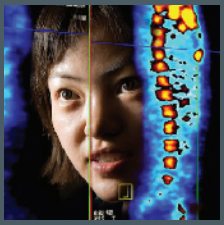

SECRETS OF THE HEART

Computer graphics automate, improve the interpretation of medical scans

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QUALIFIED AND QUANTIFIABLE

New M.S. program applies math and engineering to the complexities of finance and investment

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A FOCUS ON LEHIGH ENGINEERING • VOLUME 2, 2008

CREATIVE ENERGIES

FROM HYDROGEN TO FUSION TO HYDRATES TO CLEAN COAL, RESEARCHERS WORK FOR A GREENER, BRIGHTER FUTURE.

SEE PAGES 12–21

LEHIGH UNIVERSITY®

P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

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VOLUME 2, 2008

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LEHIGH UNIVERSITY®

CHALLENGING GREAT MINDS...INSPIRING GREAT IMAGINATIONS

Balancing energy and the environment

Welcome to the fourth issue of* Resolve*, a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

The unprecedented surge in global energy consumption and increased awareness of climate change have pushed energy and the environment to the forefront of public debate. Over the next quarter century, it is estimated that some *$20 trillion* in capital investment will be required to meet worldwide energy demand. For engineers, satisfying that demand while protecting the environment is a grand challenge that will shape research and educational priorities for decades to come.

Recently, Lehigh held a two-day workshop that sought to define a balance between the competing demands of energy and the environment. The event drew national experts from Lehigh's faculty and from among our many academic, industrial and government partners who work in energy-related fields. One outcome of the workshop was a more rigorous articulation than ever before of Lehigh's energy research agenda.

The agenda includes the development of efficient, clean and sustainable energy sources that support global economic development. It also addresses issues related to energy supply, delivery, consumption and environmental impact, as well as social, political and economic ramifications. The energy research agenda draws upon the strengths of all three clusters of research expertise in Lehigh engineering:

Bio: Bio, Environmental and Molecular Engineering
Nano: Nanotechnology and Applications
Systems: Complex Engineering and Information Systems

More specifically, we harness our research strengths in areas such as catalysis, high-performance computing, advanced materials, combustion and chemical kinetics, control systems, and fluid mechanics to solve problems related to energy generation, delivery and usage.

Lehigh's research strength in energy generation is renowned. It includes a wide variety of activities ranging from fusion modeling and simulation to clean coal technology, carbon capture and sequestration, to efficiency improvements and pollution reduction technologies. These are complemented by equally active research in alternative energy sources, with major projects in hydrogen, photovoltaics, and fuel cell and storage technologies.

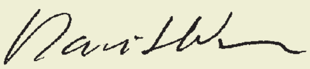
Another side to the energy equation at Lehigh involves energy consumption. In this area, our researchers are engaged in a variety of projects, from the systematic assessment and auditing of industrial energy consumption to the design of high-efficiency motors to a revolutionary approach to LED (light-emitting diode) lighting.

At the core of our energy agenda is a belief in working across disciplines to develop foundational science and technology with broad potential benefit to society. The university's Science, Technology, Environment, Policy & Society Initiative (STEPS) will create a collaborative, multidisciplinary environment that will enable our faculty and students to play a key role in finding innovative solutions to global challenges in the areas of energy and the environment. A key component of the $85 million initiative is a new facility designed to bring together the sciences, engineering and social sciences for collaborative research and education.

We are now in the process of establishing the Energy Systems Engineering Institute (see p. 16), an innovative industry-university partnership that will serve as a center of excellence in education and research for the energy industry. In collaboration with the Electric Power Research Institute (EPRI), the centerpiece of the ESEI is a new Master of Engineering program in energy systems that aims to produce the next generation of energy industry technical leaders.

I hope you enjoy this energy-focused issue of *Resolve* magazine. Please drop me a note to share your thoughts and comments.

"Lehigh's energy research agenda includes the development of efficient, clean, and sustainable energy sources that support global economic development." —S. David Wu



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A "huge breakthrough"

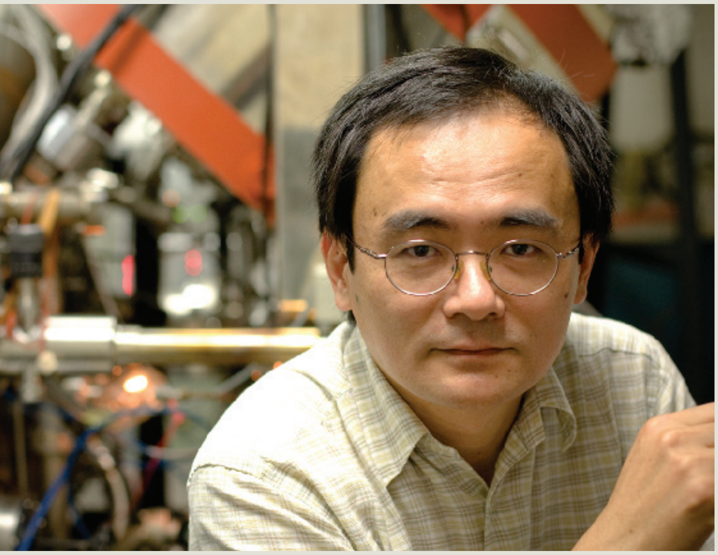
An environmental-cleanup company marketing a Lehigh University nanoparticle technology has earned national recognition from the Association of University Technology Managers (AUTM).

Lehigh Nanotech LLC, which has used iron nanoparticles to remediate heavily polluted sites in six states, was named one of the nation's top 25 technology-collaboration stories by AUTM.

AUTM, an international organization devoted to technology transfer and intellectual-property issues, included a five-page article about Lehigh Nanotech in its annual *Better World Report*.

The nanoparticles commercialized by Lehigh Nanotech contain more than 99.9 percent iron and a small amount of a noble element catalyst. They were invented by Wei-xian Zhang, associate professor of civil and environmental engineering at Lehigh.

Hazardous waste sites that once required a decade or more to clean can be remediated in one year by Zhang's nanoparticles.



The new technology, said the *Better World Report*, "is successfully cleaning up a wide range of soil and groundwater sites [contaminated by] toxic materials, heavy metals, fertilizers and pesticides in about a tenth of the time of typical environmental remediation.

"It takes only six ounces of the tiny nanomaterials, versus a ton of larger compounds, to make sweeping changes in cleaning up contaminated environments. This revolutionary breakthrough in nanotechnology is helping clean up hazardous waste sites and toxic industrial sites faster and more economically than ever before."

How much faster? In less than a year, says Paul Osimo, vice president of Lehigh Nanotech, Zhang's nanoparticles can clean up a hazardous waste that would take 10 to 20 years to remediate using traditional methods.

"This is a huge breakthrough," Osimo told AUTM. "These small nanoparticles are solving big problems."

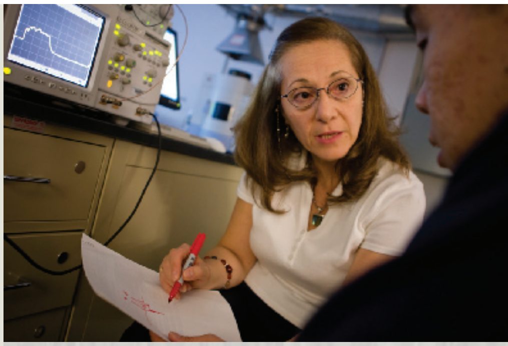
The nanoparticles' advantage, says Zhang, is their size. Measuring 20 to 50 nm in diameter, the particles have a greater proportional surface area than larger quantities of the same catalyst, giving them more reactivity with toxins. When injected into groundwater, they react with and detoxify contaminants.

"The complex molecules of chlorinated hydrocarbons, such as industrial degreasers and chemical solvents, are broken apart into simple, nontoxic compounds," said Osimo.

Lehigh Nanotech has completed remediation projects in Pennsylvania, New Jersey, New York, Maryland, Ohio and Florida. Treated sites include landfills, an electronics manufacturing plant, a vinyl chloride manufacturing plant, chemical plants and U.S. Department of Defense facilities. Contaminants removed include pesticides, vinyl chloride, trichloroethylene (TCE) and perchloroethylene (PCE).

Zhang has received funding from EPA, NSF, the Ben Franklin Technology Partners and the State of Pennsylvania.

Lehigh Nanotech was formed two years ago with help from Lehigh's office of technology transfer.



Environmental self-healing

Except for determining the fate of the occasional tennis star at the French Open, clay is not a substance that elicits much reaction.

But to Sibel Pamukcu, reactions are exactly what makes clay a unique and powerful ally in environmental mitigation.

Pamukcu, professor of geotechnical engineering, has unearthed new ways to use the physical and chemical properties of clay and other soil components to enhance the natural processes that break down certain pollutants.

An expert in electrokinetics, or the use of electrical current to direct materials in solution, Pamukcu is developing a novel electrochemical approach to her research.

"We're looking beyond the transporting of pollutants," she says, "in an effort to transform pollutants, *in situ*, into their benign chemical components."

When particles of clay interact with water molecules, says Pamukcu, a positive charge is transferred across the "electric double layer" that forms. This charge transfer enhances the chemical reactions that transform toxic substances into their benign or less toxic forms. And, because electrostatic forces cause most contaminants to reside on solid surfaces like individual clay particles, the result is a "soup of ions" that aids in environmental detox.

To demonstrate the theory, Pamukcu and her students applied a low-level electric field to saturated clay containing chromium VI, reducing it to its less toxic form, chromium III.

"Even without human intervention, clay's characteristics serve to naturally promote pollutant sloughing or chemical breakdown," says Pamukcu. "Our goal is to strengthen this natural process through an environmentally conscious and economically feasible system that performs targeted treatment of contaminated subsurfaces with clay content."

Mimicking nature

The gecko is getting a lot of exposure in insurance commercials on TV, but that's not why the lizard has stimulated scientists' imaginations. Researchers are paying heed because geckoes and other lizards and insects can run up, down or sideways on nearly any surface, wall or ceiling, without falling off. Their remarkable ability has inspired studies of new forms of adhesives.

"The secret to the lizards' mobility is the millions of micron-scale fibrils on each toe that form a self-cleaning dry adhesive," says Anand Jagota, professor of chemical engineering and director of the Bioengineering Program. "Each fibril consists of up to 1,000 spatulae, or flattened tips, that are only tens of nanometers in thickness. These nanostructures hold the promise of an entirely new type of adhesive."

The study of gecko-inspired adhesives is one of the latest examples of biomimetics, or the development of technology that mimics nature. Velcro was developed when a scientist noticed plant burrs stuck in the fur of his dog. A tropical sea sponge might inspire new fiber-optic strands, and a sea creature related to the starfish could light the way to a better design for optical lenses.

With funding from NSF and the U.S. Department of Energy, Jagota is conducting experiments to measure the gecko's adhesion and friction while also seeking to fabricate gecko-like adhesives using polymers. His group includes Chung-Yuen Hui, professor of theoretical and applied mechanics at Cornell University; Richard Vinci, professor of materials science and engineering at Lehigh; Manoj Chaudhury, professor of chemical engineering at Lehigh; and Nicholas Glassmaker of DuPont, as well as graduate and undergraduate students at Lehigh and Cornell.

"The idea is to develop the architecture of these kinds of adhesives so that they can be made from a variety of materials," Jagota says. His group has developed one design that Jagota calls a "mini-Parthenon," because its fibrils form columns and a roof block. That design, Jagota notes, is much stickier than a plain block of the material.

"By changing structure and adding two critical elements from nature – the fibril and the terminal thin film – we have improved performance eight or nine times over the performance of the design using plain material," says Jagota. "We think this phenomenon has to do with the thinness and smallness of the feet, and that is part of what we're measuring."

Bio-inspired adhesives might be more useful in applications requiring repeated adhesion than in those imposing heavy loads, says Jagota. "There is a lot of potential here and we're excited to try to demonstrate it."

Architecture is key, says Jagota, in fashioning materials that possess the gecko's adhesive powers.

Probing fatigue and its effects, at the cell level

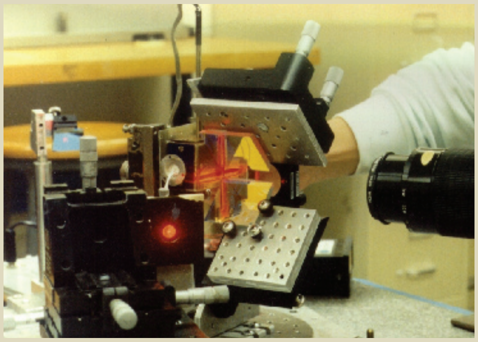
Run or jump, and the impact of your feet striking the ground reverberates up through your bones, muscles and spine, and even to the cells in your bones.

In biomechanical terms, you have imposed dynamic loading on your body parts. If you overdo it, like a soldier in basic training, you risk injury. If you underdo it, like a bedridden person, you weaken your ability to absorb shock.

And as you age, like the chassis of a car, your body frame needs better shock absorbers, regular maintenance and, sometimes, a replacement part or two.

Arkady Voloshin, professor of mechanical engineering and mechanics, has spent more than two decades studying the effects of dynamic loading on the musculoskeletal system.

Working with researchers at Università degli Studi della Basilicata in Potenza, Italy, he is subjecting a segment of a pig's spine to compression, extension and lateral bending, in an effort to learn how to measure disc displacements under various loads.



Voloshin studies the effects of fatigue on the musculoskeletal system's ability to dissipate heel-strike shock waves. He hopes to improve protocols for athletic training and general exercise.

"This study holds promise for investigating the behavior of tissue," says Voloshin, "which could lead to a better understanding of spine and disc injuries in humans and, ultimately, to improved surgical treatment of degenerative disorders of the spine."

Working with researchers in Lehigh's Sherman Fairchild Center for Solid State Studies, Bioengineering Program and electrical and computer engineering department, Voloshin is studying osteoporosis.

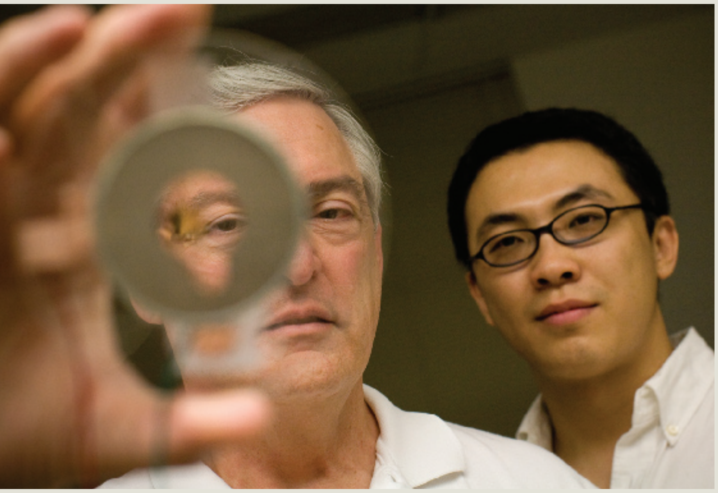
The group wants to know why bones lose their ability to respond to dynamic mechanical stimulus. The lack of response slows osteogenesis, the process of laying down new bone material. Voloshin, seeking to identify the mechanism responsible for osteoporosis, has used a polymer-based MEMS device to observe living cells and measure their mechanical properties.

Working with Israel's Loewenstein Rehabilitation Hospital, Voloshin studies runners to measure fatigue's effect on the ability of the musculoskeletal system to dissipate heel-strike shock waves on the tibial tuberosity and sacrum.

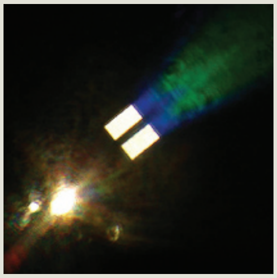
Overcoming optical obstacles

Fil Bartoli and Qiaoqiang Gan have taken a significant step towards overcoming the limitations of photonic devices by designing a plasmonic surface-wave splitter.

Surface plasmons are interactions in which light creates oscillations of charges in metal structures. The new splitter separates light of two different wavelengths, sending them in opposite directions along the surface of a device. By splitting the wavelength, Bartoli and Gan have shown that optoelectronic integrated circuits, or "lights-on-a-chip," can be developed.



Bartoli and Gan are especially interested in advances in biosensors.



"We are starting to see plasmonic structures that exhibit the predicted optical effects," says Bartoli, the Chandler Weaver Chair of electrical and computer engineering. "We want to use these structures for bioengineering studies. We're working with other departments to use light-on-a-chip to explore processes in cells and biomolecules."

Bartoli and Gan, a Ph.D. candidate, hope to achieve advances in biosensors. Commercially available biosensors can detect changes in cells, but they have their limits. Biophotonics has the potential to put even smaller sensors on a chip, which would enable biologists to examine nerve cells over a longer period of time, or many cells at once. This could lead to a better understanding of Alzheimer's, Parkinson's and other nerve diseases.

Potential applications in photonics, the technological heir apparent to electronics that power computers, TVs and cell phones, stagger the imagination, Bartoli says.

Optical fibers already span the globe, carrying voice and data. But the optical fiber carrying light signals has a diffraction limit: Its width must equal at least half the wavelength of the light waves inside the material. Optical chips today have wavelengths of about 1,500 nanometers, roughly 15 times larger than the smallest electronic devices currently in use. This hurdle must be overcome before photonics can replace electronic circuits in microprocessors and other computer chips.

When that goal is reached, says Bartoli, information can be delivered over the Internet at three orders of magnitude greater capacity, making a profound difference in health care, bioscience and everyday life.

Smaller is tougher – but why?

Experts around the globe are in a race to learn why nano-silica acts as a synergist in rubber-toughened epoxies. Interest is understandable, given the new applications for structural adhesives.

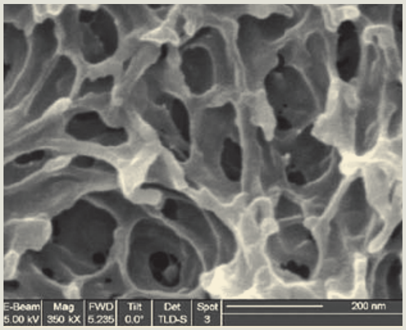
Aston Martin, whose high-end cars are favored by James Bond, recently switched from welding to adhesive bonding to join the major components in its new DB9 sports car. Lotus is using structural adhesives with mechanical fastening techniques on its upcoming 2+2 sports car. The Ford F-150 pickup truck uses new crash-durable adhesives.

High-strength adhesives have been used in aircraft, says Ray Pearson, who directs Lehigh's Center for Polymer Science and Engineering. But they were not suited for autos until recently because they were brittle in crash situations.

A breakthrough came when a modified epoxy that creates soft, micron-size toughening particles was combined with hard silica particles a few nanometers in size. Adding the well-dispersed nano-silica to rubber-toughened epoxy enhanced its toughness, enabling it to resist fracturing and to dissipate mechanical energy at a crack tip.

Pearson's group identifies and models toughening mechanisms in epoxy resins with the goal of developing new materials that perform longer and better without breaking. The group uses a multidisciplinary approach involving chemistry, mechanics and materials science.

Experts used to improve epoxy toughness by adding butadiene-based copolymers or micro-fillers like silica. Pearson experiments with rubber-toughened epoxies that contain rubber particles orders of magnitude smaller than those used in conventional rubber-toughened epoxies.



Pearson experiments with rubber-toughened epoxies that contain 40 nm rubber particles – orders of magnitude smaller than conventional epoxies.

Pearson attributes his success to the recent advent of triblock terpolymers-based toughening agents that self-assemble at the nanoscale. Filled epoxies containing glass beads 20 nm in size surely could not be as tough as those 2 microns in size or larger. Or could they?

"Conventional wisdom, based on previous published studies, was that larger filler particles were more effective in toughening epoxies," says Pearson. "But we have all been surprised by the amount of toughness these nanosize fillers can provide. Moreover, just a little bit of nano-silica can cause significant improvement in toughness in conventional rubber-toughened systems."

A high-synergy sorption selectively captures arsenic

A Lehigh invention that removes arsenic from groundwater is being used on four continents.

The technology, sold as ArsenX^{np}, utilizes a hybrid anion exchanger to disperse iron nanoparticles throughout a polymer-based bead. The nanoparticles selectively adsorb arsenic as well as phosphate, vanadate and other contaminants.

The patent has been awarded to Arup SenGupta, professor of civil and environmental engineering, and Luis Cumbal, who earned a Ph.D. in environmental engineering from Lehigh in 2005. Cumbal is now professor and director of graduate studies at the Army Engineering Polytechnic School in Quito, Ecuador.

ArsenX^{np} is licensed to SolmeteX Co. in Northborough, Mass., and manufactured by Purolite Co. of Philadelphia. It serves 300,000 people at more than 300 installations in nine states in the U.S., and is also in use in Hungary, India, Brazil and Ecuador.

In Eastern India, home to the world's worst arsenic contamination, arsenic-removal systems have been installed in the water wells of more than 150 villages. Arsenic levels in the wells have fallen from 100 to 500 parts per billion to below the 50-ppb limit set by the Indian government.

ArsenX^{np} is the first hybrid anion exchanger (HAIX) to intentionally exploit the 100-year-old Donnan effect and attain enhanced sorption of arsenate, arsenite, phosphate, chromate and other ligands, SenGupta says.

The effect, named for the British chemist Frederick G. Donnan (1870–1956), refers to the failure of charged particles to distribute evenly across the two sides of a nearby semi-permeable membrane.

"HAIX is an anion exchanger within which hydrated iron oxide nanoparticles have been irreversibly dispersed," says SenGupta. "Its synthesis posed a major challenge because the positively charged ferric ion is strongly rejected by an anion exchanger with a positively charged quaternary ammonium functional group.

"This challenge was overcome through a novel synthesis process that was scaled up for large-scale production. Very large amounts of hydrated Fe(III) oxide nanoparticles, nearly 25 percent by mass, can now be introduced within an anion exchanger."

ArsenX^{np} is now purifying water for 300,000 people in nine U.S. states, and is also being used in India, Hungary, Ecuador and Brazil.

HAIX particles, says SenGupta, are not homogeneous at the microscale, but instead remain heterogeneous down to the level of 10 nanometers, where the simultaneous presence of quaternary ammonium functional groups and Fe(III) oxide nanoparticles in close proximity creates a synergy resulting in high sorption capacity and excellent kinetics.

SenGupta and Cumbal worked more than a year before they succeeded in preparing 2 grams of hybrid anion exchanger and dispersing iron oxide nanoparticles in 2003. Since then, they have refined and scaled up the process of synthesizing and dispersing the nanoparticles. Today, an estimated one million pounds of the hybrid nanosorbent is being used in the U.S.

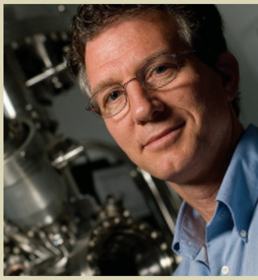
Delving deeper into the surface

Lehigh's already-renowned capabilities in the science of surface analysis have received an exciting boost, thanks to the acquisition of two critical new instruments.

With support from NSF, Lehigh will be home to a high-sensitivity low energy ion scattering (HS-LEIS) spectrometer – a first in global academia, as well as a first anywhere in the U.S. A method of characterizing a material's chemistry and structure, HS-LEIS involves directing a stream of charged particles (ions) at a surface and determining the outer-most atomic layer composition (~0.2-0.3 nm).

Bruce Koel, professor of chemistry and interim vice provost for research, and Israel E. Wachs, the G. Whitney Snyder Professor of chemical engineering, coordinated the NSF proposal effort.

"This instrument represents a significant step forward for research at Lehigh," Koel says. "Its unique sensitivity to surface composition will benefit researchers from a wide variety of disciplines across Lehigh's science and engineering landscape." HS-LEIS complements Lehigh's Scienta ESCA 300 – another analysis instrument found only at Lehigh.



"Lehigh researchers who require precise characterization of surfaces and interfaces can now push the limits further than ever before," says Wachs, citing existing Lehigh interests in nanocatalysis, fuel cells, optical and bio-sensors, functional glasses, biomaterials, polymers, ceramics, semiconductors, metal alloys, coatings, adhesives, and membranes, as benefitting from HS-LEIS.

Koel also recently installed, using funds from NSF, NASA, and Lehigh, a versatile surface analysis instrument containing a scanning tunneling microscope (STM). The new STM can be used to observe atoms and molecules on solid surfaces in vacuum and ambient environments, and complements Lehigh's aberration-corrected transmission electron microscopes (TEM). Says Koel: "Simply put, Lehigh is home to an amazing array of nanoscale characterization instruments."

Joachim Grenestedt has found uses for lightweight composite materials in submarine hulls, racing boats, airplane wings and his own two-seat plane.

Called to speed and lightness

Joachim Grenestedt glanced both ways down the long road on Lehigh's athletic campus, then strode back to his Go Kart in the empty parking lot.

Not a car in sight. The coast was clear.

Moments earlier, Grenestedt's student had tested a new titanium brake caliper with a thin membrane that replaced all moving parts. After installing the caliper in the Go Kart, the student had gently coaxed the vehicle to 30 mph, then braked.

The caliper had held. Mission accomplished.

But Grenestedt saw greater potential in the new brake. Taking the controls of the Go Kart, he zoomed off around the parking lot. He hit 30 mph, 40, 50 – and braked. Again, the caliper held. Grenestedt grinned and climbed out of the Go Kart.

Early to the water

Joachim Grenestedt, professor of mechanical engineering and mechanics at Lehigh, began building wooden boats when he was 4. Three years later, his family bought a yacht and explored the endless islands off Sweden's Baltic coast. As a teenager, Grenestedt tried out catamarans and remote-control race boats.

As an adult, Grenestedt has cultivated an appreciation for lightweight composite materials: carbon fibers, glass fibers and complex materials configured in honeycomb and sandwich patterns.

"Composite materials are very light, very strong and easy to make into complex shapes," he says. "The lightness improves speed and fuel efficiency. And the material doesn't rust or fall apart."

In the 1990s, Grenestedt helped design the *Visby*, a Swedish Navy stealth ship, which, at 239 feet in length, was the largest carbon-fiber structure ever built.

A growing repertoire

In 2004, with funding from the Office of Naval Research (ONR), Grenestedt designed and built a 20-foot model of a new hybrid ship hull whose stainless-steel frame was covered by composite sandwich panels. The panels and the epoxy bonding them to the frame sustained loads up to 40 percent above design load.

Last year, Grenestedt tested a larger, 35,000-pound hybrid hull specimen. Using Lehigh's 5-axis CNC router, he built composite panels with a corrugated fiberglass "skin" infused over a foam core. These lightweight panels outperformed heavy, ½-inch-thick nonmagnetic stainless steel, as well as conventional (non-corrugated) composite sandwich panels.

"We subjected the specimen to 300,000 cycles of fatigue at loads up to 20 percent above design loads," Grenestedt says. "A lot of cracks formed in the steel, but the lightweight composite sandwich panels remained intact."

Grenestedt is now building a 28-foot-long high-speed boat with the same steel-composite hybrid concept. He and his students will fit the boat with a 425-hp V8 engine, then run it on the water at speeds of 70 mph.

"Nobody would commit to building a bigger ship using this hybrid concept until it has been tried in real seas," he says.

The speedboat will also serve as a "slamming" test bed.

"Slamming is a hydrodynamic impact, wave against boat," Grenestedt says. "It's a random event that occurs at high speeds. We haven't figured out how best to design against it, nor do we have the computational capabilities to analyze it accurately."

Grenestedt will test various materials – carbon and glass fibers, stiff and soft – in the boat's bottom panels. He will test different asymmetrical configurations of the panels.

"By doing back-to-back comparisons, replacing panels as we go, we will see very quickly how each kind of panel behaves."

Bound for Bonneville

Next year, Grenestedt will compete in the 125cc-engine category for land-speed racing "streamliner" motorcycles at the Bonneville Speedway in Utah. He is building a streamliner out of prepreg carbon and glass fibers, vacuum-infused carbon fibers, wet-laid glass fibers, foam cores sandwich, honeycomb sandwich and single skin.

In a departure from convention, he is designing his streamliner to sit high off the ground, a fact he hopes will offer an aerodynamic advantage.

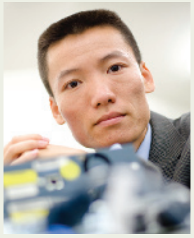
Just getting into the streamliner will be a challenge for Grenestedt, who is 6 feet, 4 inches tall. The streamliner is well under 4 feet high, and less than 2 feet wide at the driver's shoulder.

"I'll need to spend a few minutes stretching my neck and back before I squeeze myself into the 'liner," he says.

He fully expects to break the world record of 151 mph for a 125cc vehicle.

"It's a big challenge to go that fast with such a small engine. But we've got a serious shot. I think I'll get it – sooner or later."

Networks of sensors, smartly deployed



When Liang Cheng, assistant professor of computer science and engineering, imagines the future, he envisions wireless sensor networks deployed in a growing number of places and ways to give intelligence to the high-tech systems that make modern life happen.

Suppose there's a major pileup on I-78 in Allentown, Pa. Cheng and his Laboratory Of Networking Group (LONGLAB) colleagues are studying ways of wirelessly linking car accelerometers, the devices that measure acceleration forces. The resulting wireless sensor network would enable a lead car to "observe" the event and transmit information to cars from Harrisburg to Newark, N.J.

But the flow of crucial information can be disrupted, says Cheng, preventing wireless sensor networks from achieving an instantaneous end-to-end path between information sources and destinations. Cheng is working with two other professors in his department, Mooi Choo Chuah and Brian Davison, to create an adaptive system for DARPA that maintains the integrity of large-scale wireless sensor networks in challenging environments. This kind of system was used when many sensors in the World Trade Center were destroyed by heat in the 2001 terrorist attack; robots guided by undamaged sensors were then deployed to search for humans.

Cheng's group also has an NSF contract to develop "middleware," a type of software that uses a variety of operating systems to enable real-time communication among sensors, handheld devices and desktop systems. In a chemical-factory fire, middleware would enable a firefighter with a handheld device to determine whether the air in the room he's about to enter is contaminated. The same device could also guide him safely out of the building.

To be versatile, says Cheng, wireless networks must maintain their integrity in all environments.

Cheng's group is collaborating with Lehigh civil engineering professors to embed sensing systems in bridges and subsurface structures to monitor their responses to earthquakes. They have also developed embedded system and wireless network applications for LSI Corp.

"As sensors get smaller and smarter, I can see them being connected and deployed increasingly in a variety of ways," says Cheng. "We may soon see them in our clothes, shoes, appliances and gadgets, which will enable invisible computing in a ubiquitous way."

For buildings, a slap in the face

Explosions and earthquakes, says Clay Naito, damage buildings in dramatically different ways.

While an earthquake lasts up to one minute, says Naito, an explosion is over in 30 milliseconds. "It's like the building is being slapped in the face," he says.

Naito, the P.C. Rossin Associate Professor of civil and environmental engineering, is one of a dozen U.S. academics who have taken up the challenge of the blast resistance of buildings. He is spending his sabbatical at Tyndall Air Force Base in Panama City, Fla., where he conducts blast tests on three- to six-story structures that are typical of military barracks or government administration buildings.

Naito's goal is to determine the optimum placement of reinforcement in building walls. He is also concerned with the details used to connect wall panels to building frames. He uses high-speed video and instrumentation to capture the effects of blasts, and he is developing computational models that predict when a building wall system will fail.

His work is funded by the Portland Cement Association, an umbrella group for the concrete industry.

"The industry wants predictive models backed by actual tests so they can build cost-effective structures that will resist blast demands," he says. "To achieve this, we need to validate complex models and transform them into simple tools that engineers can use in designing buildings."

When an explosion is set off near a building, says Naito, the main cause of damage and injury is a sudden pressure wave measuring about 100 pounds per square inch. Normal buildings are designed to withstand 100 pounds of pressure per square foot.

"The saving grace is that, in such a short period of time, heavy concrete objects just can't start moving that quickly. A good wall will respond by simply bowing inward 1 to 2 inches."

Naito is particularly interested in the blast resistance of precast and tilt-up concrete. Precast concrete is formed at a manufacturing plant, then trucked to a building site. Tilt-up concrete walls are formed on-site, then tilted up and set in place when the concrete has hardened.

Naito conducts blast tests on multistory buildings to determine optimum placement of reinforcement features.

INTERVIEW BY KURT PFITZER • PHOTOGRAPHY BY GUARINA LOPEZ

SECURING THE FUTURE

ENGINEER-EDUCATOR LEADS EFFORTS TO DIVERSIFY ENGINEERING

Richard Buckius, an expert in thermal sciences, became vice president for research at Purdue University in September 2008 after a four-year rotation at NSF, including three years as head of the Directorate for Engineering (ENG). At NSF, he oversaw an annual budget of more than $550 million for education and research into energy and the environment, complex systems, nanotechnology and other topics. In his 33-year academic career, Buckius has won top awards from the American Society for Engineering Education, the American Society of Mechanical Engineers and the University of Illinois at Urbana-Champaign, including the Campus Award for Excellence in Undergraduate Teaching, UIUC's highest teaching honor.

Q: ***What distinguishes NSF from other government research-funding agencies?***

A: Most federal agencies have directed missions in specific disciplines. NSF looks broadly at the long-term future of the nation. We address fundamental research by promoting discovery and education in nearly all disciplines. Another unique part of the agency is that one-third of NSF's program directors are rotators, people like me who come from universities, spend a few years here and then return to their universities. That means the agency is continually changing with the infusion of new ideas.

Q: ***What do you see as ENG's major accomplishment under your leadership?***

A: ENG had one of its lowest success rates ever, in terms of number of awards made versus proposals received. To figure out how we could better serve the community, we went through strategic planning and came up with a new structure to reflect current trends in scholarship and education. The big research challenges today tend to require more than one scholar, so scholars are forming interdisciplinary teams. Our structure now helps us serve this community more effectively. In addition, our new EFRI (Emerging Frontiers in Research and Innovation) office puts out a solicitation each year around different topics at the forefront of engineering research. This flexibility enables us to focus our solicitations more strategically.

Q: ***What are some of the grand challenges for which you have solicited proposals?***

A: Energy, environment, sustainability, health and security are among the key challenges. Previous requests have considered topics in the areas of bioengineering, infrastructures and cognitive engineering. Our most recent solicitation (in August 2008) seeks proposals in the area of biofuels and biosensing/bioactuation.

Young faculty applying for NSF grants, says Buckius, should also volunteer to serve as reviewers.

Q: ***In the 1960s, the moon race triggered a national revival in science education. What endeavor today could kindle a public passion for research?***
A: The whole collection of interrelated challenges we're facing in energy, environment, climate and sustainability could kindle such a passion. We have to hope that these challenges inspire our students and faculty to concentrate their time and efforts to solve these problems.

Q: ***Have there been changes in the federal government's and NSF's emphasis on basic research?***
A: In the last five years we've seen important changes in the executive and legislative branches of government. The American Competitiveness Initiative (announced by President Bush in 2006) makes a major commitment to long-term fundamental research. The America COMPETES Act of 2007 (enacted by Congress in 2007) promotes "high-risk, high-reward projects that meet fundamental scientific and technological challenges." I no longer see a clear distinction between applied and fundamental research at NSF.

Q: ***Surveys show that, in science and math achievement, American high school students trail their peers in other countries. NSF addresses this through various programs that encourage STEM (Science, Technology, Education and Mathematics) education. What more can be done to motivate students to consider careers in science and engineering?***
A: The U.S. still has some absolutely excellent high schools and students. In the future, however, we probably will have only a fraction of the engineering students that other countries, especially India and China, will have. We have to accept that we're no longer going to lead or be productive based on sheer numbers. Instead, we need to focus on quality and to educate our students to become leaders.

We would obviously like to recruit more young people into engineering. STEM education is key to this. To try to ensure that we have pathways for undergraduate and graduate students to become engineers, as well as future faculty members, we are making a focused effort to support researchers who take their expertise into K-12 classrooms. ENG is adding to this effort through NSF's Research Experience for Teachers (RET) program. RET allows K-12 teachers to work in a university lab and take part in the research of a faculty member. The teachers get a better understanding of research and transmit their enthusiasm to their students. This has a successful multiplying effect.

Q: ***What can be done to increase the participation of women in engineering?***
A: Women are a much smaller fraction of the engineering population than we'd like. And I think the inclusion of all underrepresented groups – by gender, ethnicity and disability – needs to be a stronger element in engineering. Two years ago, ENG recruited its first-ever program director for diversity and outreach to work with the community to develop a plan to attract more people from underrepresented groups. ENG is also funding programs for K-12 students, undergraduate students, graduate students, postdocs and faculty members to increase the diversity of engineering. These programs include RET and REU (Research Experience for Undergraduates), as well as fellowships, leaves and workshops.

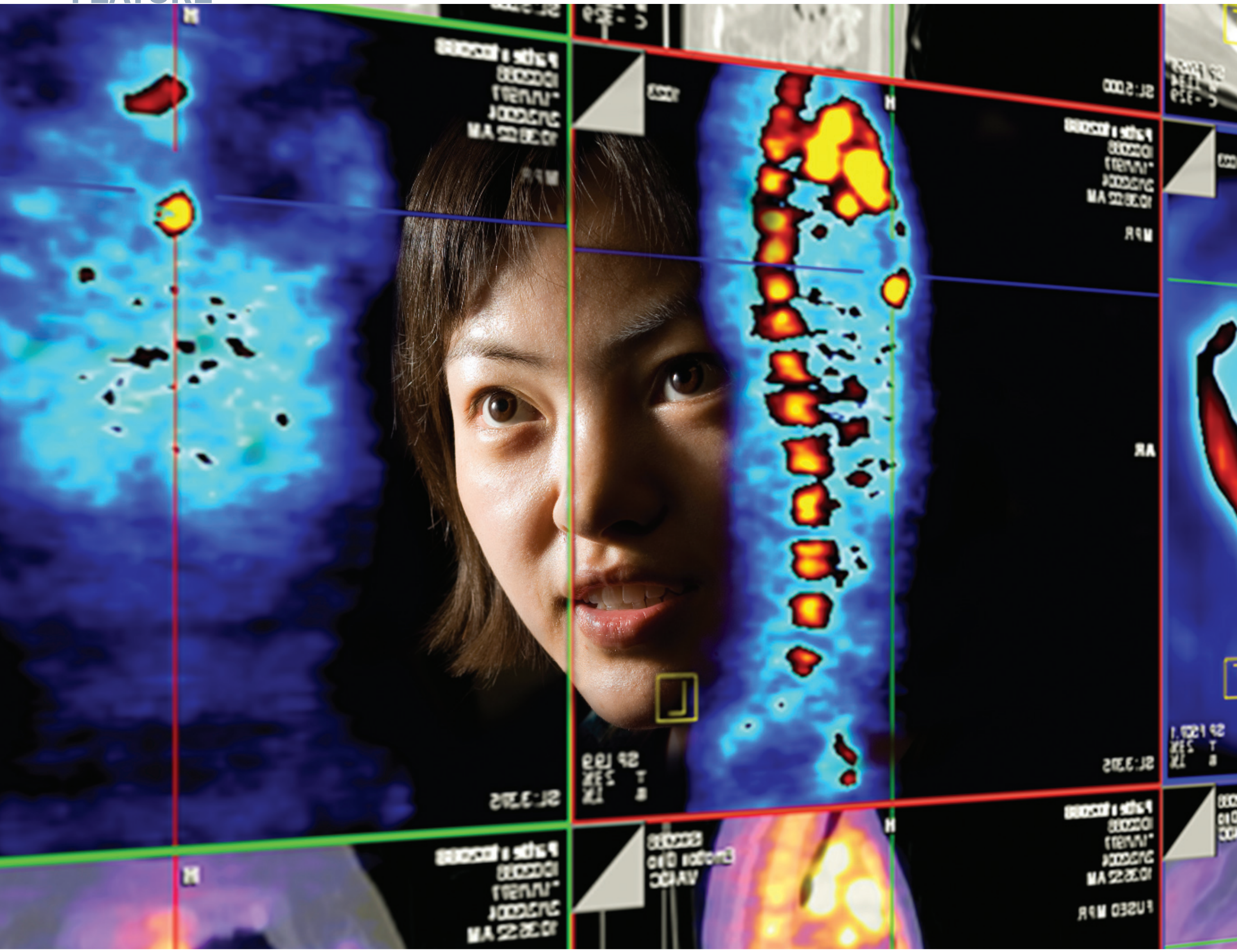
Q: ***What qualities make a good researcher?***
A: There's not one model. Some people are logical and clear-thinking. Others are scattered. I've known people on both sides who have done exceptional work. Usually, what it comes down to is passion. Whatever style they have, good researchers typically are passionate about what they do.

Q: ***What qualities make for a strong research proposal?***
A: NSF has two criteria for reviewing proposals. *Intellectual merit* includes advancing knowledge and exploring creative and original concepts, as well as the qualifications of researchers and their access to necessary resources. *Broader impacts* include promoting teaching and learning, widening the participation of underrepresented groups, enhancing the research infrastructure, disseminating your findings and benefiting society.

ENG receives 6,000 to 7,000 proposals a year. There are all kinds of models for success. But overall, you have to have a unique, transformative idea that's truly novel and will have an impact.

Q: ***What other advice would you give to young scholars writing proposals?***
A: Try to think like a reviewer. Stress the novel aspects of your work and differentiate it from the work of others. Emphasize its potential impact. Remember that the project summary is very important. Have a colleague or mentor review what you write before you send it in. And come to Washington, D.C., to meet our program directors. This is essential. You'll find out about our programs and what we're funding. And our directors will get a better appreciation for your idea. Finally, volunteer to be a reviewer. We're always looking for new people, especially younger faculty, to help with reviewing.

Q: ***Will your experience at NSF change your approach to teaching and research as you return to academia?***
A: Being at the Foundation has required me to read proposals and interact with experts in fields that are far from my own. I think this will give me a much broader perspective on research and inspire me to look for bigger challenges.



A BEATING HEART TELLS ITS TALES

Like the artist's composite sketch that slowly reveals the face of a criminal suspect, the image on Xiaolei Huang's computer screen is gradually zeroing in on America's number-one killer – heart disease.

Lines in Huang's image crisscross to form a netlike pattern called a polygon mesh. They intersect at three-dimensional nodes called vertices.

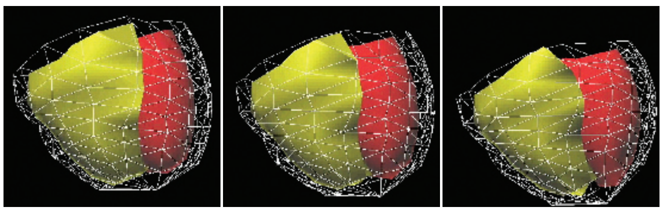
Huang has used computer graphics to render a geometric model of three phases of the beating of an actual heart that was scanned, over time, by magnetic resonance imaging (MRI).

The heart may have its secrets, but the stress and strain that it undergoes as it pumps blood is not one of them, at least not to Huang, who is an assistant professor of computer science and engineering.

Huang writes software programs that enhance the detecting powers of MRI and other medical imaging techniques. Her programs can take 4-D medical images – with time as the fourth dimension – and extract from them the precise geometric shape and motion of the heart.

Huang then builds 4-D computer models that measure the natural changes, or deformations, in the heart's structure as it expands and contracts.

These models will give cardiologists a clearer picture of the differences between the normal deformations that occur in healthy hearts and the abnormal deformations that occur in damaged and diseased hearts. They will also help physicians recognize different types of abnormal deformation and correspond them to various types of disease or damage.



"The clearer the picture we can obtain of the deformation in a normal heart," says Huang, "the more quickly and reliably we can identify abnormalities in deformation that indicate a diseased or damaged heart. And if we obtain enough examples of different types of abnormalities, we can characterize the commonalities of these abnormalities."

Tagging and tracking

The heart modeled on Huang's computer screen was scanned by an MRI technique called SPAtial Modulation of Magnetization. SPAMM tags material points within the heart wall, which can be tracked over time to reveal the 3-D motion of the heart muscle.

The tags enable Huang to outline, or segment, the heart's structures, including the boundaries separating heart and lungs, as well as those demarcating the heart's outer wall, left and right ventricles and myocardium.

Huang then locates the vertices, manipulates her image and tracks the path of each vertex as the heart deforms. Based on the displacement of the vertices, she calculates the stress and strain imposed on the heart muscle.

"The model is no longer just a geometric model," says Huang. "Now it has mechanical properties. This enables us to perform precise quantifications. We can partition the heart wall into sub-regions and follow each of these to determine whether the deformation that occurs is normal or not."

Huang collaborates with computer scientists at Rutgers University and with Dr. Leon Axel, director of cardiac imaging at the New York University School of Medicine. She has a grant from the Lindback Foundation's Minority Junior Faculty Award Program.

Huang says her model will enable diagnosticians to interpret medical images in a fraction of the time they now require.

"It takes hours for a human expert to interpret a sequence of images from one patient," she says. "Our software tool can do segmentation and build a 4-D model in 26 seconds, while finding more instances of abnormal deformations and structures, especially very localized ones."

Quantitative computer image analysis, says Huang, will not eliminate the need for human experts, but it will give technicians a valuable tool that automates the interpretation of medical scans.

"The tools of computer-aided diagnosis [CAD] are becoming more powerful, but they still don't work as well as human analysts. They can, however, help technicians do their job faster, less subjectively and more reliably."

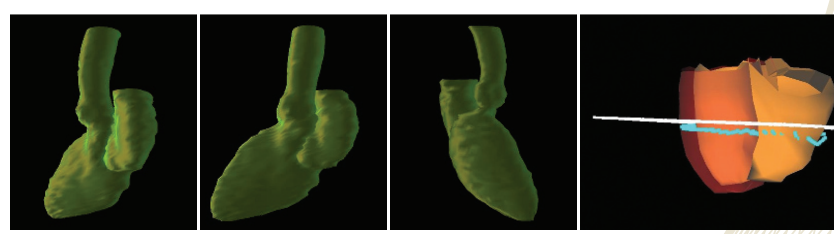
In pursuit of hot spots

One of Huang's software programs draws information from images acquired with Positron Emission Tomography (PET), a technique used in radiation oncology. PET produces a 3-D map of bright "hot spots" that represent areas of high energy activity in the body. These hot spots, however, can represent either normal sites like the heart or other organs, or abnormal sites such as tumors or inflammations.

Huang's software automates the interpretation of PET scans by differentiating between normal and abnormal hot spots. Using segmentation, she identifies the precise boundaries of all hot spots in the PET scan and its accompanying CT scan. Using pattern recognition and computer vision, she identifies organs based on their shape and location. She "suppresses" these sites and then tracks the changes over time in abnormal hot spots.

"The precise boundaries of organs and tumors are very valuable," says Huang. "Oncologists rely on them to make radiation treatment plans that protect normal organs by exposing them to as little radiation as possible while targeting tumors with high-intensity radiation."

Because Huang's software tools can do geometrical, statistical and mechanical modeling, her programs keep working when unforeseen obstacles are encountered.



Opposite: Huang's software identifies normal and abnormal "hot spots." Left: A computer-generated 3-D model of a whole heart becomes a 4-D image over time. Below: Three views of a 3-D model of the heart's left ventricle (left) and an illustration of a tag plane, also in 3-D.

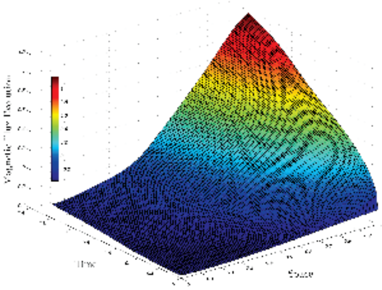
"The main challenge with medical image computing is to do it robustly. Too often, when a software program encounters noise [slight variations in intensity, unwanted disturbance, energy or interference] or artifacts [ranging from dental fillings to distortions in tissue structure], it breaks down. Once this happens, it is difficult to recover information.

"Our model can be as complex or as simple as we want. We can attach to it as many properties as we want. It can represent geometry or it can be a statistical model. It can encode variations across patients and infer a statistical model from multiple people. Or it can have mechanical properties. All of this builds in robustness."

Lehigh's fusion experts enjoy close ties with peers at the world's top nuclear fusion research facilities.

Wachs seeks to generate H_2 cleanly by using photocatalysis.

CREATIVE ENERGIES

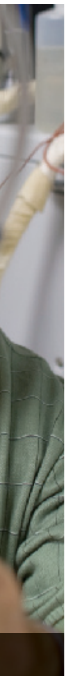


ENERGY RESEARCH SPANS THE GAMUT AT LEHIGH AND IS CLOSELY TIED TO ENVIRONMENTAL IMPACT. ENGINEERS HARVEST METHANE HYDRATES AND CHART FUSION PLASMA FLOWS. THEY WORK TOWARDS A HYDROGEN ECONOMY AND SOLVE COMPLEX POWER-PLANT CHALLENGES. THEIR GOAL: CLEANER, SMARTER ENERGY GENERATION AND END USE NOW, AND RENEWABLE SOURCES FOR THE FUTURE.

Have you seen the cartoon that shows a man standing next to his car at a gas station and aiming the gas nozzle at his head? The sentiment may be popular, but spiraling gas prices are just the tip of the energy crisis. Coal and natural gas prices are also up. Home heating costs are soaring. Deregulation is sending electric bills higher. Meanwhile, concerns grow over pollution and global climate change.

Engineers in the energy field have no shortage of work to do. They are called to develop better ways of generating and distributing energy, to improve the efficiency of systems that consume energy, and to mitigate the environmental impact of energy generation and energy use.

Only by advancing on all three fronts, experts agreed recently at Lehigh, can society find solutions to the world's grow-



Working in Lehigh's powerhouse, researchers have developed a technology that recovers water and cuts emissions from coal-fired power plants by uniquely deploying heat exchangers.

ing energy problems. Meeting at a Lehigh workshop titled "Balancing Energy and the Environment: An Exploration of Future Research Needs," the experts forged consensus on a hard truth: There will be no single fix for the world's energy dilemma. For at least the next two decades, rising global demand will obligate humans to burn coal, oil and natural gas and to build more nuclear power plants, while developing solar, wind, biomass, hydrogen, fusion and other renewable energy sources.

In the area of energy generation and distribution, Lehigh engineers focus their energy research in critical areas such as catalysis for efficient hydrogen production, fuel cells, biomass, clean coal technologies, carbon capture and sequestration, solar energy and photovoltaics, and nuclear fusion. In the area of energy consumption and conservation, researchers are working on LED lighting, power electronics, energy-efficient glass, high-efficiency motors, energy usage auditing and energy-efficient manufacturing.

Meanwhile, in response to the nation's need for innovation in energy systems engineering, Lehigh is partnering with the Electric Power Research Institute (EPRI) to launch an integrated research and educational program (p. 16) that will produce the next generation of leaders in energy systems engineering.

The following pages sample a few energy research projects at Lehigh.

LET THERE BE LIGHT ENERGY H_2 PRODUCTION

As a fuel, hydrogen (H_2) enjoys several key advantages: It emits no greenhouse gases or pollutants, and it can be burned in an engine or used to produce electricity in room-temperature fuel cells.

One barrier to the widespread use of H_2 is the lack of a clean, low-energy means of producing it. Much attention, therefore, has been focused on photocatalytic water splitting (PWS) to separate water into oxygen and hydrogen. The field of photocatalysis began in Japan three decades ago.

Ultraviolet (UV) light-active photocatalysts can split water, but scientists are seeking catalysts that react to visible light excitation and utilize the sun's broad light spectrum more efficiently.

Israel E. Wachs, professor of chemical engineering, is creating and testing structures of titania nanoparticles (NPs) to see which can best perform PWS at an industrial scale. Titania (TiO_2), a common photocatalyst, is also used in sunscreens because it absorbs UV light.

Wachs is seeking to expand titania's reactivity from the UV to the visible light range. He and his students conduct tests at Oak Ridge National Laboratory in Tennessee to measure the lifetime of photo-excited electrons in titania. Their work is funded by the U.S. Department of Energy (DOE).

"Oak Ridge has state-of-the-art spectroscopy equipment," says Charles Roberts, a Ph.D. candidate. "We do fluorescent spectroscopy. When the electron is excited, it emits light energy that can be detected as fluorescence.

"The electron's lifetime – from ground state to peak excitation back to ground state – lasts a few nanoseconds. It's important to quantify this. The longer the electron stays excited, the greater the opportunity for titania to perform photocatalysis.

"We measure this phenomenon with spectroscopy with time resolutions in pico- and even femtoseconds. By using these extremely high speeds, we're able to observe the electron's transitions."

A sorbent modeled by Caram and Sircar halves the temperature needed to produce hydrogen from methane.

The conversion of solar energy into electricity could be achieved more efficiently with indium gallium nitride (see p. 21).

Conventional titania photocatalysts consist of a polymeric network of TiO_6 units. The novel titania photocatalysts synthesized by Wachs' group include isolated TiO_4 units, polymeric chains with TiO_5 structures, rafts consisting of TiO_6 coordination, and TiO_6-containing titania NPs measuring 1-10 nm. The group is modifying these photocatalytic active sites to optimize the collection of light and the utilization of the formed electrons as well as their corresponding holes, or positive sites. The goal is to establish the fundamental relationships between structure and reactivity for titania-based photocatalysts.

"We want to see if titania's structure affects the electron's lifetime," says Roberts, who has also traveled to France and the Netherlands to work on the project. "We're trying to determine what's happening at the molecular level so we can improve titania's reactivity and efficiency. Our ultimate goal is to find the optimal catalyst for splitting clean water into H_2 and O_2.

"So far, our results show that some isolated TiO_4 sites could be superior to the block crystal structure. But although they work well in the lab, we need a lot more catalyst for it to be useful on an industrial scale."

If successful, Wachs' group could greatly increase the efficiency of producing H_2, says Roberts.

"Photocatalysis runs at very low, even room temperatures. Because light is sufficient to make it go, you are eliminating or greatly reducing your dependence on man-made energy."

Somphonh Peter Phivilay, another Ph.D. candidate in Wachs' group, recently spent two months in Japan working with photocatalysis pioneers Kazunari Domen and Masakazu Anpo.

"We tested our catalyst there," says Phivilay, "and were able to see the relationship between structure and reactivity. We split water and used gas chromatography to measure how many micromoles of H_2 we produced. We found isolated surface TiO_4 sites to be the most efficient for PWS. The process is not yet cost-effective, but we're making progress."

LOWERING THE HEAT FOR H2 PRODUCTION

Steam-methane reforming (SMR), the most common method of producing H_2, requires a catalytic reactor heated to almost 900 degrees C, a water-gas shift (WGS) reactor, and a multicolumn, multistep pressure swing adsorption process to purify H_2. The process gives off carbon dioxide (CO_2) as a by-product.

Shivaji Sircar and Hugo Caram, professors of chemical engineering, have developed and simulated a simpler method of producing fuel-cell-grade H_2 at less than 500 degrees C. Their three-year project is funded by DOE.

The new process, a three-step cyclic thermal swing sorption-enhanced reaction, uses potassium carbonate K_2CO_3-promoted hydrotalcite, a chemisorbent, to selectively remove CO_2 from the reaction zone of the reformer.

"Our sorbents permit the operation of the SMR reaction at a much lower temperature – approximately 480 degrees C – while still offering more than 90 percent conversion of methane to hydrogen," says Caram.

"This enables us to directly produce high-purity hydrogen that can be used for fuel cells or commercial applications. And we can also separate out pure CO_2, which can be sequestered or used for petroleum recovery."

By utilizing the chemisorbent, says Caram, the researchers are able to integrate the SMR and WGS reactors and the hydrogen-purification unit of the conventional process into a single unit. The chemisorbent is periodically regenerated through pressure or thermal swing adsorption. And removal of CO_2 from the reaction zone allows the high conversion of methane to hydrogen.

In another project funded by DOE, Caram and Sircar utilized K_2CO_3-promoted hydrotalcite and a second sorbent, sodium oxide (Na_2O) promoted alumina, to produce fuel-cell-grade H_2 and pure CO_2 from synthesis gas. Syngas, which contains CO, CO_2, H_2O and H_2, is produced when coal is gasified with steam at high temperatures.

Sircar and Caram reported their results last year in the journal *Adsorption* and in the *International Journal of Hydrogen Energy*. They also receive support from the Pennsylvania Infrastructure Technology Alliance and Air Products and Chemicals Inc.

PROMOTING THE CAPTURE OF CO_2

Engineers at Lehigh's Energy Research Center (ERC) develop technologies and systems that increase the efficiency of coal-fired power plants while reducing pollution and facilitating the capture and sequestration of CO_2. ERC director Edward K. Levy described some of these efforts in a May 2008 presentation to DOE's Seventh Annual Conference on Carbon Capture and Sequestration.

One new ERC technology achieves this trio of benefits while also providing a new water source for power plants. The technology, tested successfully at a coal-fired power plant, recovers water vapor from the flue gas with six "staged" heat exchangers whose temperatures are varied so that water vapor and vapors from toxic acids, especially sulfuric acid, condense in separate exchangers. (Water in flue gas condenses at 95 to 130 degrees F, and sulfuric acid at 220 to 310 degrees F.) The recovered water can be treated and used to replace water that evaporates from the cooling tower. Funding for the project is provided by DOE.

Researchers say this technology will be especially useful for power plants in arid regions that lack access to cooling water.

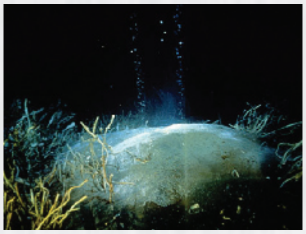
"We were able to recover 50 to 80 percent of the water from the flue gas," said ERC senior research scientist Harun Bilirgen. "We believe this will make it possible to provide as much as 20 percent of the cooling water needed for a 600-MW power plant boiler burning Powder River Basin coal and 30 percent for the same unit if it's burning lignite."

The new design will also improve plant efficiency, reduce mercury emissions 60 to 65 percent and capture sulfuric, hydrochloric and other acids, Bilirgen said. And by cooling flue gas and reducing its acid and water vapor content, the technology could cut the costs of capturing CO_2 in back-end amine and ammonia CO_2 scrubbers.

"The heat exchanger series will be located along the duct that carries flue gas to the stacks," said Bilirgen. "The existing temperature of 300 degrees F in this duct will drop to less than 110 degrees F after the exchangers.

"This will be very helpful for post-combus-

BURIED TREASURE: PROCEED WITH CAUTION



Trapped beneath the world's ocean floors, sealed by low temperatures and high pressure, lies a frozen reservoir of natural gas. These methane hydrates, or icy deposits of methane, contain more organic carbon than all the world's coal, oil and non-hydrate natural gas combined, according to the U.S. Geological Survey.

More importantly, methane hydrates are an equal-opportunity energy source, distributed evenly in the sediments beneath ocean and sea floors, and also under the arctic tundra.

But environmental challenges must be overcome, says Tae Sup Yun, before methane hydrates realize their potential.

"When you extract methane hydrates," says Yun, the P.C. Rossin Assistant Professor of civil and environmental engineering, "methane begins to dissociate from the sediment in which it is trapped. This dissociation causes the sediment to collapse."

The shifting sediment can damage marine life and cause marine landslides and even tsunamis, says Yun, who has studied hydrates in the Indian Ocean, the Gulf of Mexico and the East Sea off Korea's coast.

Careless hydrate extraction can also lead to global warming, he says.

"Dissociation can also trigger the release of methane, a greenhouse gas, into the atmosphere. This is potentially serious, as the methane in hydrates is very concentrated."

To harvest methane safely from hydrates, says Yun, engineers must prevent dissociation during recovery.

"Because the hydrate is under high pressure and is extremely cold, dissociation sets in and the ice begins to melt as soon as you remove hydrate from sediment," says Yun. "To preserve the *in situ* environment of hydrate and sediment, we must recover the material under hydrostatic pressure."

Dissociation, if done carelessly, can trigger the release of methane and lead to global warming, says Yun.

Yun has helped develop an Instrumented Pressure Testing Chamber (IPTC), which characterizes the hydrate-bearing sediment under pressure. The IPTC played a key role last year when Yun joined researchers from the Korean Institute of Geoscience in recovering hydrate-bearing sediment from the East Sea and preserving it in pressurized aluminum chambers. The chambers were aligned with the IPTC, and sensors measured the sediment's strength, electrical conductivity, and compressional and shear wave velocity.

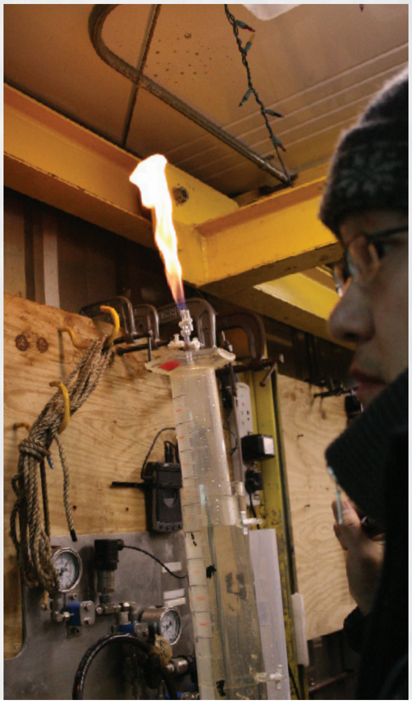
The sensors, together with x-rays, enabled researchers to identify the white veins of methane hydrate embedded in the sediment. An MRI of the chamber allowed researchers to see the orientations of hydrate seams and determine their thickness.

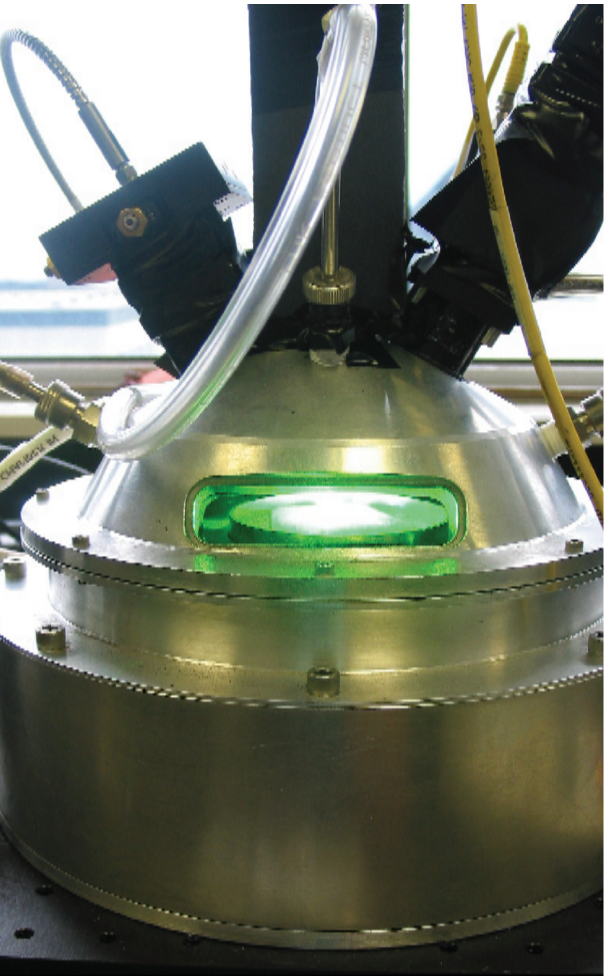
By enabling researchers to measure the properties of hydrate-bearing sediment under pressure, says Yun, the IPTC will help answer several critical questions. How much methane gas is inside each hydrate? And more importantly, how do the properties of the sediment change as gas is produced from hydrates?

"The driving question," says Yun, "is why the gas hydrate forms this kind of geometry in the sediment. Also, what are the mechanical, thermal and molecular properties of the gas hydrate and sediment?"

It will take a decade or more, Yun estimates, before researchers learn to harvest methane safely from hydrates.

"We need to understand fully how dissociation affects the sediment," he says. "This is a very complex phenomenon."





The LIBS system uses lasers and spectroscopy to obtain a distinct elemental signature of coal while it is being burned.

tion carbon-capture techniques, which require a flue gas temperature of 110 degrees F or lower for efficient operation."

SHINING A LASER LIGHT ON SLAGGING

Slagging – the accumulation of coal ash at high temperatures on the tubes carrying steam in a power plant boiler – costs power plants $2.4 billion a year, according to a recent report by the Electric Power Research Institute (EPRI).

ERC researchers have worked with the Energy Research Co. (ERCo) of Staten Island, N.Y., to develop an optical technology that lets plant operators make real-time adjustments to prevent slagging and fouling problems. Using laser-induced breakdown spectroscopy (LIBS) and artificial intelligence, the system provides instant analysis of the elemental composition of the coal as it is being burned. LIBS also correlates the fusion temperature of the coal ash, which is affected by the ratio of the elemental ingredients.

The new technology was successfully tested at Brayton Point Station, a coal-fired power plant in Massachusetts. The two-year project was funded by DOE through the New York State Energy Research and Development Authority. The researchers have won a second DOE grant to develop a commercial prototype.

LIBS uses a pulsating laser with two frequencies, one infrared and one visible light. The laser vaporizes a sample and gives a distinct elemental signature represented by intensity and wavelength. From these data, a software package containing artificial neural network models estimates ash-fusion temperature and predicts coal slagging potential.

Traditionally, says ERC associate director Carlos Romero, operators measure coal composition and ash-fusion temperature by taking a sample from a boiler and testing it in a lab. This can take days. Operators can also take measurements with a nuclear analyzer using gamma rays. But the analyzer has a large footprint, says Romero, and is potentially hazardous. LIBS is the size of a tabletop, is relatively safe to use and provides instantaneous data without interrupting the process.

"Our results have been very positive," says Romero. "LIBS analyzes coal composition accurately and with good repeatability. It also predicts ash-fusion temperature with results that compare very favorably with results obtained using standards of ASTM International."

CLEANER COAL THROUGH DRYING

Half the electricity in the U.S. is generated by coal-fired power plants, but many facilities burn low-rank coals. The moisture content in these coals can approach 40 percent, compared

ADDRESSING THE LOOMING SHORTAGE OF ENERGY ENGINEERS

Faced with a greater need for innovation than ever before, energy providers across the U.S. have placed a premium on developing the technical minds that will shape their industry's future.

Over the next decade, according to the Electric Power Research Institute (EPRI), almost half the technical professionals in the utility industry will reach retirement age. At the same time, the number of engineers entering the industry has been falling, while the demand for energy is expected to grow 50 percent in 20 years.

To help create a new pipeline of technical professionals, Lehigh is working to launch an Energy Systems Engineering Institute (ESEI) in collaboration with EPRI; the ESEI is an industry-university partnership that will serve as a center of excellence in education, research and technology transfer for the energy industry.

A goal of the ESEI, says John Coulter, associate dean for graduate studies and research in Lehigh's P.C. Rossin College of Engineering and Applied Science, is to create a new generation of professional leaders in energy systems engineering.

The centerpiece of the new institute, says Coulter, will be an intensive, 10-month Master of Engineering (M.Eng.) degree program in Energy Systems Engineering that will train science and engineering students to become future leaders in the energy industries.

Students in the proposed new M.Eng. program will complete courses in three core areas:

- Energy Generation, including coal, nuclear, oil and gas, fusion, and renewable energy sources such as wind and solar.
- Energy Management and Distribution, covering infrastructure systems, security, interconnections and distribution optimization.
- Energy and the Environment, including climate change, clean coal technologies and nuclear waste issues.

Students must also complete a project-management course as well as a hands-on research project related to a challenge facing the energy to 6 to 8 percent in high-rank coals, and it adversely affects a plant's performance and emissions.

Engineers at Lehigh's ERC and at Great River Energy (GRE) in North Dakota have developed a low-temperature coal-drying system that removes moisture from coal using heat rejected by the power plant. The 10-year project was funded by DOE and GRE. GRE is installing the new technology at its 1,160-MW Coal Creek Station, making the station the world's first to operate with 100 percent feed-dried coal.

Levy and ERC associate director Nenad Sarunac say that at Coal Creek the new technology will remove about a quarter of the moisture from low-rank coal, resulting in a 5 percent improvement in efficiency, a 5 percent reduction in CO_2 emissions, and larger reductions in emissions of NO_x, SO_x and mercury.

The cost of retrofitting Coal Creek with the new technology is relatively low compared to the cost of constructing a new plant that would operate as efficiently, researchers say. Given that low-rank coals constitute more than half the world's coal reserves, the patented technology could potentially be used on a global scale.

ERC researchers are working with U.S. and international companies to integrate the new system into an oxy-combustion power cycle and a coal-to-liquid plant.

industry. Students will focus on their individual interest areas through technical electives offered by Lehigh's engineering, chemistry and physics departments, and related studies in business, earth and environmental sciences, and political science.

ESEI and the proposed new M.Eng. program are the product of two years of planning by officials from Lehigh, EPRI and major utility companies, says Coulter. The program is expected to launch in 2009.

Coulter believes concerns over rising energy prices and energy's impact on the environment will be a boon to the new institute.

"Students who begin careers in the energy industries now will spend their lives working on globally important issues," he says. "This will be a very exciting field for engineers."

THE FUSION VISION

One of the most enticing – and elusive – sources of renewable energy is nuclear fusion, in which isotopes of H_2 join under extreme heat (up to 100 million degrees) to create helium atoms. Fusion has the potential to provide unlimited supplies of clean, safe energy, says Eugenio Schuster, assistant professor of mechanical engineering and mechanics. It emits no pollutants or greenhouse gases, it produces minimal radioactive waste, and it poses no threat of a large-scale accident.

An international team of engineers and scientists is building ITER, a $10 billion tokamak, or fusion reactor, in France. Their goal is to generate more energy from fusion – five to 10 times more – than is required to heat the hydrogen plasma. Schuster has ties with ITER researchers and with leading U.S. fusion research centers, including General Atomics in San Diego and the Princeton Plasma Physics Laboratory. He has organized workshops on fusion for DOE and NSF.

Schuster studies the conditions for a highly confined, stable hydrogen plasma. He seeks to control the shape of the plasma and the radial profiles of plasma variables such as density, temperature and current, while keeping the plasma free of magnetohydrodynamic instabilities.

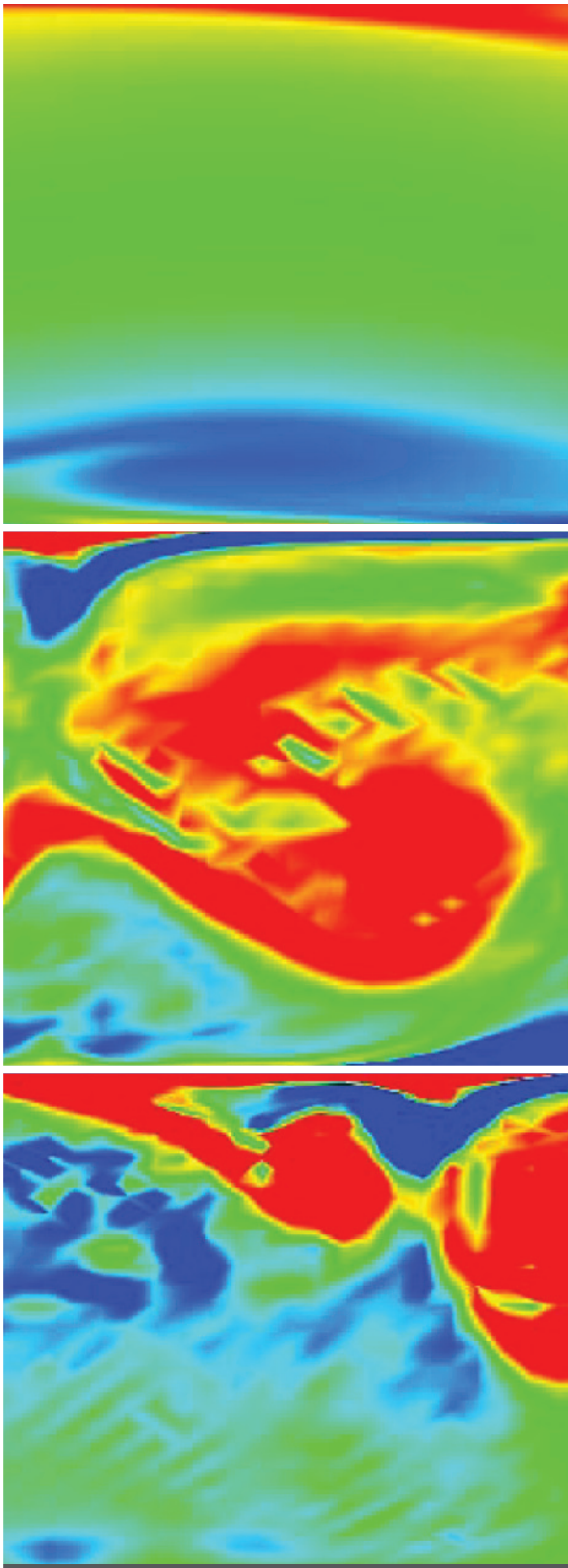
To understand the evolution of the plasma current profile, Schuster models the evolution of the related poloidal magnetic flux profile in normalized cylindrical coordinates. He uses a nonlinear partial differential equation called the magnetic diffusion equation.

By controlling the profile shape of the plasma's toroidal current, says Schuster, scientists hope to enhance the confinement of the plasma, and the steadiness of the fusion reaction.

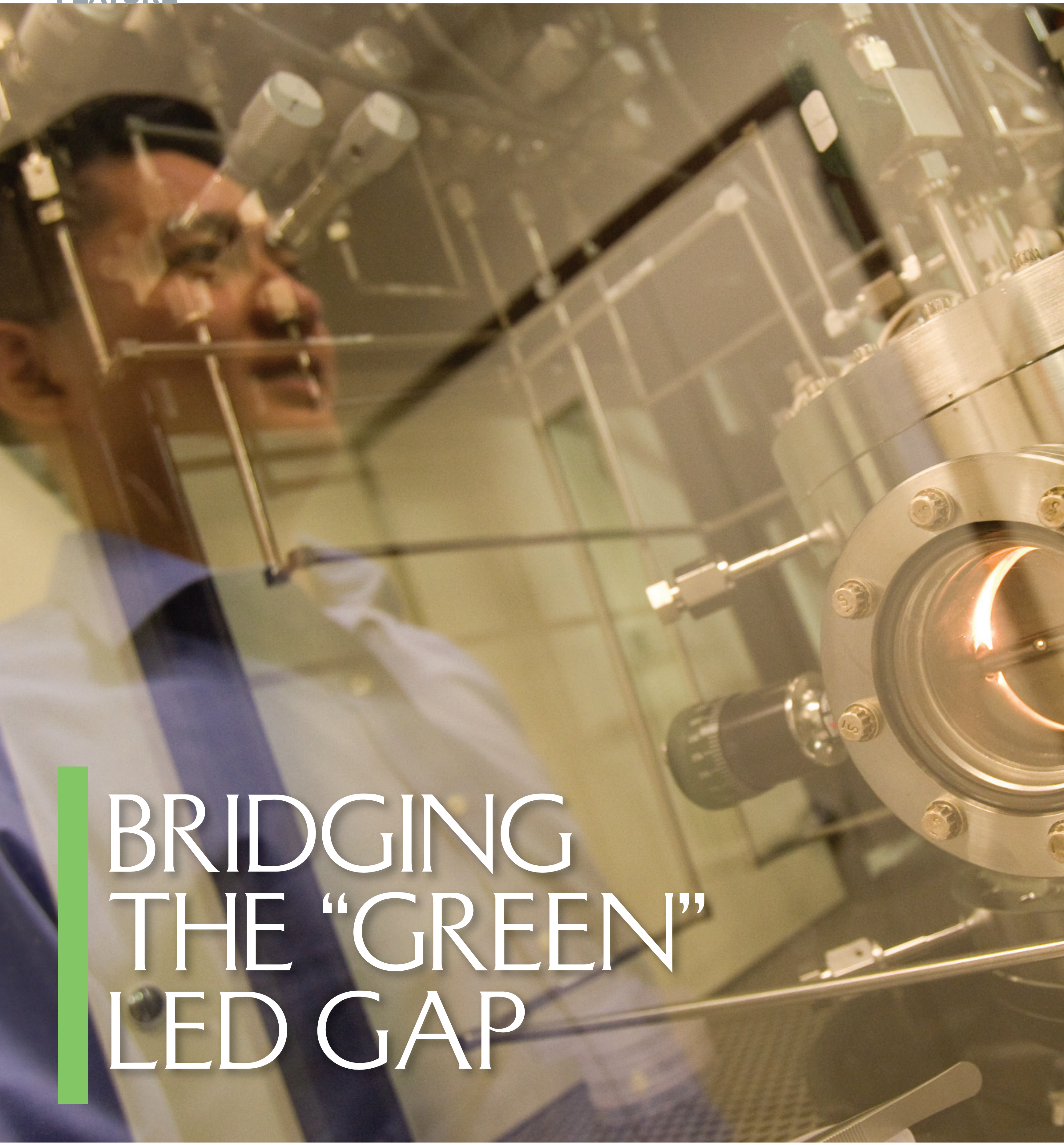
DOE regularly funds internships for Schuster's students at the DIII-D tokamak at General Atomics. This year, Yongsheng Ou and Chao Xu, two Ph.D. candidates, contributed a paper that was selected as a finalist for the Best Paper Award at the American Control Conference, the largest event of its kind in the U.S.

Experts say it could take 30 years or more before humans enjoy abundant fusion energy, but Schuster is optimistic.

"I'm confident this will be something I can tell my grandchildren about."

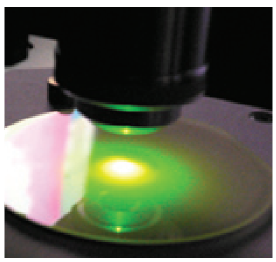


Schuster seeks to control the shape of the plasma and of the radial profiles of plasma variables while keeping it free of magnetohydrodynamic instabilities.



BRIDGING THE "GREEN" LED GAP

PHOTOGRAPHY BY DOUGLAS BENEDICT



CAN LEDs OUTSHINE FLUORESCENT LIGHTING?

Nelson Tansu thinks so. He is engineering nanostructures in the quantum wells of nitride semiconductors in an effort to boost the efficiency of green LED light – and thus the radiative efficiency of the overall white LED.

THE INCANDESCENT LAMP, ALSO KNOWN AS THE EVERYDAY LIGHTBULB, has done yeoman's work in lighting the world's buildings, flashlights and billboards since its invention in the late 19th century.

It has also come to represent one of the world's most notorious guzzlers of electric power.

When it is switched on, says the U.S. Department of Energy (DOE), the ordinary lightbulb becomes extraordinarily wasteful, dissipating 95 percent or more of its energy as invisible infrared light or heat.

This is no trivial loss of power. About one-third of the energy generated in the U.S., for example, is used to provide electricity, and about 22 percent of this electrical power is used to light buildings.

Not surprisingly, consumers are beginning to switch to fluorescent lamps, which are more energy-efficient and longer-lasting than lightbulbs. But fluorescent lighting uses mercury vapor, which poses environmental and health concerns.

A safer alternative to the lightbulb's meager return on investment, says Nelson Tansu, is solid-state lighting, which relies on light-emitting diodes. LEDs are already used in cell phones, car dashboards and the backlighting in the liquid crystal displays in laptops and TVs. They are also found in a growing number of traffic signals and city and highway billboards.

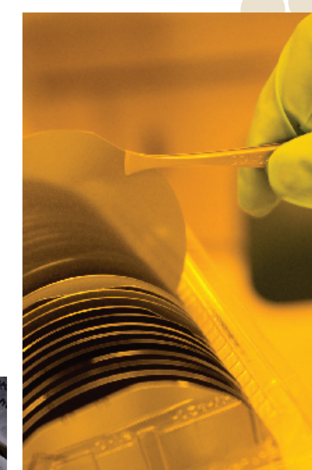
White LED light, says DOE's Sandia National Laboratory in its Web site, now achieves twice the luminous efficacy of a lightbulb and one-third that of a fluorescent lamp. In the future, however, LEDs could outpace incandescent lighting by 10 times while doubling the efficacy of fluorescent lighting.

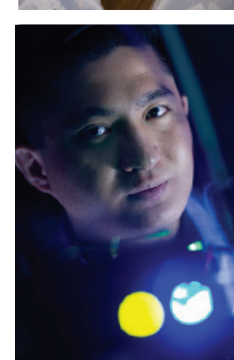
This promise will not become reality, however, until engineers overcome natural limits to the "radiative efficiency" of LED light that occur at the nanoscale.

Tansu and Volkmar Dierolf, an associate professor of physics, have received a three-year grant from DOE to study methods of improving the efficiency of white LEDs. Both are faculty researchers in Lehigh's Center for Optical Technologies (COT).

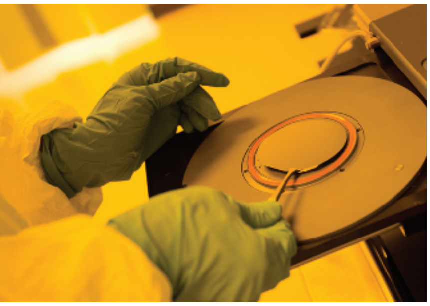
"We hope that by greatly improving the efficiency of the electrical power currently used for lighting," says Tansu, "solid-state lighting can significantly reduce the worldwide demand for energy, while providing reliable and environmentally friendly solutions."

The DOE award, matched in part by funding from the State of Pennsylvania, is being provided through DOE's





Tansu's group conducts research in Lehigh's Smith Family Laboratory for Optical Technologies, which contains state-of-the-art epitaxial growth facilities. The group is also applying semiconductors to solar cells and thermoelectric materials (see page 21).



DOE's goal – and Tansu's – is solid-state lighting that achieves 50 percent efficiency.

Solid-State Lighting Core Technology Research (CTR) Program. The agency's goal is to develop, by 2025, inexpensive and long-lasting solid-state lighting technologies that achieve 50 percent efficiency while reproducing the spectrum of sunlight.

The competitive CTR grants were awarded last year to five U.S. research groups. Two groups – Lehigh's and one from the Georgia Institute of Technology – are based at universities. The rest are led by industrial consortiums.

A GREEN LIGHT TO THE FUTURE

The light generated by an LED is emitted from a semiconducting material – usually indium gallium nitride (InGaN) or gallium phosphide (GaP) – within the LED.

An InGaN semiconductor emits light in the blue and green portions of the spectrum, and a GaP semiconductor emits light in the red spectrum. A white LED must mix these colors in the correct proportion to produce white light. It can achieve this through wavelength conversion or through color mixing, in which multiple LEDs, each one the size of a human hair, are combined in a single lamp to produce white light.

The catch, says Tansu, is the relative inefficiency of the green light produced by an LED. When combined with red and blue LED light to produce white light, this shortcoming limits the overall "radiative efficiency" of the white LED light.

> "We need to engineer the spatial position of both the electron and the hole carriers to increase the chance that they will overlap." —Nelson Tansu

The inefficiency of green LED light, says Tansu, stems from a phenomenon called the charge-separation effect, which occurs when electron and electron hole carriers are spatially separated inside the nanoscale quantum-well active region of LED devices.

In nitride LEDs, says Tansu, a large internal polarization field exists in the InGaN semiconductor quantum well that is required to generate green light. But the polarization field creates an electrical field inside the active region of the semiconductor, and the electrical field in turn promotes the separation of electron and electron hole carriers in the active region.

"This leads to a reduction in the radiative transition probability rate for electron and electron hole carriers in the active region that is responsible for generating light radiation," says Tansu.

To achieve a higher efficiency of green LED light and boost the radiative efficiency of the overall LED, Tansu is attempting to engineer a 2- or 3-nanometer structure which allows the electron and electron hole carriers to align more precisely.

"We need to engineer the spatial position of both the electron and the hole carriers to the center of the nanostructure-active region to increase the chance that they will overlap," says Tansu. "To do this, we use quantum mechanics to design the nanostructures for engineering the electron and hole wave functions, which will result in a significantly enhanced radiative efficiency."

Tansu reported the results of his work in 2007 in the *Proceedings of the IEEE/OSA Conference on Lasers and Electro-Optics (CLEO)* and in *Applied Physics Letters (APL)*. The *APL* article was coauthored with Ronald A. Arif and Yik-Khoon Ee, Ph.D. candidates and members of Tansu's group. *Laser Focus World* has also reported on Tansu's use of staggered InGaN quantum wells to enhance the radiative efficiency of nitride LEDs.

Tansu and his group, including Hongping Zhao, a Ph.D. candidate, are pursuing other approaches based on type-II nitride-based quantum wells and InGaN quantum dots. The results of these studies have been published in *APL* and the *Journal of Crystal Growth.*

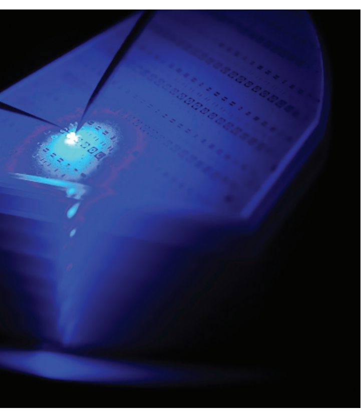
In a related effort to improve the efficiency of LEDs, Tansu and his group are experimenting with arrays of microlenses to extract, with greater efficiency, the light that is generated in quantum-well nanostructures but then trapped inside the structures in part because of the large refractive-index difference between gallium nitride and air.

The group has published the results of this research in *APL* in an article that was coauthored with James Gilchrist, assistant professor of chemical engineering at Lehigh, and Pisist Kumnorkaew, a graduate student in chemical engineering.

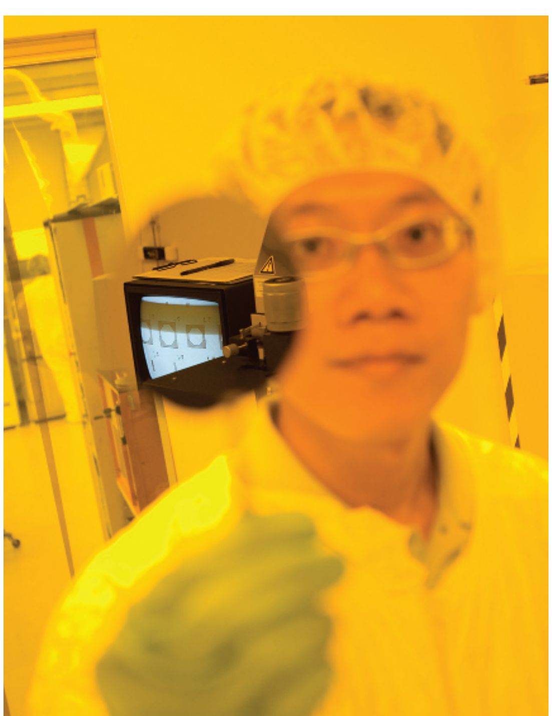
The group's work with microarrays was featured in 2008 in *Laser Focus World*, which said the arrays promised to improve light-extraction efficiency of LEDs while overcoming three challenges to previous extraction techniques – cost, scalability and process control.

Tansu is also collaborating with professors Rick Vinci and Helen Chan of materials science and engineering on research aimed at reducing defect density by decreasing the non-radiative recombination process in gallium-nitride semiconductors, which in turn will improve the radiative efficiency of the LED. This project is supported by NSF. Tansu's group has also received funding from NSF's Electronics Photonics Devices Technology research program. Tansu has filed patent applications on the microlens array and staggered quantum wells, as well as the type-II nitride-based quantum wells.

Tansu, Dierolf, Arif, Ee and Zhao are affiliated with the COT, while Gilchrist, Chan, Vinci and Kumnorkaew are affiliated with the university's Center for Advanced Materials and Nanotechnology.



Tansu's work has been featured in Laser Focus World *and* Applied Physics Letters.



A SEMICONDUCTOR'S SOLAR PROMISE

Indium gallium nitride (InGaN), the same semiconductor that emits LED light, also shows promise in converting solar energy more efficiently into electricity and in capturing heat energy wasted by cars, computers and manufacturing plants.

Nelson Tansu and his group are investigating both applications.

When its ratio of gallium to indium is adjusted, says Tansu, an InGaN-based semiconductor can be engineered to cover almost 95 percent of the sun's wavelengths, potentially achieving a solar-to-electricity conversion efficiency of 40 to 50 percent. Conventional silicon-based solar cells achieve a conversion efficiency of 11 percent. The greater range of lightwave absorption results in the generation of a larger number of electron-hole pairs, increasing the potential for electricity production.

The key to InGaN's solar potential, says Tansu, is the material's large energy bandgap range, which extends from .7 to 3.4 electron volts. By adjusting the compound's Ga/In ratio, engineers can fine-tune the tandem cell configuration to develop a solar cell device capable of capturing lightwaves spanning ultraviolet to infrared with minimal loss of energy.

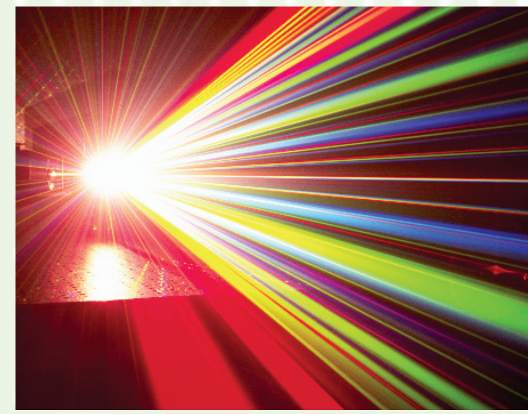
"The ability of InGaN to cover almost the entire solar spectrum," says Tansu, "makes it an excellent material candidate for developing nearly full-spectrum, high-efficiency solar cells."

Tansu's group uses Metal Organic Chemical Vapor Deposition (MOCVD) epitaxy to grow single crystals of InGaN with varying indium content on substrates of sapphire and silicon. Their goal is to assemble a tandem solar cell in which individual cells with different bandgaps are stacked in order to maximize the efficiency of solar energy conversion.

"By including several compositions of the material in the same cell," says Tansu, "we hope to trap photons of varying energies from the solar spectrum at the optimum bandgaps of tandem cells, thus generating electrons and holes with minimum thermalization energy loss. These electrons and holes can then be transported out of devices with optimum power conversion efficiency."

InGaN and other nitride materials enjoy a potential advantage over existing tandem cell technologies, says Tansu.

"Current tandem cell technology is very expensive because it requires three or four classes of semiconductors, which can necessitate multiple growths in different reactors. The advantage of nitride semiconductor technology is that you can grow the entire tandem cell in a single epitaxy in a single reactor."



The thermoelectric properties of InGaN semiconductors also enable them to convert thermal energy efficiently into electricity, says Tansu.

"A lot of heat is wasted by industrial equipment, cars, refrigerators, etc. The challenge is to convert that lost heat energy to electrical energy."

A thermoelectric material converts heat into electricity when variations in its temperature generate voltage differences. This so-called Seebeck effect triggers a flow of electrons. The challenge is to develop a thermoelectric material with a large Seebeck voltage that conducts electricity well without transferring heat.

"We're investigating InGaN and other nitride semiconducting materials," says Tansu. "We think they could make viable thermoelectric materials because of their high electric conductivity and poor thermal conductivity."

The group is focusing on phonons, the discrete nanoparticles of vibrational energy that trigger the transfer of energy within a crystal lattice.

"We're using nanotechnology to design a structure in which the electron travels rapidly through the semiconductor while the phonon's propagation is minimized by the phononic bandgap," says Tansu.

An interdisciplinary team of graduate students helps PPL Corp. determine the optimum mixture of bonds, including notes with both fixed and floating interest rates, to issue.

Where engineering and math

A new master's program draws power from collaboration

With a generating capacity exceeding 11,000 megawatts, PPL Corp. provides electricity to 4 million customers in Pennsylvania and the United Kingdom.

The power company, based in Allentown, Pa., is itself powered partly by investors who purchase its debt in the form of bonds. Like any borrower, it must repay its original loan plus interest.

But PPL can choose the type of interest rate it offers on its bonds. It can issue bonds with a fixed rate of interest or bonds with interest rates that rise and fall with fluctuations in the market. These floating rates, which are often based on the interest rates banks offer each other, are adjusted daily, weekly, monthly, quarterly, or at any other determined interval.

Because of their volatility, bonds with floating interest rates are considered riskier than traditional bonds. They have the potential, however, to yield significantly higher savings.

In September 2007, PPL turned to students in Lehigh's analytical finance program for help in determining the type and number of bonds it should issue to finance its 10-year debt.

Lehigh's M.S. in analytical finance draws students from business, mathematics and engineering and trains them to develop and implement solutions to complex, often highly quantitative problems in the finance industry.

The goal for the 14 students in last year's class was to create a mathematical tool that would adapt to changes in interest rates over time to minimize both risk and total interest paid.

The students began by trying to identify drivers of the LIBOR (London Interbank Offered Rate), a standard often used to set floating interest rates. Theoretically, these drivers could be used to determine future rates.

"We included many different variables, like the slope of the yield curve," said Drew Garrabrant '07, '08G, who holds a B.S. in industrial engineering.

Erdem Aktug, an analytical finance student pursuing a Ph.D. in economics, analyzed the initial results and discovered that the variables the students had included could not predict trends in the LIBOR. Instead of determining future LIBOR trends, said Aktug, these variables were themselves influenced by LIBOR.

In theory, the students realized in retrospect, they should have been able to gather information on current rates, determine the different risks associated with both fixed and floating rates, predict future rates and build

meet finance

models showing the optimal mix of bonds.

In reality, this task proved more difficult than anticipated. This was partially because floating rates have historically been lower than fixed rates, and could not therefore be used to forecast all future scenarios.

Back to square one

"It was interesting to see this contrast between theoretical models and what's realistic to expect from the data, and then watch the students try to reach a middle ground," said Aurelie Thiele, the P.C. Rossin Assistant Professor of industrial and systems engineering and the team's faculty adviser.

"I was very impressed with how ethical the students were."

The students turned for advice to a Morgan Stanley investment banker, who showed them the methods he had used to create investment portfolios. With a month remaining, the team changed its approach. Instead of trying to predict movements in interest rates, the students compared various ways of determining the optimum mixture of bonds PPL could issue.

"Historically, the floating rates offered to PPL were lower than the fixed rates."

—Erdem Aktug, analytical finance student

On May 12, the team presented its findings to James Abel '72, '76 MBA, PPL's vice president of finance and treasurer, and Russell Clelland '83 MBA, PPL's assistant treasurer.

The students were disappointed that they could not predict future interest rates. But they were able to recommend that PPL increase the number of floating bonds it issued.

"Historically, the floating rates offered to PPL were generally lower than the fixed rates," Aktug said.

The students also advised PPL to set bond rates based on a dynamic model, which would adjust over time, from its current static approach, which does not.

"It's now up to management to adopt the appropriate strategy," said Aktug. If PPL adopts a dynamic model, he added, it will have to hire an expert in financial modeling and pay additional research and transaction costs.

"I think this project offered students a taste of what life will be like after graduation," said Thiele. "In real life, problems are not that well-defined and you don't necessarily have all the information you need."

Thiele said the PPL executives were impressed with the students' work.

"They realized it was a high-quality report. They liked that we gave them the findings and the conclusions. We narrowed their options and saved them time," she says. "They were very pleased."

An engineering touch for financial analysis

In just four years, Lehigh's M.S. program in analytical finance has earned a solid international reputation.

For the 2007–08 academic year, the program received 108 applications and admitted 36 students. For the 2008–09 academic year, applications skyrocketed to more than 250.

Two-thirds of the program's current students hail from developing countries with growing economies.

"We have applications from students in the top schools in China and India," says Vladimir Dobric, professor of mathematics and one of three program codirectors. "Students who come here are informing other students about the program."

The analytical finance program is a collaboration among the departments of economics, finance, mathematics, and industrial and systems engineering. It blends concepts in financial theory, mathematical finance and engineering decision-making to train students to create and implement solutions to complex financial issues. Students complete an industry project that prepares them for careers as financial analysts, hedge fund managers and consultants.

The program was the first graduate program to receive a grant from Wall Street West, a nonprofit partnership in Pennsylvania that funds financial institutions outside of New York City to act as a backup in case of a disaster.

Students work in Lehigh's state-of-the-art Financial Services Lab, which offers access to the real-time data used by firms on Wall Street.

"Analytical finance is a very rigorous program," says Robert Storer, program codirector and professor of industrial and systems engineering. "It is very focused on financial mathematics and is deeper than other interdisciplinary programs."

Richard Kish, professor of finance and the program's third codirector, says analytical finance not only grooms students for jobs on Wall Street but also prepares them to "fill the niche between the front and back offices of banks and financial institutions.

"In the back office they do mathematics, and in the front office they sell products. There's a need for people who understand both that can act as a go-between."

Surviving an increasingly noisy world

You're in a crowded, noisy room raising your voice to be heard. Everyone else is doing the same, and the cacophony makes you wish you knew sign language, because conversation is out of the question.

The same problem occurs in wireless communications, says Tiffany Jing Li, the P.C. Rossin Assistant Professor of electrical and computer engineering.

As a growing variety of messages vies for bandwidth, says Tiffany Jing Li, data must become more robust so it can be transmitted without drowning in noise.

Many wireless conversations over a radio frequency band spell trouble, because distorted signals interfere with each other and cause errors.

When Li thinks of magnetic data storage devices, she pictures millions of tiny Post-It notes crammed together. As notes are added and space becomes tighter, things get unstable and you can find yourself reading a few of your neighbor's notes in addition to your own.

Li's research is in a field known as error correction coding. She seeks to accommodate, in a limited-frequency bandwidth or storage space, the rapidly increasing global appetite for cell phones, text messaging, multimedia streaming, optical signals and hard disk drive storage. Her coding helps prevent an unacceptable rate of errors by making data robust enough to be transmitted across devices without drowning in noise.

What is an acceptable rate? With voice, says Li, it's one error per thousand signals; with text, one per million; with optical, one per billion; and with data storage, one per trillion.

Li does coding research for WiMax (Worldwide Interoperability for Microwave Access), a standards-based technology that enables the delivery of last-mile wireless broadband access as an alternative to cable and DSL. Her coding will enable cameras to transmit photos wirelessly to computers, allow handhelds to exchange data and multimedia files reliably, and improve the quality of digital video broadcasting over the Internet.

In digital video broadcasting, a "tail-biting" code chases the signal and makes corrections after one trial transmission. The Mobile WiMax standard (IEEE 802.16e) and Digital Video Broadcast (DVB) standard adopt tail-biting codes, whose "code trellis" must start from an initial state that coincides with the end state. The current encoding method must run through the entire encoding module two times, the first time to feel out the possible end state so that the correct starting state can be initiated, and the second time to actually encode the data.

"We have a smarter way," says Li. "We can cleverly predict the end state without needing to run through the code trellis. It's twice as fast."

"We are entering a new world, and noise levels are about to increase substantially. But we'll handle it." —Tiffany Jing Li

Li also has found a better way to disseminate data in broadcasting. Currently, 10 or 20 "packets" of video are broadcast wirelessly at one time to many receivers. If one packet is not received by any of the destinations, all 20 are re-broadcast.

"This is inefficient," she says. "Instead, our code sends 30 packets, so even if you don't receive a few, you will have everything you need."

Li also has developed new classes of "digital fountain codes" for disseminating data in broadcasting or multicasting. A digital fountain encodes a set of data packets into an infinite sequence of coded packets or "digital drops," any of which can be used to reconstruct the original set of data packets.

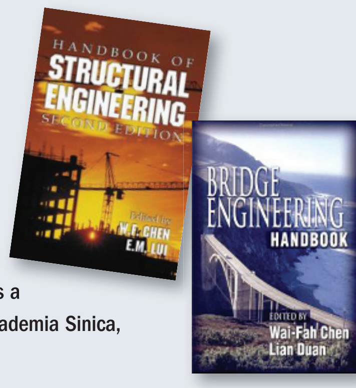
Consider, for example, that 50 people are simultaneously downloading a video clip from YouTube. A 15-second clip often consists of 400 frames of images, which are transmitted in a string of data packets. Because of channel noise, packet collision and buffer overflow, some data packets will be lost or corrupted. Resending the missing packets is costly. But by using digital fountain codes, the set of images can be encoded into many coded packets and transmitted continuously to end users. Some packets get lost, but as long as each user's computer receives enough packets, it can reconstruct the original video clip.

Li says these smart codes have applications in teleconferencing, online-classroom, e-medicine, Internet TV, video-on-demand, and digital video broadcasting. She and her students have found new ways to construct these codes, some of which will likely outperform the best-known fountain codes.

Li is also developing error-resilient coding solutions for hostile environments such as disaster recovery and battlefield communications. Her work is supported by NSF and industry. "These new codes will become increasingly critical to our way of life," she says. "We used to use the Internet for just e-mail and Web surfing, but now we're using it for peer-to-peer content distribution. We are entering a new world, and noise levels are about to increase substantially. But we'll handle it."

Lehigh Engineering: Producing Top Scholars

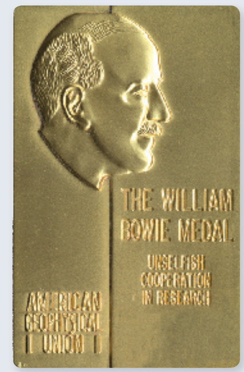
Lehigh alumni have made significant contributions to the scholarly pursuit of engineering. Here are a few examples:



Wai-Fah Chen

Civil Engineering, M.S., 1963

Chen advanced the mathematical theory of plasticity in civil engineering, especially in applying limit analysis methods to geotechnical engineering. He is a member of NAE and an Academician of Academia Sinica, Taiwan's premier academic institution.



William Bowie

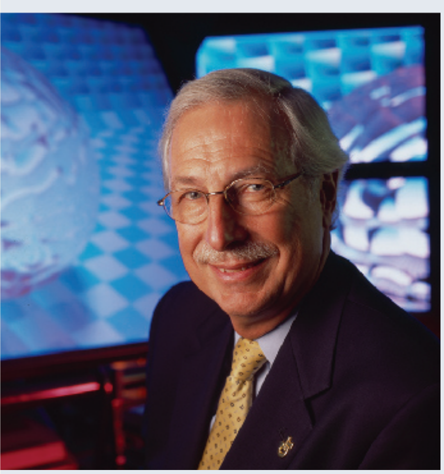
Civil Engineering, B.S., 1895, Ph.D., 1922

Bowie helped unify the triangulation system of North America and establish the American Geophysical Union, whose highest honor is named after him. He was elected to the NAS and to the French Academy of Sciences.

Kenneth R. French

Mechanical Engineering, B.S., 1975

French holds an endowed professorship in finance at Dartmouth's Tuck School of Business. A member of the American Academy of Arts and Sciences (AAAS), he helped develop the "three factor model" that challenges traditional thinking about capital asset pricing in financial economics.



James Foley

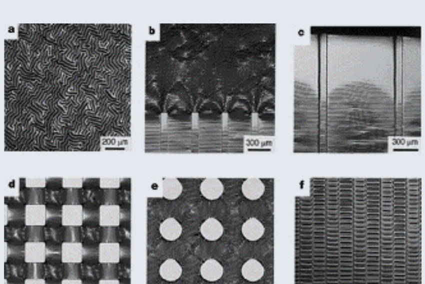
Electrical Engineering, B.S., 1964

Foley coauthored the text *Fundamentals of Interactive Computer Graphics*, perhaps the most authoritative work in the field. The founder of Georgia Tech's Graphics, Visualization and Usability Center, Foley is also CEO of MEITCA and an NAE member.

John Hutchinson

Engineering Mechanics, B.S., 1960

One of the youngest professors ever to receive an endowed chair at Harvard, and a member of NAE, NAS and AAAS, Hutchinson is internationally recognized for contributions to solid and structural mechanics and the mechanics of materials.



James Rice

Theoretical Mechanics, B.S., M.S., Ph.D., 1964

One of the most accomplished engineering scholars of the last half century, Rice is credited with discovering the "J-Integral," a critical concept in fracture mechanics. He is a member of NAE, NAS, AAAS and the Royal Society of London.

To learn more about the achievements of Lehigh engineers, visit the Lehigh Engineering Heritage Initiative at

www.lehigh.edu/heritage

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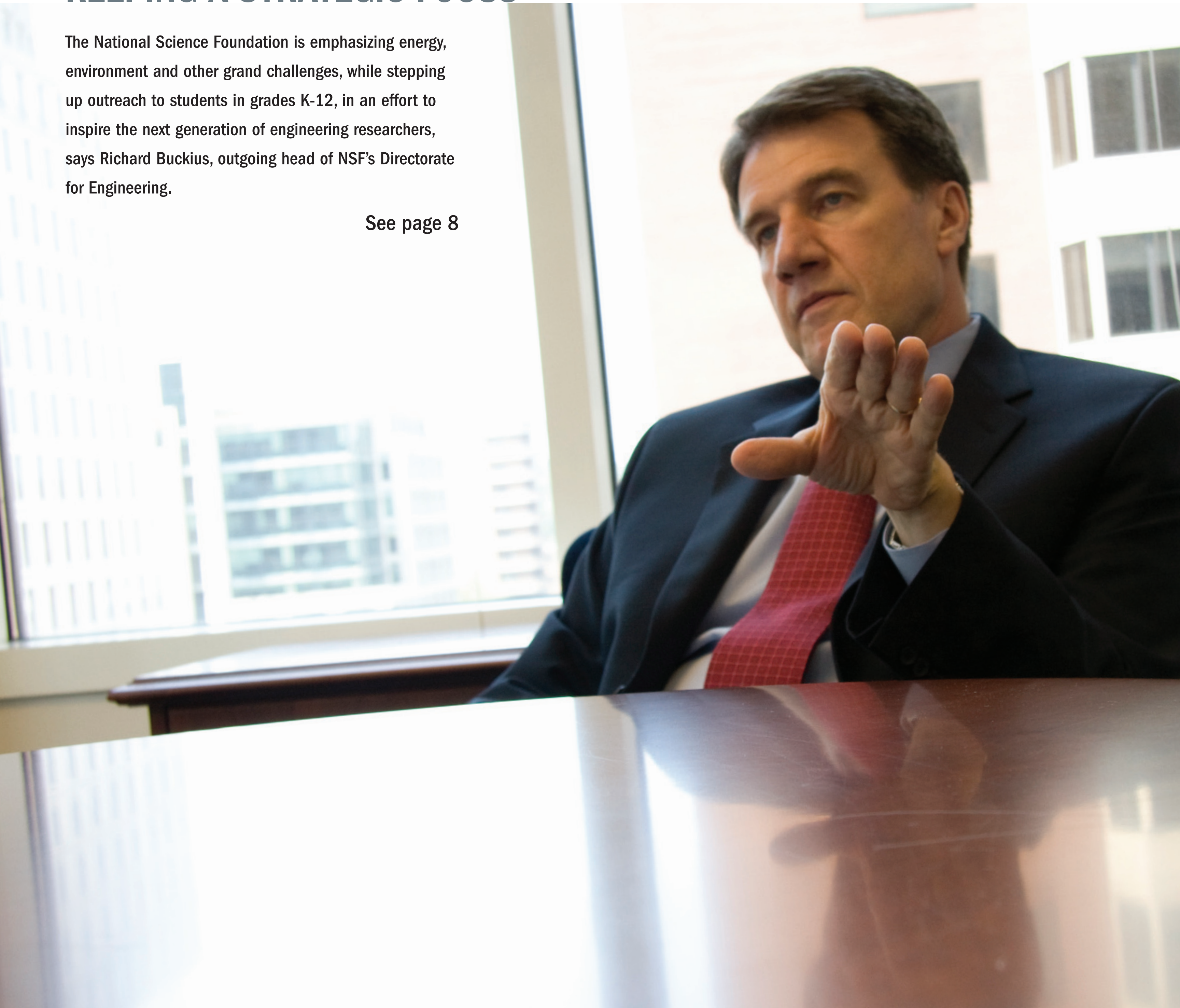

The National Science Foundation is emphasizing energy, environment and other grand challenges, while stepping up outreach to students in grades K-12, in an effort to inspire the next generation of engineering researchers, says Richard Buckius, outgoing head of NSF's Directorate for Engineering.

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