapolis-based engineering and environmental consulting company that serves such industries as fuels, power, mining, manufacturing and natural resources. "We specifically recruit from the UW-Madison geological engineering program for interns and full-time employees," says Sara Daftin (BSGGE '99), a senior geological engineer at Barr who manages personnel for a multidisciplinary department of approximately 170 people. "I saw the value of the degree and I know how it really prepared me for my career in consulting—and it's easy for me to make the pitch for us to target geological engineering students." One aspect of the UW-Madison geological engineering undergraduate educational program that differentiates it from its peers is the rigor of its core curriculum. Courses are design-centric and application-driven and immerse students in real-world principles in real projects," says Benson. "They get experience from both sides and that provides them with their well-roundedness." That breadth and flexibility serve geological engineering graduates well at Shell Exploration & Production Co., says David Schaper (MSE '12), a petrophysical engineer whose unit includes a mix of geological engineers, mechanical engineers, chemical engineers, geologists, physicists and others. "For petrophysical engineering, there’s not a degree," says Schaper, who serves on the UW-Madison geological engineering board of visitors. "We tend to bring people in from various backgrounds and then do lots of classroom and on-the-job training. I think it’s an easier transition for geological engineers because they understand both sides of the equation. They come in with a very strong geology background.” Beyond the UW-Madison geological engineering core curriculum, courses are design centered and application-driven and immersed students in hands-on laboratory, fieldwork and research experiences, including geological mapping, assessment of natural landfill capping, or a deep geothermal well system. "When I’m talking to the students, I’m amazed at the diversity of projects they’re working on," says Schaper. "And students are hearing about each others’ projects and learning from that.” Faculty work in applied areas and, in the case of engineering, also are licensed professional engineers. "There’s a real practice orientation in our design courses so that students get fundamental engineering science and pragmatic application of real-world principles in real projects," says Benson. In the end, students learn in one 125-credit program, bachelor’s degrees in geological engineering and in geology and geophysics. They also leave UW-Madison prepared to contribute at high levels in a variety of industries and positions, but also able to learn the basics that will enable them to succeed in those settings. "If you have the background in both of those very different focus areas helps them to be able to relate to many different people, and we see the value in that," says Daftin. "A science degree prepares you to look at data, while engineering is focused on problem solving. A geological engineer understands those two critical components, and as a result, can develop the best solutions for our clients.” Interdisciplinary Degree Programs

In addition to its nine departments, the UW-Madison College of Engineering offers six degree-granting programs with strong emphasis on interdisciplinary studies. Participating UW-Madison faculty members are based in these schools and colleges: College of Agricultural and Life Sciences, College of Engineering, College of Letters and Science, Wisconsin School of Business, School of Education, School of Nursing, School of Medicine and Public Health, School of Pharmacy

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Seated at the intersection of an academic department and two research institutes, Assistant Professor Jeremy Rogers finds himself in what he calls a perfect opportunity.

A co-investigator in the UW-Madison Laboratory for Optical and Computational Instrumentation (LOCI) and a member of the McPherson Eye Research Institute, Rogers welcomes the highs that come from collaboration. “The institutes are really interesting because they bring people together from very different backgrounds,” he says. “You get everybody together and it’s really amazing what we can do.” The institutes really facilitate that,” Rogers adds.

Rogers comes to UW-Madison after earning a PhD in optics from the University of Arizona and doing a postdoc at Northwestern. While at Northwestern, Rogers began researching a process that will screen for disease using specialized optics inside an endoscope. Rogers’ research stems from a phenomenon called coherent backscattering, where he measures the intensity of light waves reflected off individual cells.

Like many good lab discoveries, this one came about by accident. While trying to engineer healthy heart valves, Associate Professor Kristyn Masters was discouraged that cells her student was culturing were forming nasty-looking nodules. These nodules can be present in disease and made the sample cells impossible to use for their intended purpose. “It was very frustrating,” Masters says. “One day, it just sort of clicked in my head: We’re looking for a surrogate site within the body, using specialized optics inside an endoscope. Rogers’ research stems from a phenomenon called coherent backscattering, where he measures the intensity of light waves reflected off individual cells.

...
For Platypus Technologies, liquid crystals fit the bill

In 1999, researchers in New York City identified the first case of West Nile virus, which over the next five years spread across the country. Infected mosquitoes transmit the virus into sleeping, amphibians, and some mammals—including humans—and into more than 100 species of birds, which “frost” the virus.

At the time, identifying the disease in dead birds was cumbersome and time-consuming because existing tools required a different diagnostic reagent to detect antibodies in each species. “We developed a way to use liquid crystal to report antibodies to West Nile virus in a way that was species-agnostic,” says John T. and Magdalen L. Sobota Professor Nicholas Abbott, who with Christopher Murphy and Barbara Israel (then both faculty in the School of Veterinary Medicine), co-founded Platypus Technologies in 2000 to commercialize the technology.

Liquid crystals, which are materials that combine properties of solids and liquid, are known to change their ordering and optical appearance in response to stimuli such as temperature or electrical fields. As a result, they are useful in everything from cell phone displays to environmental sensors.

Over the past 13 years, the Platypus founders have developed a variety of liquid crystal-based technologies for protein and cell-based studies and environmental monitoring. In August 2013, the company debuted a wearable sensing badge that allows, for example, workers in an oil field to automatically monitor their exposure to hydrogen sulfide in real time. The U.S. Occupational Safety and Health Administration regulates worker exposure to the chemical, which is a highly toxic, flammable gas—and currently, hydrogen sulfide sample gathered in the workplace are analyzed days later in a laboratory.

The badge is somewhat like a detector worn by radiological workers: “A worker can read it at the end of a shift,” says Abbott.

In addition to its own technologies, the company also licenses several UW-Madison patents from the Wisconsin Alumni Research Foundation. And, says Abbott, one key to long-term success, simply is persistence. “It takes a long time to translate a university discovery into a technology,” he says. “We’ve been at it more than 10 years.”

When Ekaterine and Michel Boudart Professor James Dumesic looks at a dried corn stalk, he sees the energy embedded within it. For years, Dumesic and his colleagues have made major contributions to the science and process of converting plant wastes into transportation fuel.

And while renewable fuels historically have been the end goal, the researchers now are focusing on a suite of useful chemicals they can create throughout the conversion process. “The biosolvents area has moved from focusing on biofuels to now looking at biochemicals, and we have some very good technologies for making these furan-based chemicals,” says Dumesic.

Recently, for example, his group demonstrated an efficient process for simultaneously converting two differing components of plant biomass into either furfural or levulinic acid, which are valuable non-petroleum-based commodity chemicals. In the United States, furfural is used to manufacture everything from plastics to pesticides—yet manufacturers import it almost exclusively from China—and levulinic acid is a value-added biochemical used to make solvents, monomers for the polymer industry, and fuel additives.

New, Dumesic and colleagues at Iowa State University have founded Biocatalytics to take advantage of sustainable processes they have developed for converting plant sugars into furan derivatives. The company aims to be a reliable U.S. source for such chemicals.

The team, which includes Brent Shanks, an Iowa State professor of chemical and biological engineering; Peter Keeling, the Iowa State National Science Foundation Engineering Research Center for Biobased Chemicals innovation director; and CEO Victoria Barankova, received grants from the NSF Small Business Innovation Research program and the state of Iowa. Currently, the group is raising funds to conduct pilot testing and is seeking venture capital funding for a pilot plant.

Growth countries is an effort to strengthen disciplines that align with its strategic goals. Dow Chemical Company has invested $4.5 million over five years in research at UW-Madison. Part of a broader funding program Dow launched in 2012 at 11 universities, the initiative combines expertise in engineering and chemistry in a quest for innovative, sustainable solutions in such areas as chemical production and energy generation and storage.

The company’s motivation to support university partnerships is driven by its interest in helping those institutions stay strong in disciplines important to Dow based in part on the strength of the UW-Madison chemistry and chemical engineering programs; the company established its partnership with the university in late 2011. “It’s about technology and talent,” says Lou Graziano, director of university R&D for Dow Sustainable Technologies & Innovation Sourcing.

On the university side, bright, motivated undergraduates conduct research alongside graduate students. Through this partnership, they gain experience interacting with an industrial partner and potential employer. Several UW-Madison faculty teams are collaborating on research with Dow scientists, who invest at least a quarter of their time in projects that include studying new materials and new methods for coating battery components; using catalysts to convert natural gas-derived raw materials into higher-value chemicals; investigating catalytic systems for green chemical production; developing novel membrane reactors for safer, more controllable reaction conditions; and improving solar power generation through advanced collectors, thermal storage and system design. “Welt love to see some innovative solutions that have commercial relevance for us,” says Graziano. “But our primary goal is to build a sustained, mutually beneficial relationship with Wisconsin through collaboration in the disciplines that are essential to continued success.”
Peel back the outer layers of a skyscraper built in an area vulnerable to earthquakes and you’ll find a tangle of steel-reinforced concrete beams that span doors, windows and other openings in the structure’s many supporting walls.

Those coupling beams play a critical role in helping a skyscraper withstand the effects of an earthquake. Yet, says structural engineer Craig Kopczynski, coupling beams reinforced with fiber are cost-effective and difficult to build.

Kopczynski’s Bellevue, Washington, structural engineering firm designs high-rise buildings in sailingly active areas on the west coast. Nearly a decade ago, he began exploring ways to simplify coupling beam construction. Along the way, he met C.K. Pfeiffer. “We thought it was good enough to merit a detailed review. “Data from a well-known, well-respected independent industry expert was valuable in gaining acceptance from engineers, owners and regulators,” says Athanassopoulos. “This year, we are seeing the new products gain some traction, with important project wins in North America and overseas.”

For building owners, IPD is A-OK

“I believe, truly, particularly in tough economic times. We’re a nation of cost-conscious consumers seeking to get the biggest bang for our buck. However, in many situations, the lowest price doesn’t automatically guarantee a high-quality product or a high level of customer satisfaction. Take, for example, the commercial construction industry. “Clients will look at a project and say, ‘We thought we had a great contract, engineer, architect, contractor—and we still had problems. What’s at fault?’” says Boldt, who is chief executive officer of The Boldt Company. “As we look at all these things, we say, ‘How can this be improved?’”

In America,” says Tom Boldt, “we revel in low price.” It’s true, particularly in tough economic times. “We’re a nation of cost-conscious consumers seeking to get the biggest bang for our buck. However, in many situations, the lowest price doesn’t automatically guarantee a high-quality product or a high level of customer satisfaction. Take, for example, the commercial construction industry. “Clients will look at a project and say, ‘We thought we had a great contract, engineer, architect, contractor—and we still had problems. What’s at fault?’”

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That’s where Professor Alex Hanna comes in. Drawing on extensive connections in the construction industry, Hanna and his collaborators collected and analyzed data about virtually every IPD project in the nation. In addition to cost of project and time to completion, they also measured factors such as quality, worker safety, ease of communication and customer satisfaction, among others.

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A ‘SMART’ MOVE FOR ELECTRONICS

Professor B. Ross Barbour hopes his current National Science Foundation-funded research will build a bridge between control theorists and financial scholars. Barbour stands with notions that day by day the predictive statistical approach by which financial scholars tend to swerve.

“Instead of using statistics and saying, ‘Well, something worked in the past,’ I say, ‘No, here’s a theoretical basis that doesn’t depend on the past or future,”’ Barbour says.

Enter control theory, a field of applied mathematics that has addressed the control and stability of systems ranging from physical machinery to economics. Barbour is particularly interested in “robustness”—the ability of a machinery to economics. Barmish is particularly interested in “robustness”—the ability of a system or approach to hold up under uncertainty and disturbances. It’s easy to see, then, why he’d be drawn to the volatile and uncertain world of financial markets.

The day-to-day work of his current National Science Foundation—funded research involves running simulations of what returns a control-theory approach might yield with certain stocks. Barbour models a trader’s decisions as a sort of feedback loop, responding to returns on investment with patterns determined by various algorithms. To simplify it greatly, sometimes this can mean investing more money as returns increase, or investing less as returns decrease.

The IEEE Control Systems Society has awarded Barbour the 2013 IEEE Section Lecture Prize, which recognizes distinguished contributions to control systems science or engineering. In his abstract for the lecture—which he’ll deliver in December 2013 at the IEEE Conference on Decision and Control in Florence, Italy—he boldly proposes a new theoretical framework for stock trading.

Barbour’s ultimate goal is to give traders nascent stock trading “tools,” he says, but to show that control theory can explain strategies that previously have been studied only in a statistical framework. “My accountability has to be to the application area,” he says.

A control theorist crashes the market

Closing the loop on big data … one beer at a time

Computers serve as powerful tools for categorizing, displaying and searching data, but they aren’t the only medium for big data. “We really need people to interact with the machines to make them work well,” says University of Wisconsin-Madison Professor Rob Nowak.

Unlike machines, people work at a finite speed and at rising costs. Nowak wants to improve interactive systems that can optimize the performance of both humans and machines tackling big data problems together.

Typically, human experts—people who categorize data—will receive a large, random dataset to label. The computer then looks at those labels to build a basis of comparison for labeling new data in the future. Nowak suggests the model should be flipped. “This machine gets the set of examples, then asks a human for further classification of a specific set of data that it might find confusing,” he says.

With support from the National Science Foundation and Air Force Office of Scientific Research, Nowak has been exploring an active learning model, in which the machine receives all the data up front. Initially, the machine makes very poor predictions, improving as a human expert supplies clarifications for confusing data.

To explore these sorts of human-machine interactions, Nowak and his student Kevin Jamieson have applied the idea to a technology that’s a natural fit in Wisconsin—an iOS app that can predict which craft beers a user will prefer. Using data gleaned from searching through thousands of beer reviews on RateBeer.com, the researchers’ algorithm presents the user with two beer options, then has them choose their preference, slowly winnowing the options down toward to the user’s ideal beer.

“There’s no research to be done on the infrastructure side,” he says. “We have big data infrastructure. What we don’t understand is how to optimally yoke humans and machines together in big data analyses.”

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In Wisconsin, cold-spray coating knowledge is a hot commodity

ask in the mid-1990s, Fisher Barton founder Richard Wilkey (BSMetE ’59) was looking for coatings to extend the life of his lawn-mower blades. His Wisconsin-based company manufactured for help; he looked to

Frank Worzel, then a professor of metallurgical and materials engineering, and Worzel’s master’s student Bill Lanning (BSMAE ’84, MSMAE ’86), who was seeking research funding.

Ultimately, the project was so successful that Wilkey spun the coatings startup and make it work well at Princeton,” he says.

“The more we learn through simulation, the more we can understand and optimize noninductive effects that span spatial and temporal scales and involve a phenomenon called magnetohydrodynamic activity—essentially, how electrical and magnetic fields interact to move, or ‘drive,’ the plasma.

Sovinec is among the developers of the NIMROD code for solving magnetohydrodynamic equations. With support from the U.S. Department of Energy, he and O’Bryan used the code to conduct numerical simulations of the Pegasus startup technique on computers both at UW-Madison and at Lawrence Berkeley National Laboratory.

Their simulations reproduced the initial behavior in which the current in Pegasus follows the vacuum magnetic field set by the experiments’ external magnetic coils. It snakes up a helical path—somewhat like a loosely coiled spring. The simulations also show how these passars interact with each other as the current increases, the plasma double back around, and fills itself in.

The research, says Sovinec, will help Pegasus scientists implement the technology on a larger scale—the National Spherical Torus Experiment Tokamak at Princeton Plasma Physics Laboratory. “The more we learn through simulation, the more we can understand and optimize noninductive startup and make it work well at Princeton,” he says.

While a laptop computer failure due to that warming and cooling might be personally catastrophic, the effects of thermal expansion are magnified in such aerospace applications as satellites or space telescopes, which don’t enjoy any expansion I want,” says Lakes. That was 1996.

Since then, other researchers have followed up, and recently, the U.S. Defense Advanced Research Projects Agency announced plans to build on the idea, particularly for applications in space.

Now, using common materials such as steel, aluminum and invar, Lakes and master’s student Jeremy Lehman have developed lattices that are tuned to exactly zero expansion, yet are optimized to be as stiff and strong as possible.

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It was a sweltering day on Long Island, and young Red Lakes and his family were stuck in the middle of a traffic jam. Up the road, there was a drawbridge. Its two halves had expanded due to the heat and, instead of closing properly, the pieces overlapped.

“Cold spray does neat things other processes can’t do,” says Lanning. “Cold spray is more like friction welding of the particles on each other. So, you don’t have high-temperature reactions, and these are applications where that can be very important.”

UW-Madison is the only U.S. university with a high-pressure cold-spray system, which Distinguished Professor Kumar Sridharan acquired through a U.S. Department of Defense instrumentation grant. One of a handful of U.S. cold spray coating experts, Sridharan and his students currently are using the system to conduct cold-spray research for the U.S. Navy and for accident-tolerant nuclear reactor cladings.

Now also—as Wilkey did more than two decades ago—Lanning and TST technology director Daryl Crammer have turned to UW-Madison to explore cold-spray applications. They are collaborating with Sridharan on research that could help them decide if a flyby into cold spray coating technology is a worthwhile pursuit for the company. With a UW System applied research grant, they’re studying the technique for increasing the durability and corrosion resistance of high-density electronics for the semiconductor industry. “The collaboration can help us figure out if we can make a business investment into the technology,” says Lanning. “It’s the kind of thing that will help us keep up with our competitors.”
A new opportunity for P.E.’s to talk about ethics

For a state department of transportation, completing a construction project isn’t simply a matter of dropping a final check in the mail to the contractor.

Rather, the highly administrative closeout process includes such tasks as ensuring the project objectives have been met, auditing labor and payroll records, and reviewing and reconciling material costs and material quantities, among others. For the Wisconsin Department of Transportation, it was a process that could take as long as 10 months—and one the department hoped to improve.

The DOT received a unique opportunity to standardize and streamline the construction closeout process across its eight regional offices in July 2012, when the Wisconsin governor directed state agencies to identify ways to operate more efficiently. DOT officials contacted Director of Corporate Education Carl Vieth and Assistant Faculty Associate Jeff Oelke, a lean process improvement expert, for help.

Working closely with staff in each of the eight regional DOT offices, Oelke and PhD student Dave Miller developed a glossary of terminology and adopted each office’s best practices to optimize and standardize the closeout process across the state. The group also defined the roles and responsibilities of people involved in the process, created a flowchart, improved software that tracks the progress of a construction project, and updated procedures in the DOT standard specifications and construction and materials manual. Now members of any closeout team in any regional office can network, share advice and problem-solve together.

Already, the new team-based closeout approach has had a positive effect on staff morale. “This teaming has generated a greater understanding and a recognition of how important everyone is to the successful completion of our projects and our work,” says Beth Cannestra, who directs DOT project closeouts.

Throughout the project, Oelke and Miller mentored DOT staff, giving them the knowledge and tools to lead future process improvement projects. And in the long run, both the DOT and contractors will benefit. “We will have project issues resolved in the field and at a time when they are best resolved,” says Cannestra. “Contract payments will be made closer to the time of the work and encumbered funds that are not needed will be freed and resolved,” says Cannestra. “Contract payments will be made closer to the time of the work and encumbered funds that are not needed will be freed and resolved,” says Cannestra.
McLay is an expert in operations research, which she defines as “the discipline of applying advanced analytical methods to help make better decisions.” Operations research received a major awareness boost after Professor Emeritus Rajan Suri, wanted to show that U.S. manufacturers could compete against manufacturers worldwide regardless of labor costs. And current QRM Center director, Professor Ananth Krishnamurthy, has done just that over the past 20 years, helping more than 200 companies improve their bottom lines by shoring up inefficiencies and reducing lead times from assembly to delivery.

The QRM Center as a partnership between companies, faculty and students at UW-Madison, Suri could not be prouder of the center’s successes. “We’ve not only preserved manufacturing jobs,” he says, “but we’ve grown manufacturing jobs in our member companies in the face of stiff global competition.”

While the QRM Center is focused on company-wide strategies, the UW-EBC applies a holistic view of a business to its member companies from diverse industries across 160, its founder, Professor Raj Wiegmann, realized that UW-Madison was uniquely positioned to provide a trusted, non-commercial environment where companies can explore, learn about, and examine different business technologies and strategies. Global competition and accelerating advances in technology will require companies to be increasingly nimble, Wiegmann says. “The cross-pollination of best practices and innovative ideas, within and across industry sectors, through UW-EBC’s unique collaborative learning community is a powerful mechanism to amplify the Wisconsin Idea and to enhance the competitiveness of U.S. companies.”
How waste wood works for forests

At first glance, they may look lush and green, but many of the nation’s forests also are check full of trash—often, invasive species and diseases transmitting biomass—just waiting for a spark. “One of the reasons wildfires are so catastrophic is that many forests are unhealthy and there’s a lot of excess biomass in the forest,” says Joshua Jakes. “By creating new and expanded markets for the low-value biomass, we aim to provide economic incentives for people to come in and selectively remove the hazardous biomass—which will simultaneously accelerate forest restoration and create jobs in the U.S. forest products industry.”

A materials research engineer at the U.S. Forest Products Laboratory in Madison, Jakes (BSChE ’05, MSAMP ’07, PHD ’10) is using advanced research tools to extend the value of that “waste” wood—for example, in developing more effective bio-derived adhesives for engineered products such as plywood or particle board.

When “glued” wood gets wet, it swells and causes adhesive bonds to fail. In collaboration with Professor Don Stone and PhD student Nayomi Plaza, Jakes is studying, at the cellular level, how these failures occur.

One challenge is that researchers still do not have a clear understanding of the nanostructure of wood. “It’s a very old problem, but there are new techniques for looking at it,” says Stone. Jakes himself has developed nanoindentation methods that allow researchers to measure the mechanical properties of individual wood cell walls. And working at Argonne National Laboratory, he developed advanced microscopy techniques that allow him to correlate changes in mechanical properties with the amount of adhesive infiltration at the cell-wall level.

He and Plaza have created unique actuators that allow them to study moisture-induced swelling forces where adhesives bond to wood cells. Plaza is conducting research at Oak Ridge National Laboratory, where she has developed methods and customized tools that enable her to use neutron scattering to study how unmodified and modified wood swells at different moisture levels.

The big picture, says Jakes, is restoring the nation’s forests and maintaining their health for generations to come. “And in my area, we’re using advanced materials research to try to understand and develop better wood adhesives and to improve the durability of forest products,” he says.

Future looks bright for carbon nanotube solar cells

In an approach that could challenge silicon as the predominant photovoltaic cell material, UW-Madison materials engineers have developed an inexpensive solar cell that exploits carbon nanotubes to absorb and convert energy from the sun. The advance could lead to solar panels just as efficient, but much less expensive to manufacture, than current panels.

The proof-of-concept carbon nanotube solar cell can convert nearly 75 percent of the light it absorbs into electricity, says Assistant Professor Michael Arnold (right). “We’ve made a really fundamental leap step in demonstrating that it will be possible to use these new carbon nanotube materials for solar cells one day,” he says.

Silicon is abundant and an efficient solar energy gatherer, yet is expensive to process and manufacture into solar panels. As a result, researchers are studying alternative materials—among them, carbon nanotubes. The thin spaghetti-like tubes are easy and inexpensive to manufacture, stable and durable, and are both good light absorbers and electrical conductors.

Building on a half-decade of research—including foundational studies by PhD student Dominik Blind—Arnold and PhD student Matthew Shea developed a solar cell that uses carbon nanotubes to collect light and convert it to electricity. Their proof-of-concept solar cell is an ultrathin sheet, or film, of carbon nanotube-laden paper another thin sheet of a material called buckytafelene, or Bt. The nanotubes absorb the bulk of the sunlight and retain the positive charge, while the Bt draws the negative charge.

In contrast with the 15-percent average efficiency of conventional silicon solar cells, the proof of concept is 1 percent efficient. The next step in boosting that efficiency already is underway. The researchers now are focusing on augmenting the thickness of the carbon nanotube thin film from a mere 5 nanometers to at least 200–500 nanometers, according to their theoretical models, ultimately could put the power conversion efficiency of their solar cells in line with that of silicon cells. “What our work shows is that you will be able to get as high efficiency as silicon eventually, and that’s why we’re excited,” says Arnold, who received funding for the research from the Army Research Office.

Advancing industry through materials research and education

As a materials research engineer at the U.S. Forest Products Laboratory in Madison, Jakes (BSChE ’05, MSAMP ’07, PHD ’10) is using advanced research tools to extend the value of that “waste” wood—for example, in developing more effective bio-derived adhesives for engineered products such as plywood or particle board.

Through membership in the 8-year-old consortium, companies also can use a variety of specialized facilities, such as a focused ion beam, a Zeiss confocal scanning microscope, and an atomic force microscope for imaging biological samples, among many other instruments for imaging, characterization and analysis. “We have facilities these companies don’t have,” says McCarthy, who oversees the UW-Madison Materials Science Center, Soft Materials Center and Grant Corps. “We have approximately 130 principal investigators who work with materials in diverse fields, about 60 grad students and postdocs, and 30 companies using these facilities. With all of the materials research and characterization capability that’s going on in these laboratories, we have a broad capability to offer state and national companies—many of which don’t have their own R&D, but should know about.”
Ebullient uses an environmentally safe dielectric fluid that evaporates at low temperatures and then re-condenses as it flows through processing units. This idea evolved from long-term research project-to-business idea in late 2011, when Shedd and his students began experimenting with 3-D printers in the Wisconsin Institute for Discovery. The printers allowed Shedd to create components optimized for the system. "Without then, I probably never would have thought of starting a company," Shedd says.

The project also has advanced with help of the Wisconsin Alumni Research Foundation and an Innovation and Economic Development grant from the UW-Madison Graduate School.

In summer 2013, Shedd and graduate students Brett Lindeman and Robert Buschman installed a prototype Bulliant system on a bank of about 20 computers in Engineering Hall. Shedd says this alone will save UW-Madison about $2,500 per year in cooling costs.

Ebullient’s ideal hot clients will be companies that run small- to mid-size data centers. These could be medical records companies, video-delivery companies, large law firms, hospitals, and universities, obviously," Shedd says. "We're hoping Wisconsin and northern Illinois will provide Bulliant's first clients and investors."

"We're looking at investors who are interested in investing in Wisconsin--in people as much as the technology," he says.
FACTS AND FIGURES

The College of Engineering is among the most innovative and consistently highly ranked U.S. colleges of engineering. We are internationally renowned for our leading-edge research and widely recognized for our ability to transfer technological advances into real-world applications via strategic partnerships with industry. Through our world-class undergraduate, graduate- and professional-level educational programs, we enable students to develop as thoughtful, ethical leaders and to acquire the technical expertise they need to tackle complex global engineering challenges.

State, national and global impact

- College inventors disclosed 235 inventions to the Wisconsin Alumni Research Foundation in 2010–2011 fiscal year.
- College faculty, staff and students have bagged 22 consecutive years of 100 or more patent disclosures.
- The college offers 44 research centers in a broad range of areas.
- More than 300 companies, mostly from the Midwest, participate in one or more of 15 industrial consortia, on topics of strategic importance such as power engineering, small engines, a business and advanced manufacturing.
- In the past 30 years, the college has produced more than 80 spinoff and startup companies based on faculty, staff and student innovations.
- Startup companies and technology transfer from the college strengthen the Wisconsin economy. Examples include SHINE Medical Tech, which is building an $85 million manufacturing facility in Janesville that will employ 120 people; and Virent Energy Systems, which is experiencing strong growth in the U.S. biofuels and jet fuel markets.
- The college communicates the value of engineering to Wisconsin middle schools—a time when students make key decisions about their academic future. Society’s Grand Challenges for Engineering incorporates engineering modules into Wisconsin middle school science courses, while the summer Camp Badger for Teachers helps instructors integrate core engineering ideas into classes.
- A strong percentage of UW-Madison engineering graduates stay in Wisconsin and help the state economy. In 2010–11, more than 60 percent of engineering graduates obtained jobs in Wisconsin.

By the numbers: 2012–2013

The 2012 total does not include $2.1 million in Wisconsin Energy Institute expenditures.

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STUDENT ACHIEVEMENTS

Student success

- College graduation rates for students who enter a degree program (typically by sophomore year) are 85 percent or higher for all 12 engineering degree-granting programs.
- More than 95 percent of December 2012 graduates are either employed in the engineering field (80 percent) or pursuing graduate education (15 percent).
- 85 percent of all engineering majors participate in either an internship or eight-month co-op experience.
- The college has 58 registered student organizations that provide engineers a wide variety of opportunities for involvement.
- The college fosters student innovation and entrepreneurship through major competitions, including the 20-year-old Innovation Days Prize, the Qualcomm Wireless Prize and the Wisconsin Energy and Sustainability Challenge.
- The college Engineers Without Borders chapter is the largest in the country, with active or recent projects in El Salvador, Haiti, Kenya and Rwanda.
- Competitive teams have a track record of success, including hybrid vehicles (six national titles since 1993), clean snowmobile (four national titles in the last eight years), concrete canoe (six national titles) and steel bridge (five top-10 finishes since 2002).

International opportunities

- 144—Students who studied abroad, for academic credit, in fall 2013 and spring and summer 2013
- 30—Countries they visited

Internships, co-ops and career opportunities

- 160 students on co-op—fall 2012
- 140 students on co-op—spring 2013
- 249 students on co-op—summer 2013
- 545 students on internships—summer 2013
- In two career fairs, thousands of students talked with recruiters from more than 350 local, state and national corporations.

Engineering Professional Development Impact

- 25—Technical and professional subject areas ranging from the basics to high-level topics
- 75—Faculty and support staff
- 249—Course instructors
- 351—Short courses per year
- In 2012, students who participated in EPD continuing-education courses came from 50 U.S. states, Washington, D.C., Puerto Rico, and 87 countries around the world.
- 7—Distance-delivered master’s degrees
- 11—Certificate series

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Snapshots of some unique college materials research tools and facilities

1. The FEI Titan aberration-corrected scanning transmission electron microscope
2. The TF 30 transmission electron microscope
3. An atomic force microscope for biological and soft materials.
4. An imaging x-ray photoelectron spectrometer
5. The wet chemistry bay in the micro-fabrication cleanroom