Optical Technology

Interdisciplinary Team Finds New Insights into How Feathers Produce Color

Assisted Living

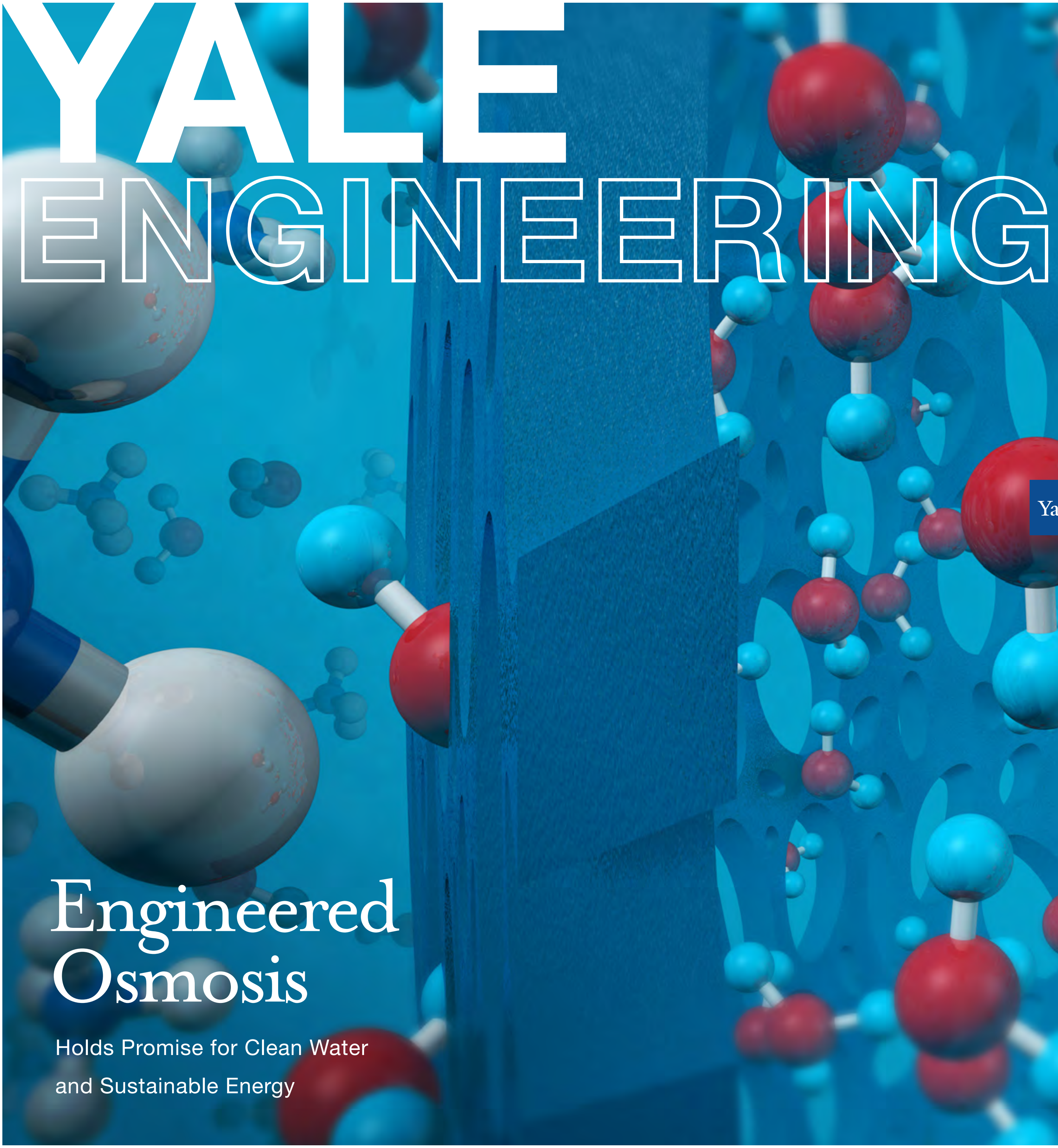
"Smart" Cameras and "Intelligent" Sensor Networks Provide Independence

Beyond Theoretical

Engineering Undergrads Practice Sustainable Engineering Around the Globe

2009

YALE ENGINEERING



Engineered Osmosis

Holds Promise for Clean Water and Sustainable Energy

Yale

The Publication of Yale's School of Engineering & Applied Science

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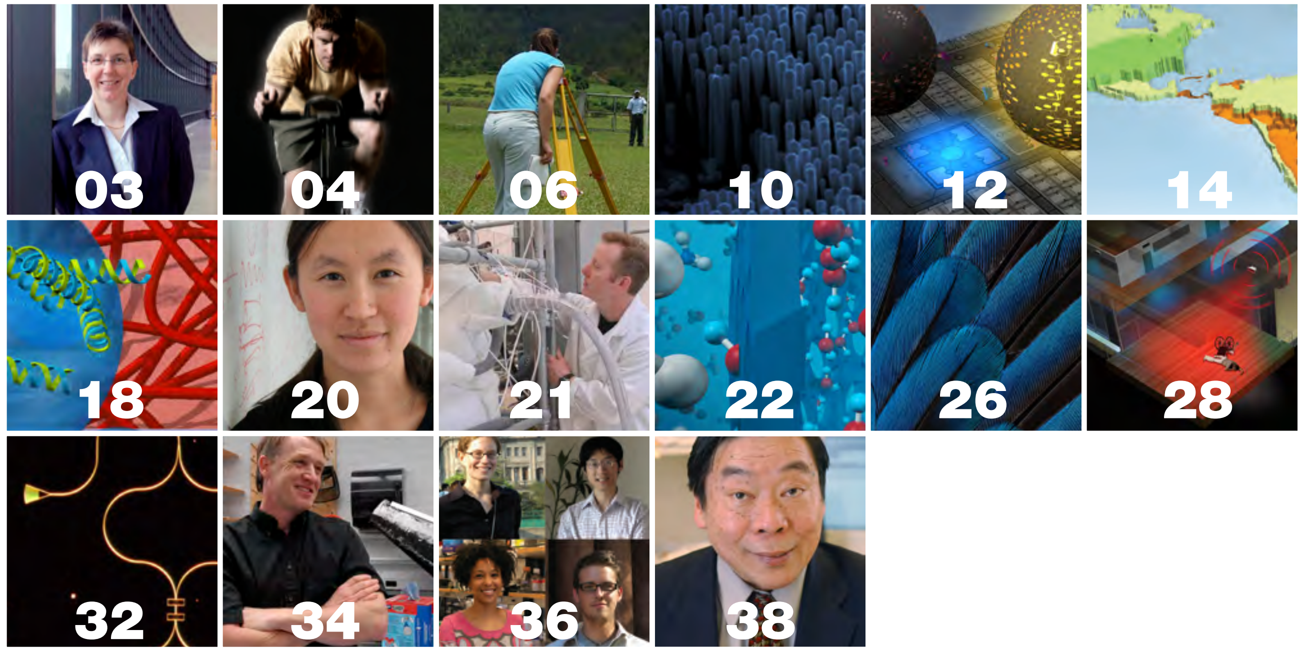

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Message From the Dean

As every engineer knows, forces can be applied by either pushing or pulling. Great research universities are elevated by both types of actions: undergraduate students do the pushing and graduate students do the pulling. The undergraduates push on the university as a whole. For the most part, students apply to Yale because of the sum of its parts (the multitude of academic and nonacademic components). As such, the undergraduate student and alumni base establishes the overall reputation and general character of the university. The primary parts of the whole are, of course, the academic departments and programs - six in the case of Engineering (biomedical engineering, electrical engineering, mechanical engineering, chemical engineering, environmental engineering, and applied physics). Graduate students generally base their decision on whether to attend a particular university on the research opportunities, standing, and culture provided in their intended areas of study. In turn, the reputation of a department is established by the quality and achievements of its graduate student and alumni base. By pulling up departments, the university as a whole is further elevated.

Engineering at Yale is on the move and our new magazine is designed to showcase the many pushes and pulls that are boosting us to new altitudes. Much of our momentum is related to the exciting range of research opportunities found throughout the School of Engineering & Applied Science. What we lack in mass (we are a smaller School of Engineering by national standards), we make up for in our velocity of scientific breakthroughs and technological innovation. All of our accomplishments are directly fueled by the creative energy of our students and faculty, working closely together in the collaborative and stimulating environment that makes Yale so special. If there is one place where this kind of energy is not in short supply, it is at YALE ENGINEERING.

"Green" Workout

Electrical Engineering Student Harvests the Energy of Exercise

Yale fitness enthusiasts have found a new way to charge their electronics at the Adrian C. Israel Fitness Center of the Payne Whitney Gym. This past spring, PRECOR exercise bikes were retrofitted to harness the energy produced by riders to charge iPhones, iPods, BlackBerry smart phones and Nokia cell phones. The "green" workout demonstration was part of a Senior Project by Henrique Rocha, a 2009 graduate in Electrical Engineering who conducted his research under the supervision of associate professor of electrical engineering, Hür Köser.

This is only the first step, according to Köser. Interest in energy harvesting has led Köser's group to find innovative ways of making use of waste energy – or that which is not used to do work – as a means of reducing demands for electrical power inputs. With the looming threat of global climate change and increasing demand for energy independence, the search for such alternative energy sources is ever important.

In the "green" workout concept, Köser draws attention to the fact that most stationary exercise equipment – elliptical, bicycle and rowing machines – are already equipped with a small alternator that generates electricity from the user's motion to power up their control panel. However, only a fraction (less than ten percent) of the energy generated by the user's motion is actually used, which means that more than 90 percent of the harvestable energy is lost – eventually dissipated as heat.

Rocha calculates that a moderate workout produces about 100 Watts (W) of excess electrical power that needs to be dissipated and that a regular exerciser could easily produce 200 – 250 W – more than enough to power and charge a variety of small electronic devices.

Recently expanded to the remaining 40 compatible machines in the gym, this technology has the potential to harvest enough energy to power gym light fixtures, televisions and other utility devices. In fact, the combined electrical generating capacity would be around 10 kW – enough to power several average-sized households.

Photo /
Yale Gym members can now charge electronics on exercise machines.

"Our main purpose," says Köser, "is to create energy awareness in the Yale student and staff community, as well as the general New Haven and Connecticut population." The benefit of using exercise to charge personal electronic devices is particularly interesting. When you consider the fact that most personal electronic devices are charged overnight out of user convenience and that charger adapters continuously dissipate energy, especially after the battery has been fully charged, energy is wasted. While the impact may be modest at the individual level, when you take into account the 250 million cell phone users in the U.S. alone and the millions of portable power tools, digital cameras and laptops, this wasted power exceeds 520 MW – the equivalent of several dozen medium-size coal-burning power plants.

"Educating exercisers about this fact is a first step in achieving a more energy-aware society," says Köser. "At this initial stage, we need user feedback. I would encourage our fellow engineers and regular exercisers to try the system and see how long they can go without ever plugging in their mobile electronic device."

In collaboration with the Yale Athletics Department, Yale Office of Sustainability and Yale Information Technology Services, Köser and Rocha moved from prototype to a full-gym scale-up. The next phase may include a wireless sensor network and large information board or an iPod app that will inform users of how much they are contributing to a greener environment through exercise.

Rocha received the 2009 Franz Tuteur Prize for best Senior Project in the Department of Electrical Engineering.

Beyond Theoretical

Engineering Undergrads Practice Sustainable Engineering Around the Globe

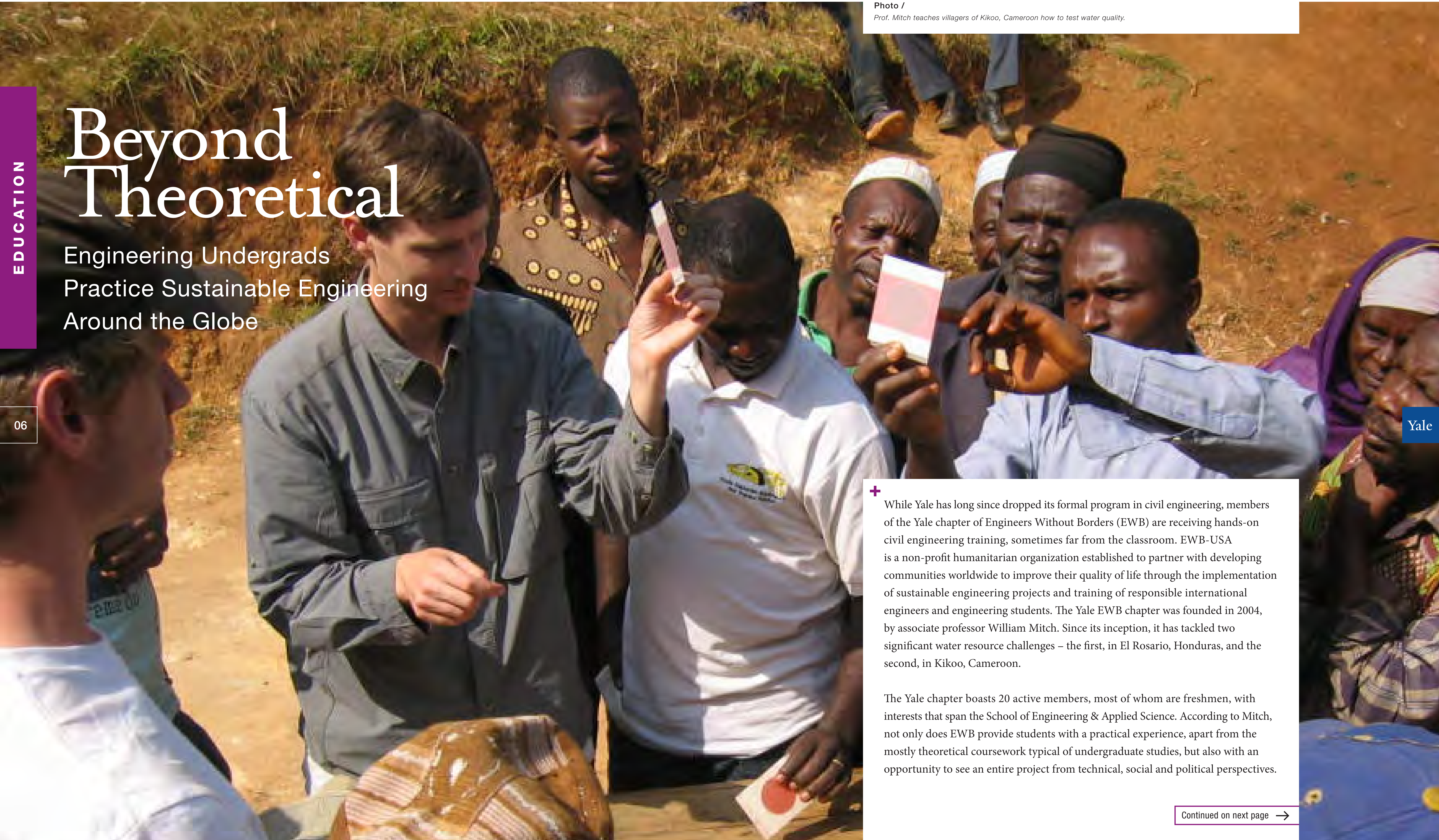

Photo /
Prof. Mitch teaches villagers of Kikoo, Cameroon how to test water quality.

While Yale has long since dropped its formal program in civil engineering, members of the Yale chapter of Engineers Without Borders (EWB) are receiving hands-on civil engineering training, sometimes far from the classroom. EWB-USA is a non-profit humanitarian organization established to partner with developing communities worldwide to improve their quality of life through the implementation of sustainable engineering projects and training of responsible international engineers and engineering students. The Yale EWB chapter was founded in 2004, by associate professor William Mitch. Since its inception, it has tackled two significant water resource challenges – the first, in El Rosario, Honduras, and the second, in Kikoo, Cameroon.

The Yale chapter boasts 20 active members, most of whom are freshmen, with interests that span the School of Engineering & Applied Science. According to Mitch, not only does EWB provide students with a practical experience, apart from the mostly theoretical coursework typical of undergraduate studies, but also with an opportunity to see an entire project from technical, social and political perspectives.

Continued on next page →

EDUCATION

Photo /
Without electricity, surveying equipment is critical to determine which areas of the Cameroon village can be reached by the gravity flow of water.

Photo /
EWB student, Noah McColl, visits with residents of Kikoo, Cameroon.

Yale

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This past December, EWB made their third trek to Kikoo, Cameroon, a village whose primary drinking water source, until recently, was "essentially a modified open sewer," says Mitch, ripe with E. Coli and fecal coliforms. In their first trip, they located springs, tested their water quality, and performed an initial survey to enable the design of a system to convey clean spring water to the 1,000 villagers. In August of 2007, a new crop of students returned to implement the designs.

With the support of the villagers, in excess of 10,000 man-hours, the students were able to successfully supply spring water to a portion of the community. "There's no running to Home Depot for supplies," says Mitch. To obtain sand and gravel for concrete, the villagers and students located sand borrow pits and chipped gravel from bedrock outcrops. "I like to think of it kind of as a cross between theoretical engineering and Gilligan's Island engineering. You have to think on your feet while you're out there and come up with solutions on the fly."

When EWB returned this December, they brought yet a new crew of students – five in total – and more sophisticated surveying equipment. Because electricity is not available, a more accurate survey was needed to evaluate which elevations within this hilly community could be reached by gravity flow alone. "They're competent plumbers," says Mitch of the villagers, but the surveying equipment helps make sure they don't needlessly waste money by putting a standpipe in a location where they cannot get water.

The team also led sanitation classes in the primary school and taught village leaders how to periodically test the system for bacterial contamination. Lastly, the team met with village elders about the village water committee's progress in collecting funds for system maintenance and repair. "For the most part, the project has been driven by interest from the village versus an outside NGO," says Mitch. This is critical for long-term sustainability, which is often an issue in the developing world.

For Elizabeth Marshman, co-president of Yale EWB, "it has been amazing to see how technical expertise can make such an impact." As a biomedical engineering student, she reminds us what might be possible "if there was only clean water." The students recognize the significance of what a little technical expertise and surveying technology is doing for this village and are glad to be a part of it.

At this point, there is no mark on the calendar for their next trip. While there is no shortage of student interest, funding is always an obstacle to overcome. Until enough funds are secured, they will move ahead, as they have in the past, with design plans and training workshops in the local area. Before students embark on their next project abroad, they must have a firm understanding of the work they will be doing. For that reason, EWB welcomes and encourages alumni and industry partners to share their knowledge and expertise in hands-on training activities. In addition, they gladly take donations of old equipment.

Visit the Engineers Without Borders / Yale Chapter website

www.yale.edu/ewb

Photo /
SEM image of bulk metallic glass mold at the Nanoscale.

Photo / credit - Mark Morosse/Yale Alumni Magazine
Last year Schroers was contacted by Chanel and asked if he could reproduce Chanel's signature perfume bottle in metal. Not a problem, according to Schroers.

TECHNOLOGY

Metallic Glass

Revolutionizing Nano-fabrication to Develop "Stronger than Steel" Computer Chips

Yale engineers have created a process that may revolutionize the manufacture of nano-devices – from computer memory to biomedical sensors – by exploiting a novel type of metal that can be molded like plastics with nanoscale detail, yet is more durable and stronger than silicon or steel.

The search for a cost-effective and manageable process for producing higher-density computer chips with nanoscale precision has been a challenge, according to Jan Schroers, professor of mechanical engineering and senior author of the breakthrough research reported in the February 12, 2009, issue of *Nature*. Nanoimprint lithography – a molding process – is one technique that holds promise, but requires stamps or master molds with nanoscale features. While silicon-based molds produce relatively fine detail, they are brittle and fail after limited use; metals are stronger, but their grains are too large to allow for nanoscale detail.

For the past ten years, Schroers, has been exploring the use of amorphous metals known as "bulk metallic glasses" (BMGs), understanding that they may hold the key. BMGs do not form crystal structures when they are cooled rapidly after heating and although they seem solid, they are more like a very slow-flowing liquid that has no structure beyond the atomic level – a characteristic that makes them ideal for molding fine details.

"We have finally been able to harness their unusual properties to transform both the process of making molds and producing imprints," Schroers said. "This process has the potential to replace several lithographic steps in the production of computer chips."

Schroers says BMGs have the pliability of plastics at moderately elevated temperatures, but they are stronger and more resilient than steel or metals at normal working temperatures. "We now can make template molds that are far more reliable and lasting than ones made of silicon and are not limited in their detail by the grain size that most metals impose," said Schroers.

To actually get detail at the nanoscale, the researchers had to overcome an issue faced in any molding process – how to get the material to cover the finest detail, and then how to separate the material intact from the mold. Surfaces of liquid metals exhibit high surface tension and capillary effects that can interfere in the molding.

Postdoctoral fellow, Golden Kumar, found that by altering the mold-BMG combination they could create surfaces so that the atoms take advantage of their favorable interaction with the mold – to both fill the mold and then release the product.

Schroers' team reports nano-patterning of details as small as 13 nanometers – about one ten-thousandth the thickness of a human hair – and the scientists expect that even finer detail will be possible. "Theoretically, the size limit is the size of a single atom," says Schroers.

"Plastics revolutionized society when they were first invented 50 years ago. I expect that will happen again as these metallic glasses combine the best of metals and plastics to eventually replace both."

Yale

Illustration /
Nanosensors (gray) integrated in an electronic chip can be singly activated by a specific type of T cell.

MEDICAL INNOVATION

Disease Detectors

Nanowire Sensors Identify Highly Specific Antigens with Speed and Sensitivity

Yale scientists have created nanowire sensors, coupled with simple microprocessor electronics, that are both sensitive and specific enough to be used for point-of-care (POC) disease detection.

As reported in the October 8, 2008 issue of *Nano Letters*, the sensors use activation of immune cells by highly specific antigens – signatures of bacteria, viruses or cancer cells – as the detector. When T cells are activated, they produce acid, and generate a tiny current in the nanowire electronics, signaling the presence of a specific antigen. The system can detect as few as 200 activated cells.

In earlier studies, these researchers demonstrated that the nanowires could detect generalized activation of this small number of T cells. The new report expands that work and shows that the nanowires can identify activation from a single specific antigen even when there is substantial background "noise" from a general immune stimulation of other cells.

Describing the sensitivity of the system, senior author Tarek Fahmy, assistant professor of biomedical engineering, said, "Imagine I am the detector in a room where thousands of unrelated people are talking – and I whisper, 'Who knows me?' I am so sensitive that I can hear even a few people saying, 'I do', above the crowd noise. In the past, we could detect everyone talking – now we can hear the few above the many."

According to the authors, this level of sensitivity and specificity is unprecedented in a system that uses no dyes or radioactivity. Beyond its sensitivity, they say, the beauty of this detection system is in its speed – producing results in seconds – and its compatibility with existing CMOS electronics.

"We simply took direction from Mother Nature and used the exquisitely sensitive and flexible detection of the immune system as the detector, and a basic physiological response of immune cells as the reporter," said postdoctoral fellow and lead author, Eric Stern. "We coupled that with existing CMOS electronics to make it easily usable."

The authors see a huge potential for the system in POC diagnostic centers in the U.S. and in underdeveloped countries where healthcare facilities and clinics are lacking. He says it could be as simple as an iPod-like device with changeable cards to detect or diagnose disease. Importantly, Stern notes that the system produces no false positives – a necessity for POC testing.

The authors suggest that in a clinic, assays could immediately determine which strain of flu a patient has, whether or not there is an HIV infection, or what strain of tuberculosis or coli bacteria is present. Currently, there are no electronic POC diagnostic devices available for disease detection.

"Instruments this sensitive could also play a role in detection of residual disease after antiviral treatments or chemotherapy," said Fahmy. "They will help with one of the greatest challenges we face in treatment of disease – knowing if we got rid of all of it."

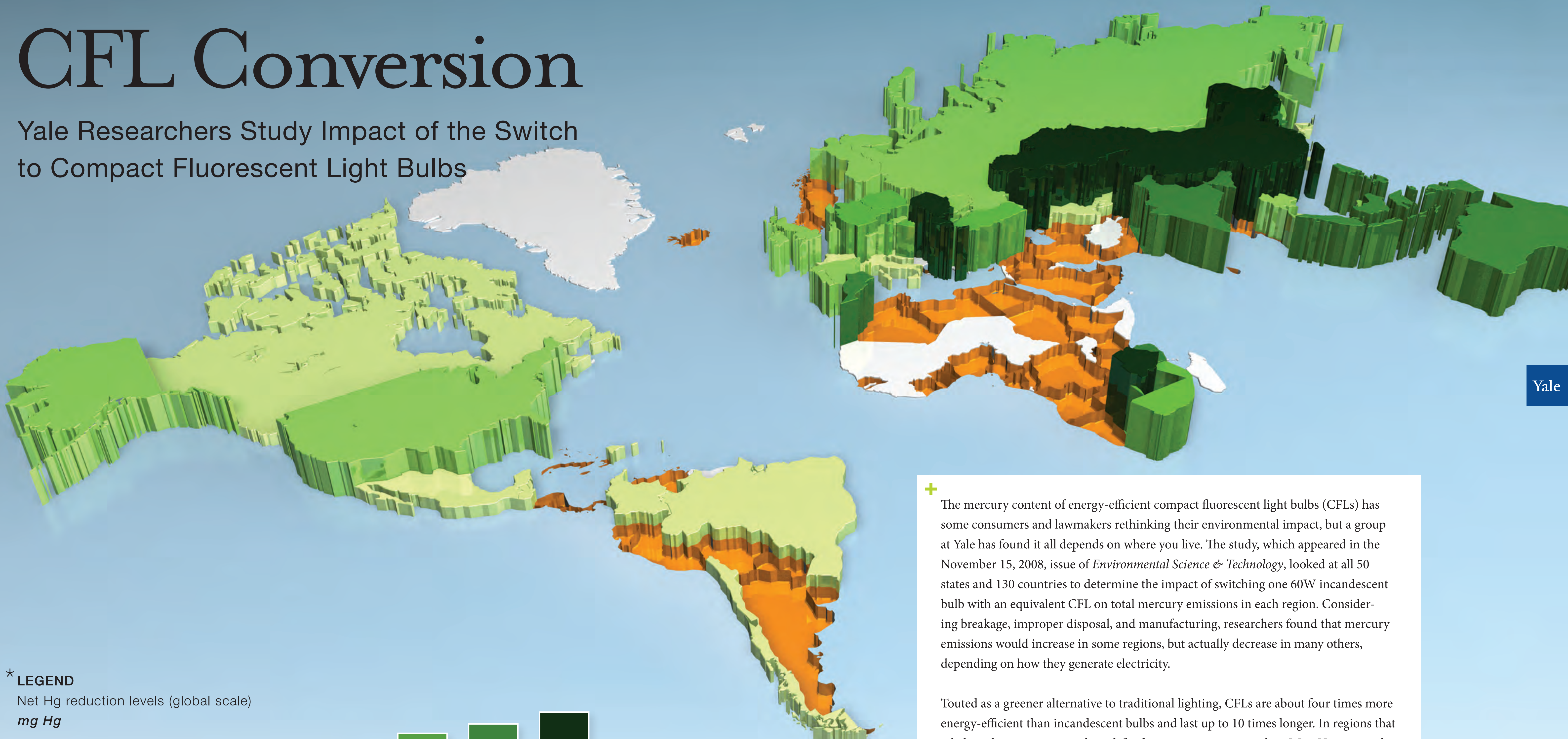
The work resulted from collaboration between the laboratories of Fahmy and Mark Reed, the Harold Hodgkinson Professor of Engineering & Applied Science within the Yale Institute for Nanoscience and Quantum Engineering (YINQE). Reed and biomedical engineering graduate student, Erin Steenblock, are also authors on the study that was funded by the Department of Defense, the National Institutes of Health, the Department of Homeland Security and the National Science Foundation.

SUSTAINABILITY

CFL Conversion

Yale Researchers Study Impact of the Switch to Compact Fluorescent Light Bulbs

Illustration /
Net reduction in atmospheric mercury emissions from the replacement of one incandescent bulb with a CFL in 130 countries.



The mercury content of energy-efficient compact fluorescent light bulbs (CFLs) has some consumers and lawmakers rethinking their environmental impact, but a group at Yale has found it all depends on where you live. The study, which appeared in the November 15, 2008, issue of *Environmental Science & Technology*, looked at all 50 states and 130 countries to determine the impact of switching one 60W incandescent bulb with an equivalent CFL on total mercury emissions in each region. Considering breakage, improper disposal, and manufacturing, researchers found that mercury emissions would increase in some regions, but actually decrease in many others, depending on how they generate electricity.

Touted as a greener alternative to traditional lighting, CFLs are about four times more energy-efficient than incandescent bulbs and last up to 10 times longer. In regions that rely heavily on mercury-rich coal-fired power generation, such as West Virginia and China, the reduction in electricity demand would not only translate to lowered greenhouse gas emissions, but mercury emissions as well.

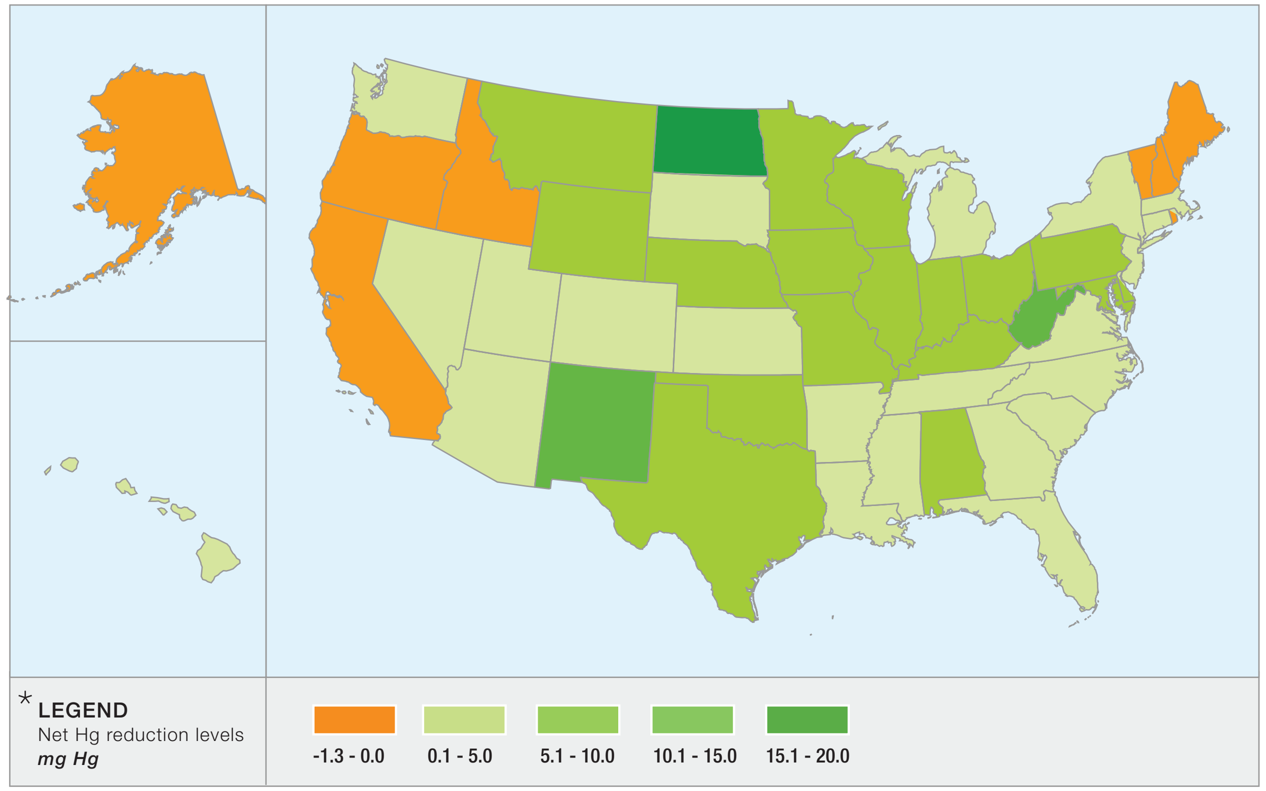
Continued on next page →

Yale

SUSTAINABILITY

Illustration /

Net reduction in atmospheric mercury emissions from the replacement of one incandescent bulb with a CFL in the United States.



The impact depends on complex relationships among a number of factors, including how dependent a region is on coal-powered energy generation, the chemical makeup of the coal used in those plants, pollution control technology employed, the number of bulbs replaced, and existing recycling programs for CFLs.

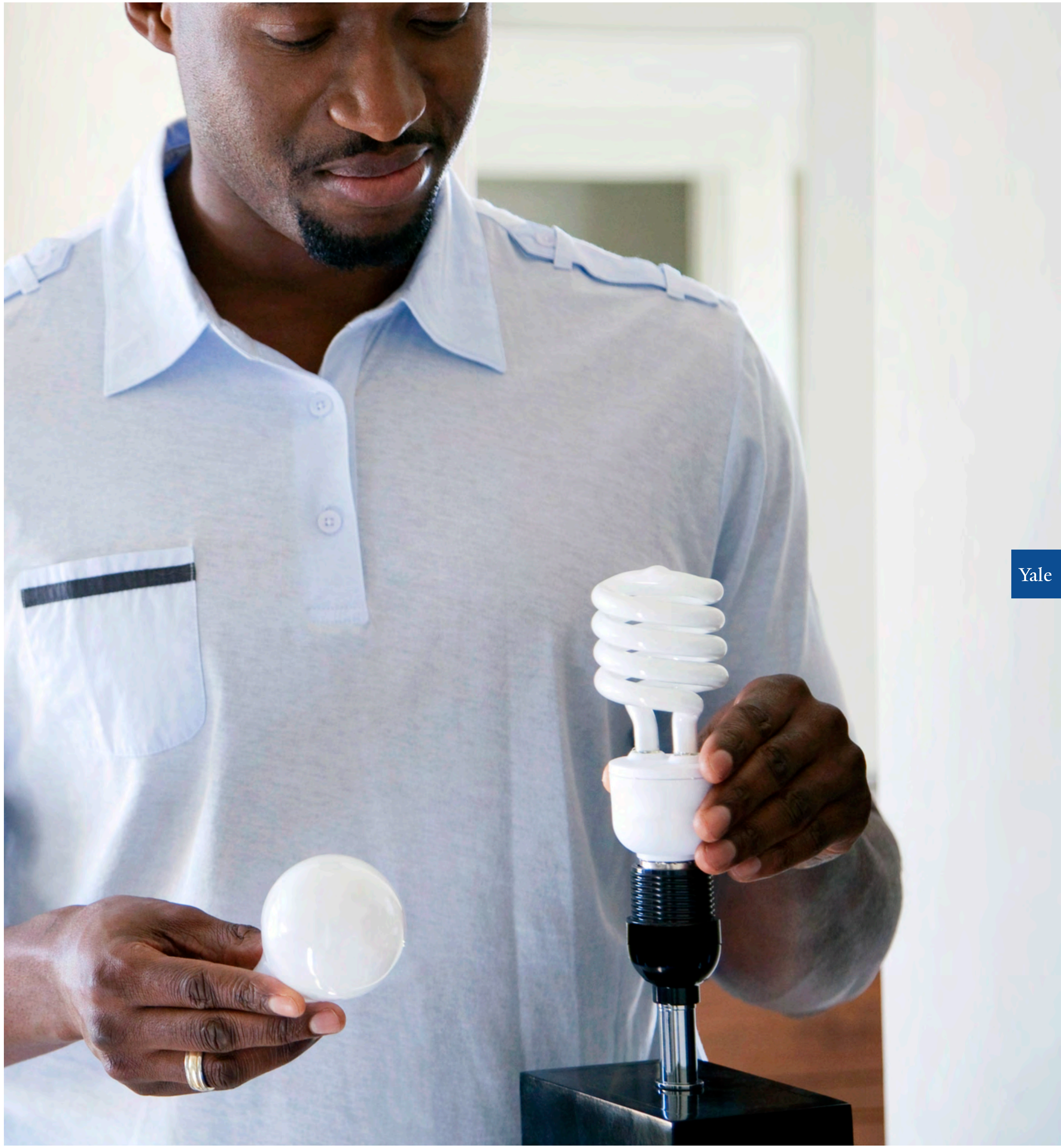
Places in which coal is only a small fraction of the energy equation, such as California and parts of Europe, will still see improved energy efficiency, but at the cost of increased mercury emissions. Already dealing with the unintended consequences of CFL use, California has enacted a mandatory recycling program to recover mercury from the millions of bulbs sold annually.

"It's always good to promote energy efficiency, but we have to be aware of possible tradeoffs," said lead author Matthew Eckelman, a graduate student in Yale's Program in Environmental Engineering and the Center for Industrial Ecology. "You may get a lower energy bill at home, but as a consumer you don't see the emissions at power plants or waste disposal sites."

Overall, their study estimates that the U.S. could avoid about 25 metric tons of mercury by switching all incandescent bulbs to CFLs by 2012. This equates to about half of the mercury emitted from U.S. coal-fired plants in a single year.

While the authors stress that they do not promote the continued use of inefficient incandescent lighting, they caution that nation-wide strategies, such as recent bans on incandescent bulbs, adopted by several countries, including U.S. legislation to phase out incandescent lighting by 2012-2014, may be too general. "All sustain-ability issues are local," said Zimmerman. "We need to ask if we should be making decisions on a national level, or if this is something better left to local governments."

Ultimately, a better bulb will be available. CFLs are improving and affordable LEDs (light-emitting diodes) are on the horizon.



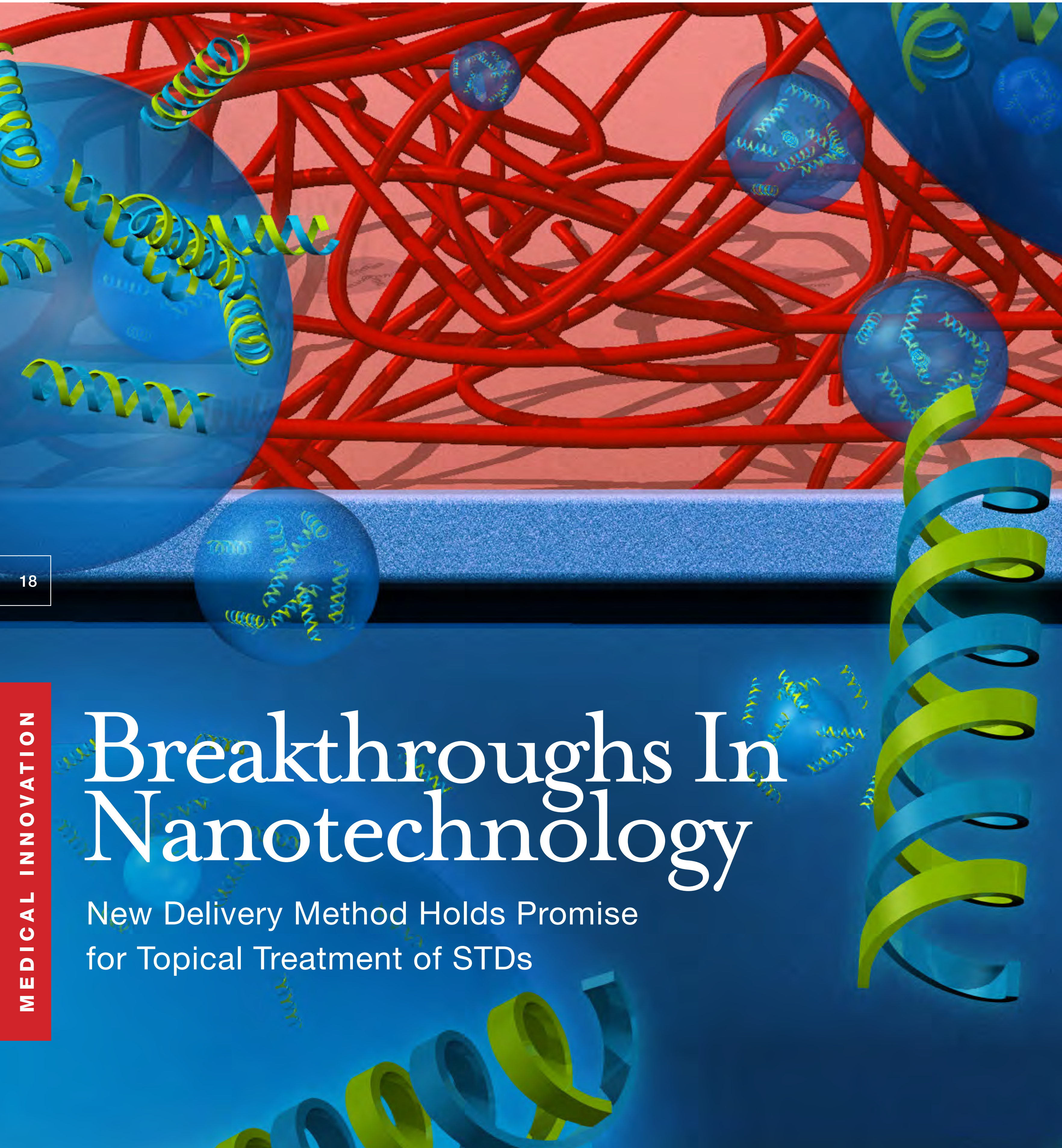


Illustration /
"Time release" vehicle for delivery of siRNAs to sensitive mucosal tissue for preventing and treating diseases such as HIV.

Breakthroughs In Nanotechnology

New Delivery Method Holds Promise for Topical Treatment of STDs

According to the Joint United Nations Programme on HIV/AIDS (UNAIDS), in 2007, an estimated 33 million people were living with HIV, with approximately 2.7 million new HIV infections and 2 million AIDS-related deaths that year. The epidemic continues to affect developing nations, particularly those in sub-Saharan Africa, where some nations report one-quarter of the population is infected.

While the search for a vaccine continues, there is a growing effort to develop topical antimicrobial treatments. As applied to the female vaginal mucosa – the primary port of entry for HIV – researchers believe such treatments may provide the best defense against this and other sexually transmitted diseases (STDs).

Yale biomedical engineers have been part of this growing effort and have recently reported a breakthrough in the administration of potential antiviral drugs – small interfering RNA (siRNA) molecules that silence genes. Their work was published in the May 4, 2009 issue of *Nature Materials*.

"RNA interference is a promising approach for prevention and treatment of human disease," said lead author Kim Woodrow, postdoctoral fellow in biomedical engineering. "We wanted to develop a new strategy of delivering siRNAs with an FDA-approved material."

As their name suggests, siRNAs interfere and knock out the function of genes in higher organisms as well as in microbes that may cause STDs. In their proof-of-principle work, the researchers designed siRNAs to target a gene expressed widely in the lining of the female mouse reproductive tract.

Using densely-loaded nanoparticles made of a biodegradable polymer known as PLGA, the researchers created a stable "time release" vehicle for delivery of siRNAs to sensitive mucosal tissue like that of the female reproductive system.

They found that the particles, loaded with the drug agent, moved effectively in two important ways, penetrating to reach cells below the surface of the mucosa and distributing throughout the vaginal, cervical, and uterine regions. Of significant note, they also found that the siRNAs stayed in the tissues for at least a week and knockdown of gene activity lasted up to 14 days.

While past work has focused on delivery of siRNAs with liposomes, bubble-like carriers made of phospholipids similar to those found in cell membranes, liposomes are potentially more toxic to the mucosal tissues and are unable to provide sustained release. In the current work, the researchers demonstrated that PLGA nanoparticles were safer than the best current lipid vehicles.

Gene interference therapy is moving rapidly from basic research to application. The PLGA packaging these researchers chose is already approved as safe and non-toxic by the FDA, speeding the path to clinical trials for infectious agents such as HPV and HIV.

"Before human clinical testing can begin, our next step in research will be to test this approach directly in disease models – for example in the HIV model mice that have an immune system genetically identical to humans," said senior author, W. Mark Saltzman, the Goizueta Foundation Professor of Biomedical Engineering & Chemical Engineering.

This approach holds promise for global health and the ability of people to self–apply antimicrobial treatments. "It is safe and effective and much easier than getting an injection of vaccine," Woodrow said.

Photo /
Post-doctoral Fellow, Kim Woodrow, in the Malone Engineering Center, home of the Biomedical Engineering Department.

In The Spotlight /
Kim Woodrow

Kim Woodrow received a B.S. in Biochemistry and Molecular Biology from Wells College and a Ph.D. in Chemical Engineering from Stanford University. She is the first in her family to receive a four-year degree.

Woodrow first worked with Mark Saltzman – then professor of chemical engineering at Cornell – in 1998, as part of a 10-week GE summer fellowship. She had just completed her undergraduate degree and was unclear of her future. This proved to be a career-defining experience.

"The research naturally fused my interests in the chemical and biological sciences, and it had clear applications for human health," says Woodrow. "Mark included me at every stage of the research. And, as I watched Mark connect with his students and collaborators to tackle biomedical problems, it became obvious that I would seek a graduate education in chemical engineering. I wanted the skills I saw Mark using every day to approach scientific problems."

Following graduation from Stanford in 2006, Woodrow accepted a postdoctoral fellow position at Yale, where she would work with Saltzman once again. As she departs Yale for her faculty position as an assistant professor of bioengineering at the University of Washington, Woodrow leaves a record of high productivity: several high impact scientific publications, a patent and numerous awards. Woodrow attributes this success to having Saltzman as a mentor.

← Read more about Kim's work on the previous page in ***"Breakthroughs In Nanotechnology"***

Photo /
Doctoral candidate, Rob McGinnis, tests the forward osmosis system he has engineered in Mason Laboratory.

In The Spotlight /
Rob McGinnis

Rob McGinnis' path to Chief Technology Officer at Oasys Water is far from conventional – high school dropout turned plumber's apprentice, door-to-door salesman, veteran of the Persian Gulf War, theatrical studies major, playwright and inventor.

His appreciation for engineering function and design was born in the Navy; his love for the humanities was born at Yale.

His work in forward osmosis began at a community college in Santa Cruz, CA. After completing an associate's degree, he came to Yale. Like many students, McGinnis was captivated by Yale's excellence in humanities and arts. His research continued, but his studies veered far from the sciences and engineering, graduating without taking a single class in either.

McGinnis entered the graduate program in environmental engineering in 2005, as a means of completing his research in forward osmosis. In 2009, he began work on commercializing the technology he helped invent.

Read more about Rob's work on the next page in ***"Engineered Osmosis"*** →

Engineered Osmosis

Holds Promise for Clean Water and Sustainable Energy

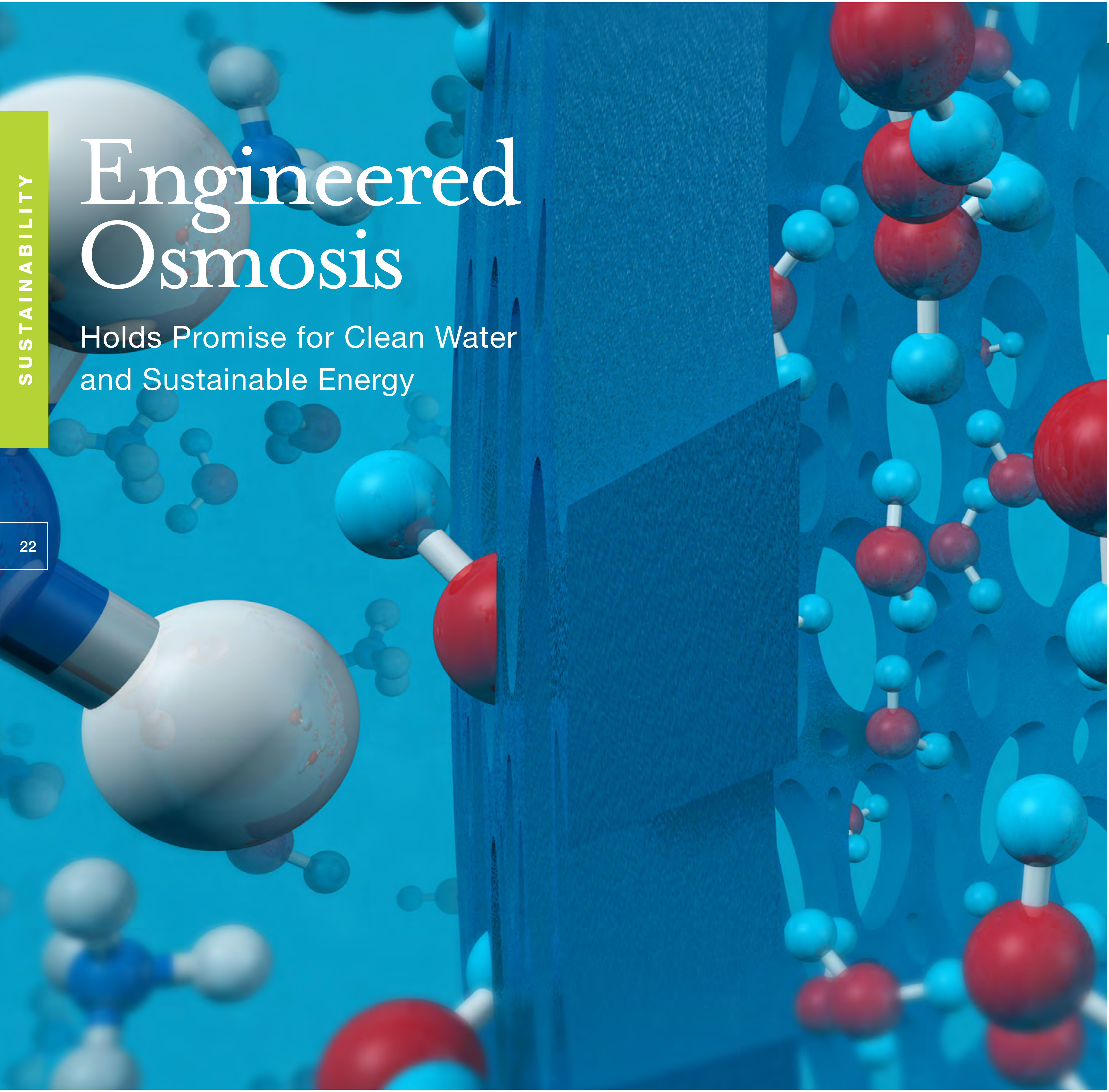


Illustration /
Water molecules move through a semi-permeable membrane by way of forward osmosis.

Water and energy are two resources on which all of modern society depends. As demands for each increase, researchers look to alternative technologies that promise both sustainability and reduced environmental impact. Yale researchers, Menachem Elimelech (Roberto Goizueta Professor of Environmental and Chemical Engineering and Chair of the Chemical Engineering Department), Jeffrey McCutcheon (former Ph.D. student of Elimelech, now assistant professor in the Chemical Engineering Program at the University of Connecticut), and Robert McGinnis (former Ph.D. student of Elimelech, now chief technical officer of Oasys Water, Inc.), propose engineered osmosis as a key to addressing both energy and water resource challenges. Their work has resulted in several patents and publications. One publication was featured in the December 2, 2008, issue of *Environmental Science & Technology*. In this feature article, Elimelech and McGinnis propose engineered osmosis as an answer to the global need for affordable clean water and inexpensive sustainable energy.

The solution to these resource challenges may lie in the design of osmotically-driven membrane systems, capable of producing freshwater from nonpotable sources, including seawater; producing electrical power from naturally occurring salinity gradients; and generating electricity from low-temperature heat sources, such as reject heat from thermal processes and conventional power plants.

Unlike commercial membrane separation systems, which rely on hydraulic pressure to drive water flux, engineered osmosis exploits the natural phenomenon of osmosis—diffusion of water through a semi-permeable membrane from a solution of low solute concentration to a solution of high solute concentration. The effectiveness lies in the "draw solution," or solution of higher solute concentration. This solution must possess a high enough osmotic pressure to effect separation; must contain solutes that are well-rejected by the semi-permeable membrane; and must be capable of being readily, efficiently, and completely removed at low cost.

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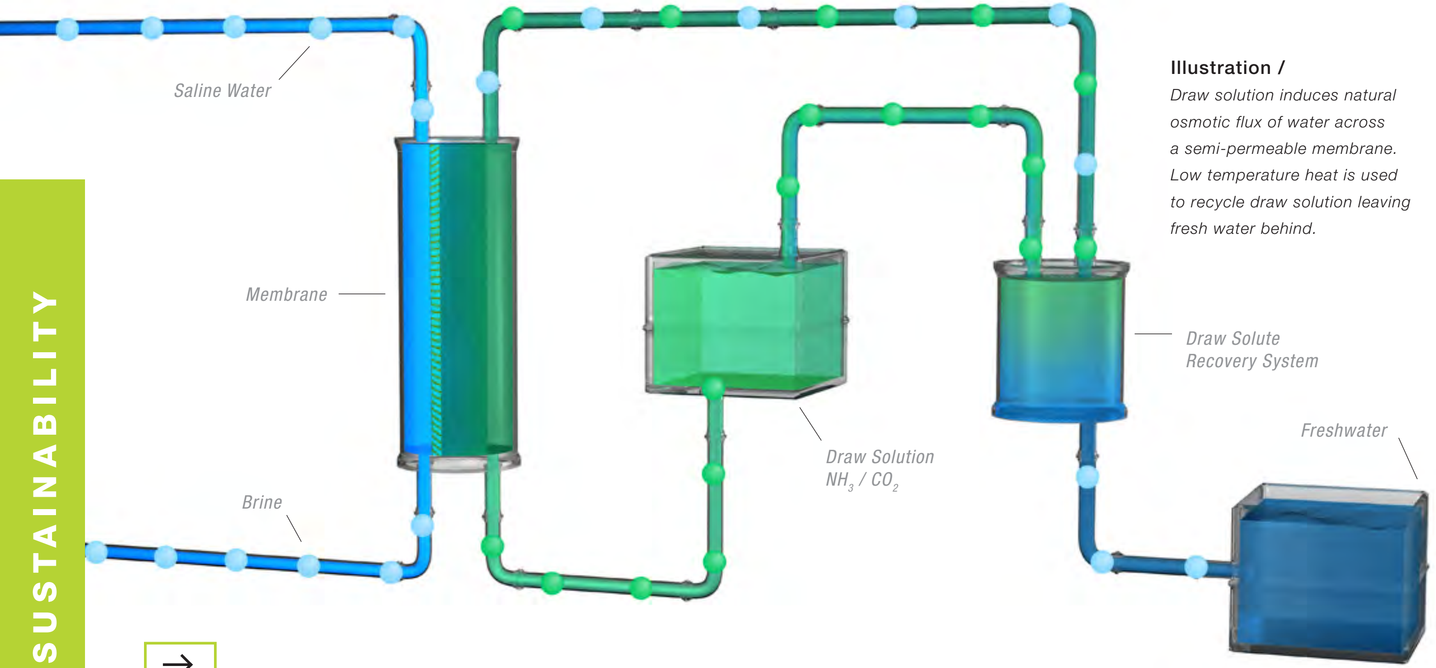

Illustration / *Draw solution induces natural osmotic flux of water across a semi-permeable membrane. Low temperature heat is used to recycle draw solution leaving fresh water behind.*

Engineered Osmosis for Sustainable Water Supply

According to the authors, desalination and reuse are the only options for increasing water supply above that which is available through the hydrologic cycle, but both, utilizing conventional technologies, rely on substantial energy input. "The ideal solution," says Elimelech, "is a process that makes use of low quality heat, at or below the temperature of its rejection from a power plant or similar thermal process and below a temperature at which it would be useful for any other purpose, while using little or no electrical energy input." In other words, the ideal process would effectively utilize "waste heat." A technology designed to fit this criteria is forward osmosis.

The system, designed by Yale researchers, uses a draw solution of concentrated ammonium salts, formed by the dissolution of NH_3 and CO_2 in water, to effectively induce natural osmotic flux of water across a semi-permeable membrane. As the draw solution is diluted, a portion is directed to a simple distillation column where low temperature heat (waste heat) is used to strip out the dissolved NH_3 and CO_2 gases, which are then recycled, leaving behind freshwater.

By utilizing a "draw" solution of concentrated salts, which can be readily removed with low temperature heat, researchers are able to effectively desalinate water with little electrical energy input. The only electrical input required is limited to that which is needed to pump fluids in unpressurized process equipment and piping.

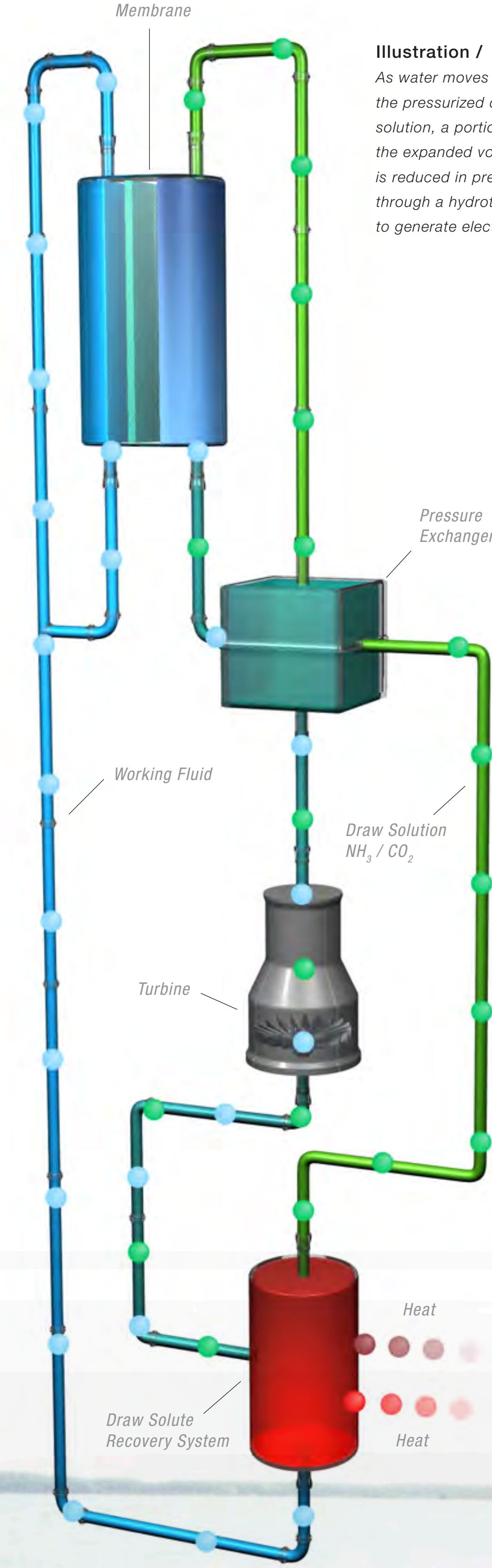

Illustration / *As water moves into the pressurized draw solution, a portion of the expanded volume is reduced in pressure through a hydroturbine to generate electricity.*

Engineered Osmosis for Sustainable Energy

Utilizing another tool of engineered osmosis, the osmotic heat engine (OHE), Yale researchers believe that it is possible to economically produce electricity from lower-temperature heat sources, including low quality geothermal heat and waste heat, using the principles of pressure-retarded osmosis (PRO). In PRO, the draw solution is placed under high hydraulic pressure. As water moves into the pressurized draw solution, a portion of the expanded volume is reduced in pressure through a hydroturbine to generate electricity. As in forward osmosis, the draw solution is efficiently recycled using low temperature heat.

Technology Commercialization

According to the World Health Organization, 2.4 billion of the world's 6.8 billion people now live in highly water-stressed areas. With sustainable solutions in great demand, it is no surprise that the Yale desalination technology is drawing investors to its spinoff company, Oasys Water, Inc., and quickly moving toward commercialization.

Oasys estimates that its patented engineered osmosis (EM™) process will produce drinking water at less than half the cost of current desalination processes by reducing electricity and fuel demands by more than 90%. While this technology greatly improves the economic viability of seawater desalination, Oasys will also market this technology for treating other non-potable water and wastewater sources.

Photo /
Brilliant blues of some bird feathers are the result of light scattering by tiny nanoscale structures.

INTERDISCIPLINARY

Optical Technology

Interdisciplinary Team Finds New Insights into How Feathers Produce Color

Some of the most stunning colors in nature are not created by pigments, but are instead the result of light scattering by tiny – nanoscale – structures. The vivid blues observed in the feathers of bluebirds and Blue Jays are just one such example. Now an interdisciplinary team of Yale engineers, physicists and evolutionary biologists has taken a step toward uncovering how these structures form. They conclude that the color-producing structures in feathers appear to self-assemble using the same physical mechanisms that produce the foam on a glass of beer. The process is phase separation and it occurs when materials become unstable and separate from one another. The researchers hypothesize that bubbles of water form in a protein-rich soup inside the living feather cell and are replaced with air as the cell dies, creating a structure similar to that of a sponge.

Mechanisms of self-assembly have received much interest recently in various fields of nanotechnology, but the Yale group is the first to provide new insight into how organisms exploit these same physical mechanisms for optical color production. "This finding is fascinating on many levels," says evolutionary biologist, Richard Prum, who is focused on the important implications for the role color plays in birds' plumage. Experimental physicist and assistant professor of mechanical engineering, Eric Dufresne, is interested in the potential technological applications of the finding. "We have found that nature elegantly self-assembles intricate optical structures in bird feathers. We are now mimicking this approach to make a new generation of optical materials in the lab."

"The diverse research team is not your usual collaboration," says Prum. "It took a long time for us to understand each other and to realize our common interests." While the collaboration is unique, it is one of many interdisciplinary partnerships, pooling diverse knowledge and capabilities to advance research at Yale.

Eric Dufresne was recently named the John J. Lee Assistant Professor of Mechanical Engineering. He holds joint appointments in the Departments of Chemical Engineering, Physics and Cell Biology.

Illustration /
A house equipped with an intelligent sensor network could alert authorities in the case of a fall or medical emergency.

TECHNOLOGY

Assisted Living

"Smart" Cameras and "Intelligent" Sensor Networks Provide Independence

"Help, I've fallen and I can't get up!" – so goes the catch line of a 1989 infomercial for a product designed as a simple alert system to aid people living alone. The ad, though amateurish, reminds the viewer of what it could be like to be without assistance when you most need it – elderly and suddenly incapacitated, unable to get help, perhaps for hours or even days.

Increasingly, seniors are choosing to live independently – be it a matter of pride or cost. As a result, there is a growing need for in-home elder care services, and Yale researchers believe that technology can help fill the gaps left by a limited care-giving workforce and dispersed families.

Electrical engineering faculty members, Eugenio Culurciello and Andreas Savvides, are tackling this issue. With their pioneering development and use of "smart" cameras and "intelligent" sensor networks, they hope to help provide an inexpensive option for safer independent living.

Continued on next page →

TECHNOLOGY

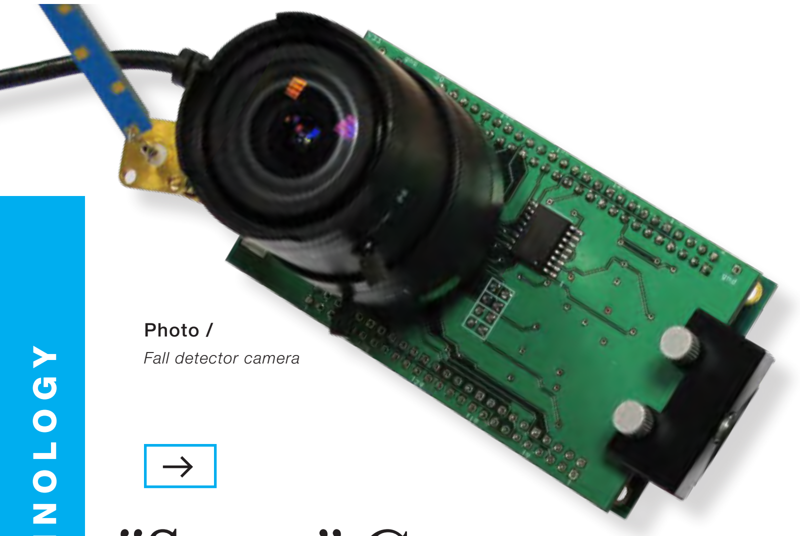

Photo /
Fall detector camera

→

"Smart" Cameras

Culurciello specializes in the development of advanced sensory communication circuits and systems. Among a list of novel technologies, Culurciello has developed a vision system designed to detect accidental falls in elderly home care applications.

Employing a low-power temporal difference image sensor, the device collects images as a series of imprecise and largely unrecognizable outlines, then processes them to distinguish the movement the individual makes – bending over, kneeling, sitting down, walking or falling. According to Culurciello, the system can "easily distinguish a person who is falling versus a box falling off a counter or a cat jumping off a table." Once a fall has been detected, the device monitors the scene for 30 seconds before sending out an alert. No push of a button is required nor any violation of privacy.

The core technology is an asynchronous temporal contrast (ATC) vision sensor, which recognizes motion events by extracting changing pixels from the background. With a lightweight moving average algorithm, developed by Culurciello's team of researchers, the detector can compute instantaneous motion vectors and report fall incidents immediately with low computational effort.

"Approximately one-third of individuals age 65 and older fall each year," says Culurciello. While many falls do not result in injury, nearly 50% of non-injured fallers cannot get up without assistance and the length of time they spend immobile often affects their health outcome. "Getting help quickly is essential," Culurciello adds.

Several commercially available technologies exist today to address this need, including camera systems and wearable devices. Culurciello's detectors, however, offer several advantages, including: easy installation, low power requirements, small and non-intrusive size, low maintenance, and protection of privacy as no discernable images are collected and no data is communicated until a fall event has occurred. Unlike wearable devices, Culurciello's detector does not rely on a patient's ability to push a button to sound the alarm or his or her willingness or ability to remember to wear the device. "We see it as a practical and personalized way to coordinate families and teams for elder care," says Culurciello.

He recognizes that falls are not the only concern for elder independent living. In his latest work, Culurciello extends his fall recognition technology to posture recognition, which can be used to help monitor behavior of individuals suffering from dementia and depression.

"Intelligent" Sensor Networks

Currently 5.3 million people in the U.S. are afflicted with Alzheimer's disease – the most common type of dementia. As the baby boomer generation ages, this number will continue to escalate, with projections that it will more than double by 2050, According to the Alzheimer's Association.

Andreas Savvides sees a need for technological innovation in this area. With his unique whole-house sensor networking system – BehaviorScope – Savvides brings a new dimension to the concept of assisted living. BehaviorScope employs off-the-shelf technology to evaluate patterns in the way people move around their living areas with an eye toward detecting telltale changes in behavior. "We can use this system to ask questions like, 'Is your mother getting out of bed today?'" says Savvides. "'How much time is she spending in the bathroom or the kitchen?' 'Is she wandering around the house or doing the things she usually does?' 'Has her schedule changed?'"

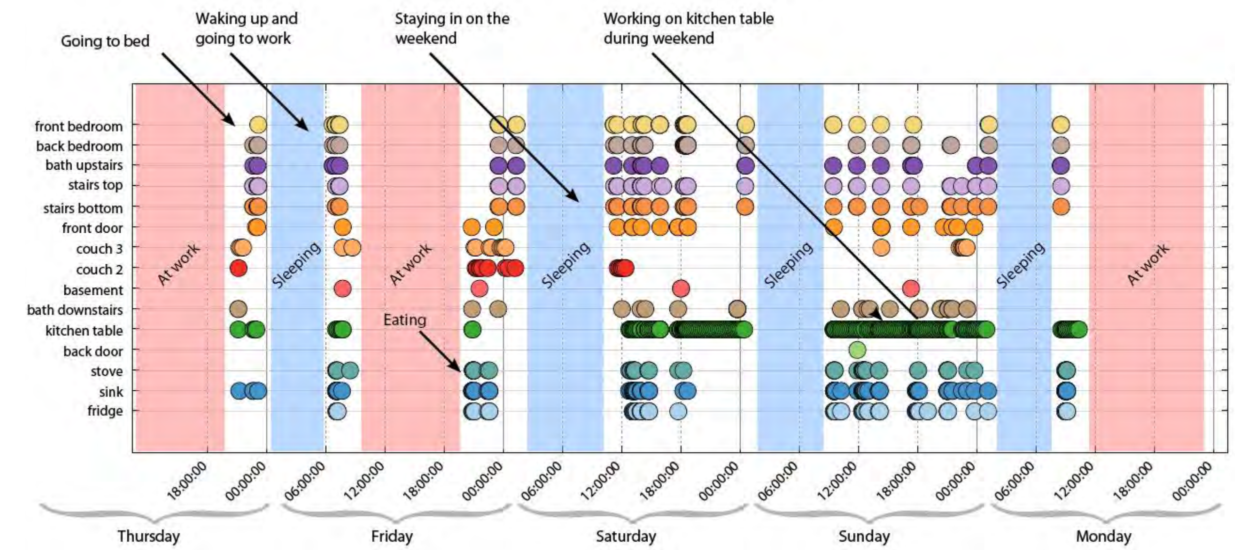

Illustration /
Architecture of low-level sensor measurements are interpreted to high-level semantics using a hierarchy of sensory grammars.

Savvides' detectors report on the time intervals associated with motion around a living space and deviations from the person's usual daily pattern. Like Culurciello's system, no detailed imaging is recorded. When deviation to a predefined set of rules or recognized pattern occurs, such as a change in a regular sleep schedule, the system sends an alert to a caregiver.

Beyond recognizing patterns of movement, Savvides' system integrates cameras; motion, pressure, door, temperature and humidity sensors; as well as wearable medical monitors for more complex sensing. "The correlation across different sensors shows something that each system individually does not show," says Savvides. While a medical sensor may register an increase in heart rate, a motion sensor may show the person is engaged in an energy-intensive activity, such as walking up or down steps.

Very soon these systems will become sophisticated enough to distinguish among medical issues like a change in gait that signals an impending heart attack. "With built-in 'talk back,' today's devices can tell the person to sit down and take medications," says Savvides. "It's like having someone watching out for you throughout the day, without needing someone there."

Savvides recently set up a test of the system in a small town in his native Cyprus, where he envisions use of the device as a public service to citizens in small communities or remote areas. Through this service, individuals in the elder's social network receive notifications on their mobile phones when behavior patterns deviate from the norm.

Savvides' hope is that this communication will not only improve caregiving, but will keep elders connected to their social network, preventing them from becoming isolated.

In addition to enhancing day-to-day safety, Savvides hopes that this research will create more knowledge about the structure of human routines and that the developed system will offer a new and unique way to study medical conditions such as dementia and depression. Most importantly, however, "this new technology offers a way to provide seamless personal services without the cost and personal disruption of moving to an elder home," says Savvides.

Andreas Savvides was recently named the Barton L. Weller Associate Professor of Electrical Engineering & Computer Science.

Watch the Video Online

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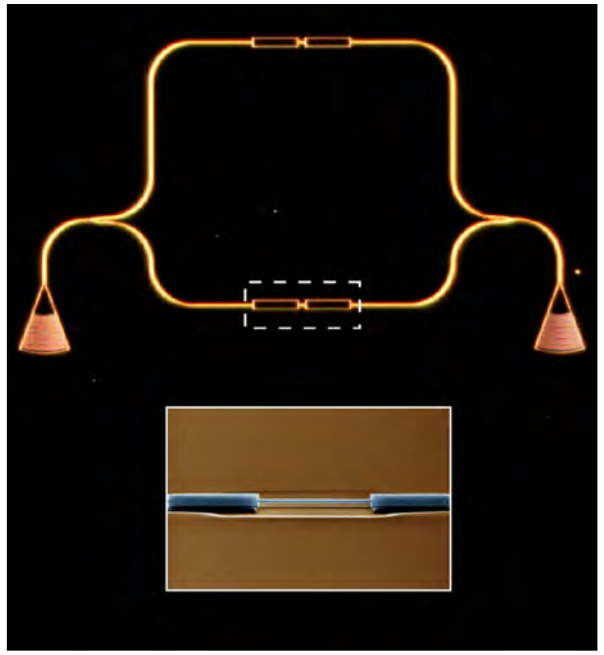
Yale

Photon Force

Harnessing the Force of Light to Drive Nanomachines

Photo /
Photonic circuit in which optical force is harnessed to drive nanomechanics.



Science fiction writers have long envisioned sailing a spacecraft by the optical force of the sun's light. But, the forces of sunlight are too weak to fill even the oversized sails that have been tried. Now a team of researchers led by assistant professor of electrical engineering, Hong Tang, has shown that the force of light indeed can be harnessed to drive machines — when the process is scaled to nano-proportions.

Their work opens the door to a new class of semiconductor devices that are operated by the force of light. They envision a future where this process powers quantum information processing and sensing devices, as well as telecommunications that run at ultra-high speed and consume little power.

The research, which first appeared in the November 27, 2008, issue of *Nature*, demonstrates a marriage of two emerging fields of research – nanophotonics and nanomechanics – which makes possible the extreme miniaturization of optics and mechanics on a silicon chip. The energy of light has been harnessed and used in many ways. The force of light is different – it is a push or pull action that causes something to move.

"While the force of light is far too weak for us to feel in everyday life, we have found that it can be harnessed and used at the nanoscale," said Tang. "Our work demonstrates the advantage of using nano-objects as 'targets' for the force of light – using devices that are a billion-billion times smaller than a space sail, and that match the size of today's typical transistors."

Until now, light has only been used to maneuver single tiny objects with a focused laser beam – a technique called "optical tweezers." Postdoctoral scientist and lead author, Mo Li noted, "Instead of moving particles with light, now we integrate everything on a chip and move a semiconductor device."

"When researchers talk about optical forces, they are generally referring to the radiation pressure light applies in the direction of the flow of light," said Tang. "The new force we have investigated actually kicks out to the side of that light flow."

While this new optical force was predicted by several theories, the proof required state-of-the-art nanophotonics to confine light with ultra-high intensity within nanoscale photonic wires. The researchers showed that when the concentrated light was guided through a nanoscale mechanical device, significant light force could be generated – enough, in fact, to operate nanoscale machinery on a silicon chip.

The light force was routed in much the same way electronic wires are laid out on today's large-scale integrated circuits. Because light intensity is much higher when it is guided at the nanoscale, they were able to exploit the force. "We calculate that the illumination we harness is a million times stronger than direct sunlight," adds Wolfram Pernice, a Humboldt postdoctoral fellow with Tang. "We create hundreds of devices on a single chip, and all of them work," says Tang, who attributes this success to a great optical I/O device design provided by their collaborators at the University of Washington.

In their latest work, first published in the July 13, 2009, advanced online issue of *Nature Photonics*, Tang's group demonstrates for the first time the bipolar, or attractive and repulsive, optical forces and the capability to switch the sign of the forces reversibly by tuning the interacting lightwaves. The ability to engineer this force could pave the way to a new class of light force-driven devices and circuits on the ubiquitous silicon platform in which mechanical components can interact with light routed through a layout much like electrons are in today's electronic circuit.

It took more than 60 years to progress from the first transistors to the speed and power of today's computers. Creating devices that run solely on light rather than electronics will now begin a similar process of development, according to the authors.

"While this development has brought us a new device concept and a giant step forward in speed, the next developments will be in improving the mechanical aspects of the system. But," says Tang, "the photon force is with us."

Tang is the recipient of the National Science Foundation's CAREER Award and, most recently, the prestigious Packard Fellowship from the David and Lucile Packard Foundation.

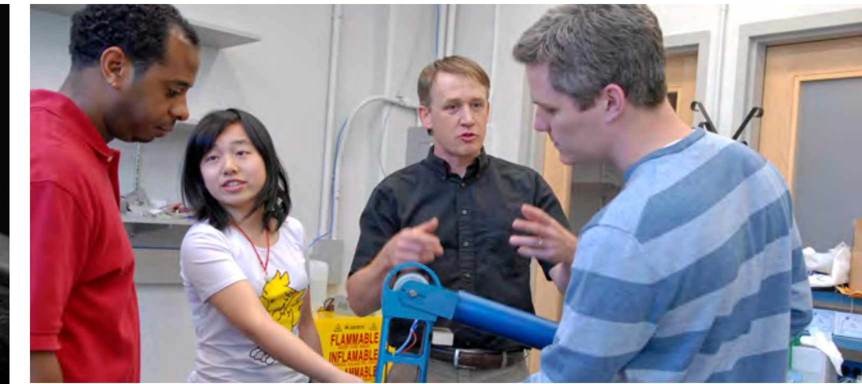
EDUCATION

Hands-On Learning

Students Learn Importance of Risk-Taking and Failure in Achieving Success

Watch the Video Online

http://seas.yale.edu/publication



Photos /
Prof. Morrell teaches students that success comes from embracing the lessons of failure.

By the time they complete his mechanical engineering class, Professor John Morrell's students will have designed and built a hybrid car or model airplane and entered it in national competitions.

During the semester, the Yale undergraduates in his class will have confronted some of the toughest and most unpredictable variables any engineer must face – their own colleagues.

Morrell teaches a lesson he learned firsthand while creating new products in private industry: No engineering design project succeeds unless participants account for the innovative and volatile force of human interactions. "They learn to do something they couldn't do as an individual," says Morrell, assistant professor of mechanical engineering. "They also learn that everybody has to deliver to complete a project. If someone doesn't make a strong landing gear, the plane isn't going to take off or land in one piece."

Morrell was one of the lead dynamics engineers on the Segway – a self-powered standup scooter hailed as a revolution in personal transportation when it was unveiled in 2001. The Segway, brainchild of inventor Dean Kamen, was revolutionary because its design gave the device dynamic stability that allows the rider to remain upright while controlling the vehicle simply by leaning forward or backward.

However, the design process involved in creating the Segway was not straightforward, but a sometimes messy and contentious affair, says Morrell, adding that the eventual design was born from many farfetched, risky ideas.

"At Segway, we used to hold 'Frog Kissing Days' because Dean Kamen was always saying, 'you have to kiss a lot of frogs to find a prince,'" Morrell says. "So we'd take some time to try out crazy ideas and we explicitly celebrated our spectacular failures. Trying new – sometimes called 'stupid' – ideas needs to be rewarded if you're going to innovate. Sometimes, you find a prince."

That's what he tells his students: Each failure has its own lesson; they should embrace their mistakes and move forward quickly. "I want students to fail early and often," he says. "That way, they learn how to recover. Once they know how to recover quickly, they can take bigger risks with more confidence."

Morrell says the world is filled with "maestros" or "tribals" – a framework formulated by psychologist Nicholas Lore. "Maestros" are defined as people who would choose to be the starting pitcher on the baseball team, even if it means they play on a losing team. "Tribals" are willing to sit on the bench, if it means their team plays in the World Series. The students in Morrell's engineering class learn to which category they belong.

When Terrence Myelle '08 enrolled in Morrell's class last spring, he just wanted to get his hands dirty designing and building a hybrid car. But after he was assigned to a team, he quickly learned what isn't said is sometimes as important as what is.

He was voted team leader immediately. Sometimes, he admits, he had to swallow hard and let a fellow student, for example, place a wire harness on one part of the chassis, even though he thought there might be a better location. "Before this class, I didn't think much about the decision-making aspect of working in a group," Myelle says. "In addition to managing the technical challenges, you have to manage the coordination of the project as well." When asked if he would rather be on the bench in the World Series or starting for a losing team, Myelle doesn't hesitate: "I want to be on the winning team."

"That's why he became the leader," Morrell says.

Morrell divides up his class, with some students working on designing a model airplane and some, a hybrid car. The airplane project was based on the rules for the Society of Automotive Engineers (SAE) Aero Design contest. One year's airplane inspired a student to build his own airplane for the contest in Marietta, Georgia. Myelle and several students took their hybrid car to New Hampshire for the SAE Formula Hybrid competition.

"Most students don't get to see something of this magnitude accomplished in a semester," Morrell says. "Yet this is what mechanical engineering is for many people. Some people thrive on it, others have trouble engaging with it. If you're thinking about becoming a mechanical engineer, you should know what this experience is like."

NEW FACULTY

New Faculty

Aaron Dollar

Assistant Professor
Mechanical Engineering

Aaron Dollar, assistant professor of mechanical engineering, comes to the Yale School of Engineering & Applied Science after serving as a postdoctoral associate with the Biomechatronics Group in the Massachusetts Institute of Technology Media Lab. His research interests include robotic grasping and manipulation, tactile sensing, prosthetics and rehabilitation robotics, active exoskeletons, and robot locomotion.

Dollar is an active member of the American Society of Mechanical Engineers (ASME), the IEEE, and the American Society of Engineering Education (ASEE). He is also the editor and co-founder of RoboticsCourseWare.org, an open repository for robotics pedagogical materials.

Dollar holds Ph.D. and S.M. degrees from Harvard University in engineering sciences and a B.S. in mechanical engineering from the University of Massachusetts at Amherst.

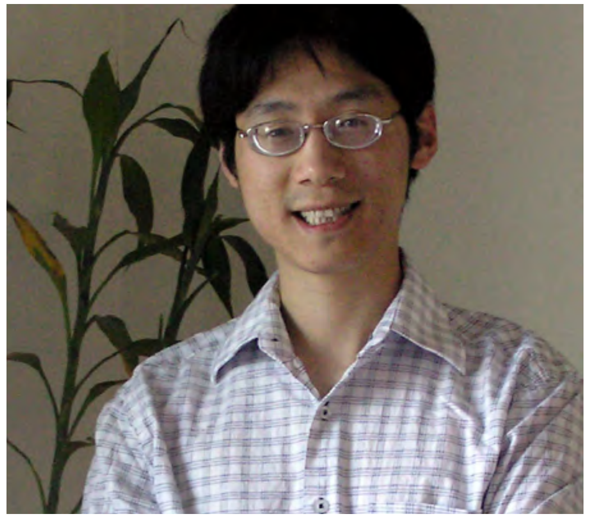
Anjelica Gonzalez

Assistant Professor
Biomedical Engineering

Anjelica L. Gonzalez, assistant professor of biomedical engineering, received her B.S. at Utah State University and a Ph.D. from Baylor College of Medicine in computational biology. She continued her education with post doctoral work at Texas Children's Hospital in leukocyte biology and pediatric intensive care before joining Yale's Department of Biomedical Engineering as a research associate in 2007. Gonzalez's research is focused on the development of biomaterials for use as investigational tools, particularly for the investigation of immunological responses to inflammatory signals from endogenous and exogenous sources.

Her research has been acknowledged by a number of organizations, including the National Institutes of Health, American Society for Investigative Pathology, and the American Physiological Society and National Institute of Diabetes and Digestive and Kidney Diseases.

Gonzalez currently serves as a co-author and consultant with the Yale-Griffith Prevention Research Center, whose primary goal is to serve the underserved communities of New Haven, Hartford and Bridgeport, CT in an effort to ameliorate health disparities, particularly as they relate to diabetes and heart disease. Gonzalez also contributed to these efforts through her volunteer work with not-for-profit organizations, including the Sickle Cell Disease Association of Texas-Gulf Coast.



Rong Fan

Assistant Professor
Biomedical Engineering

Rong Fan, assistant professor of biomedical engineering, will join the Yale School of Engineering & Applied Science in January from the California Institute of Technology, where he is a postdoctoral associate with the NanoSystems Biology Cancer Center (NSBCC), founded by the National Cancer Institute. His research interests are centered on exploiting systems biology principles to develop integrated micro- and nanotechnologies for differential diagnosis of human cancer. These technologies are anticipated to be used to stratify cancer patients and enable personalized treatment.

Fan is an active member in the NCI Alliance for Nanotechnology in Cancer, and recently won the NIH K99/R00 Pathway to Independence Grant that will support his research on probing tumor-immune interactions. He is a member of several professional societies including the Materials Research Society (MRS), the American Chemical Society (ACS) and the American Society for Cell Biology (ASCB).

Fan holds a Ph.D. degree in chemistry from the University of California at Berkeley and a B.S. in applied chemistry from the University of Science and Technology of China.

Kathryn Miller-Jensen

Assistant Professor
Biomedical Engineering

Kathryn Miller-Jensen, assistant professor of biomedical engineering, will join the Yale School of Engineering & Applied Science faculty in January from the University of California at Berkeley, where she was an NIH Postdoctoral Fellow at the Institute for Quantitative Biosciences. Her research focuses on computational modeling and experimental testing of intracellular signaling network dynamics in response to viral infection.

Miller-Jensen is a member of the Biomedical Engineering Society and the American Association for the Advancement of Science. She is also a former Christine Mirzayan Science and Technology Policy Fellow at the National Academies in Washington, DC. Miller-Jensen holds a Ph.D. degree from the Massachusetts Institute of Technology in chemical engineering and A.B. and B.E. degrees in engineering sciences from Dartmouth College.

EDUCATION

Faculty Spotlight: T.P. Ma

Tso-Ping Ma is the Raymond John Wean Professor of Electrical Engineering and Applied Physics, co-director of the Yale Center for Microelectronics, and co-director of the Yale-Peking Joint Center for Microelectronics and Nanotechnology. After receiving a Ph.D. in Engineering from Yale in 1974, Ma conducted research at IBM on advanced silicon device technology and ionizing radiation effects in MOS devices. In 1977, he joined the faculty at Yale.

Ma's research and teaching have focused on the scientific and technological issues related to semiconductor devices, especially those involving MIS (Metal-Insulator-Semiconductor) systems. He is renowned for his contributions to this field – elected to the National Academy of Engineering in 2003 and most recently awarded the 2008 Connecticut Medal of Technology.

This interview was recorded on June 30, 2009 and can be viewed on our website at: http://seas.yale.edu/spotlight

Watch the Video Online

http://seas.yale.edu/publication

Alumni Notes

Please share with us your experiences at Yale and where you are today. Go to the web address below to link to our alumni notes page.

http://seas.yale.edu/alumninotes

Giving To Yale

The School of Engineering & Applied Science is entering an exciting new chapter in its existence. With the re-establishment of the School and the opportunity for growth in educational initiatives and cutting-edge, scientific research, the generosity of alumni and friends is critical to our success. Go to the web address below to make a gift to Yale Engineering.

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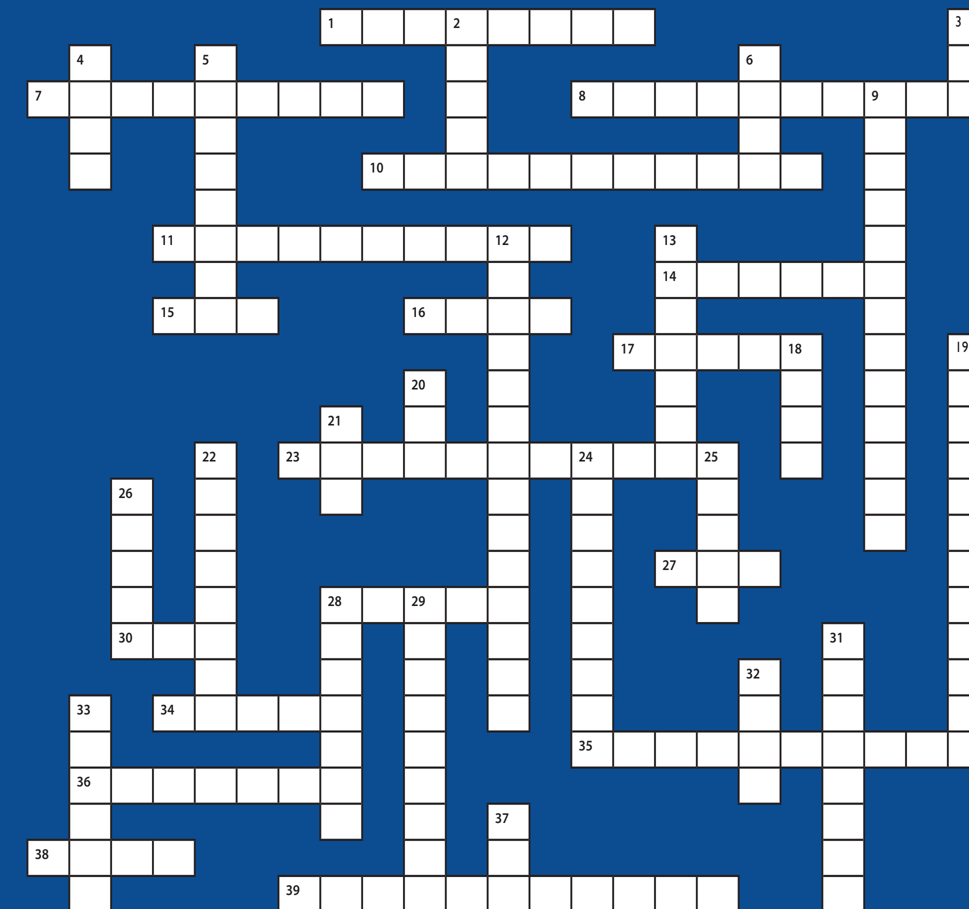


2009 Engineering Crossword Puzzle

Fill out the online interactive crossword puzzle

http://seas.yale.edu/crossword

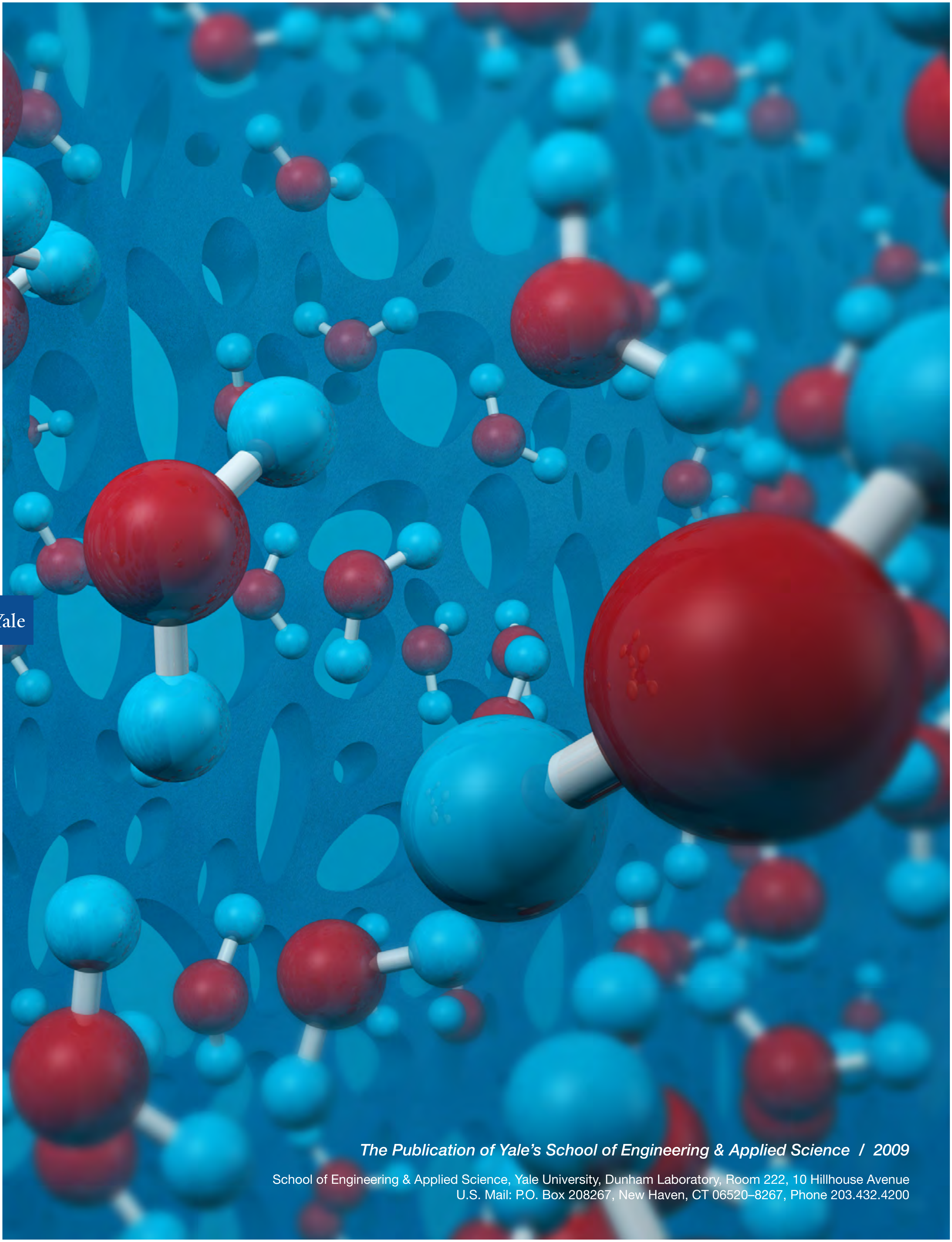
For the answers to the crossword, visit http://seas.yale.edu/crossword_answers

ACROSS:

1. initiate chemical reaction
7. Sheffield made his money
8. SEAS Department
10. structure of most metals
11. atomic force _____; high-resolution imaging
14. basic "unit" of light (p. 32)
15. genetic information
16. bird colors formed, ____ assembly (p. 27)
17. first Ph.D. in Engineering (free energy)
23. weak attraction between molecules
27. stronger than steel, molded like plastic (p. 11)
28. mechanical design able to perform tasks
30. read-only memory
34. negative terminal in a Galvanic cell
35. easily deformed by thermal forces; colloids (example of)
36. engineered process for desalination (p. 22)
38. EE society
39. nano imprint technique involving photo resist

DOWN:

2. bronze (example of)
3. energy efficient lighting (p. 14)
4. 10^{-9}
5. force opposing motion
6. electronic term, amplification
9. greenhouse gas (2 words)
12. process combining several monomers
13. ______ tweezers; light manipulation (p. 32)
18. sodium chloride
19. thin film fabrication involving alternating layer desposition
20. energy efficient lighting (p. 16)
21. highest recognition for engineer (membership)
22. Yale chemist enabled kerosene production
24. without crystalline structure (i.e., BMG) (p. 11)
25. nano imprint method; molding (p. 11)
26. two monomers
28. _______ osmosis, common filtration process
29. measured in hertz
31. year Yale Engineering established: 18__
32. microelectromechanical system (acronym)
33. law describing long-term trend in computing hardware
37. mathematical term (abbr.)



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