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EQuad News

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WATER IN OUR WORLD

PRINCETON
School of Engineering
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DEAN'S MESSAGE

Addressing the mystery and urgency of water

For simple elegance, deep mystery and life-giving power, it's hard to beat the water molecule. Just two hydrogen atoms affixed to an oxygen atom, water continues to surprise and confound scientists who seek to understand how it evaporates, freezes and interacts with other materials. Even the question of what it means for something to get wet is not as simple as it seems (see page 14). At the largest scale, access to clean water is a pressing issue across the globe, and investigating the relationship between water, weather and climate has taken on new urgency.

Often the questions present seemingly harsh trade-offs. How can we meet the demand for hydroelectric power while preserving the role of river fisheries in providing food (page 11)? How can we protect waterways and marine ecosystems from the damaging effects of agricultural fertilizers without jeopardizing the global food system (page 18)?

The stories in this issue of EQuad News touch on the variety of ways in which Princeton engineers are addressing such questions. They reflect an increasing drive within the University to build the expertise, partnerships and resources needed to help secure and understand this precious resource for future generations. The complexity of the issues surrounding water demands a combination of scientific expertise and nimble collaborations across academia, government, industry and the nonprofit sector.

Bringing together that mix of depth and breadth to solve problems of critical importance is a hallmark of engineering at Princeton. It is one of the core reasons I am proud to work here and proud of our many alumni who bring this approach to bear in their work around the world. Please stay in touch with your stories.

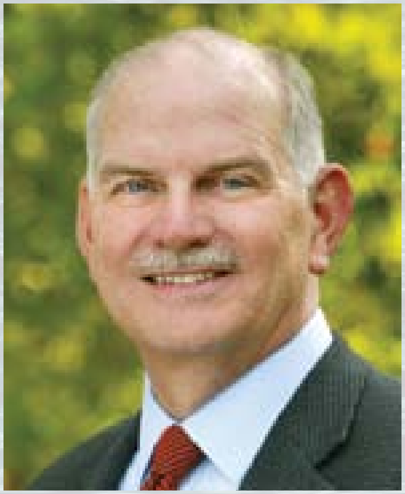

Photo by Frank Wojciechowski

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A note about QR codes
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In the Nation's Service and in the Service of All Nations

Rendering by TWBT Architects

Andlinger Lab design reflects science in service of the planet

By John Sullivan

The new home of Princeton's Andlinger Center for Energy and the Environment, now under construction, is intended to reflect the goal of science and technology in service to the planet. This rendering shows the Andlinger Laboratory main entrance from Olden Street. A stairway tower connects the main parts of the lab. Graduate student space at the lower level opens to a garden. An elevated walkway, at left, connects to the Engineering Quadrangle's E-Wing.

When architect Billie Tsien talks about the design for the new Andlinger Center for Energy and the Environment, you can almost see the shape of the low buildings at dusk, framed by rustling gardens and lit by the quiet beacon of an illuminated tower.

"You are walking through a series of gardens," said Tsien, one of the principal designers of the new Andlinger Laboratory, which will house the center. "We thought it was important to emphasize the ground plane, the green aspects of a garden, and to bring in light by creating a series of courtyards."

Inside, researchers in brightly lit laboratories will search for new energy sources to power societies around the world. Yet the structures themselves are spare and almost primal, rooted firmly in the earth.

This merger of humanity and technology is the balance the architects of the Andlinger Lab have tried to strike. Pablo Debenedetti, vice dean of the School of Engineering and Applied Science and chair of the project's building committee, said the University wants the construction to reflect the goal of

Photo by Denise Applewhite

Emily Carter, founding director of the Andlinger Center for Energy and the Environment, overlooks the site of the Andlinger Laboratory, which is to be completed in 2015. A key feature of the design for the lab is that all levels are exposed to natural light and plantings. A space for graduate student offices opens to a park-like setting, below, designed to maximize interactions between people. At the rear of this view, steps lead up to the lecture hall entrance at the corner of Olden and Prospect streets.

Rendering by TWBT Architects

Andlinger Lab design, continued from page 1

science and technology in service to the planet. Instead of a massive stand-alone laboratory building, the committee felt the design should incorporate the research space into the surrounding landscape.

"It is the idea of the center as a place," Debenedetti said, "of gardens that take you from one area to another. It will be a place for accomplishment, but also for thinking and contemplation."

Over the next three years, construction crews will build a series of linked structures in an L-shaped plot that extends back from the intersection of Olden Street and Prospect Avenue. From the street, the site will look like three two-story buildings connected by plazas, gardens and pathways. The appearance is deceptive. The Andlinger Lab is actually one building that will break through the surface of the ground like an iceberg emerging from the sea. Much of the linked structure will rest in the bedrock, which both insulates the structure and dampens vibrations that could interfere with sensitive equipment.

Two sections of the complex — housing laboratories, classrooms and offices — will fill the space between the Engineering Quadrangle and Bowen Hall. The third, at the corner of Olden and Prospect, will house a lecture hall and meeting rooms. A glass-sided tower, holding open stairwells, will rise at the connection between the central lab building and the southeastern corner of the EQuad.

The design team also worked to decrease the lab's environmental footprint. The ventilation system relies as much as possible on natural air flow, and the roofs will hold plantings designed to filter stormwater to reduce runoff and improve groundwater quality in the area.

Construction crews have been digging at the site and moving utility cables and pipes for the past few months. Work is scheduled to continue steadily at the site — and webcams are available to watch the progress (http://acee.princeton.edu/building)— until the Andlinger Lab's scheduled opening in the spring of 2015.

When it is finished, the Andlinger Lab will provide 127,000 square feet of new space, about a third of the size of the EQuad. With the construction, the University is roughly doubling its available space in "clean rooms," labs suited for work so sensitive that even minute dust particles would be disruptive. The Andlinger Lab's ventilation system is powerful enough to reduce the amount of dust in the clean rooms 1,000-fold.

The facility will hold machines that can create etchings at the nanometer scale and imaging equipment detailed enough to look at individual atoms. And everything will be enfolded in a park. ▶

Andlinger Lab design, continued from page 2

Building for 'collisions'

When a scientist peers at a lattice of atoms, the smallest vibration can make the microscope image bounce like a cork in a stormy sea. With that in mind, the architects plan to set much of the Andlinger lab space firmly in the bedrock. The construction will shield sensitive equipment from vibration and sound.

Anthony Novembre, associate director of the Princeton Institute for the Science and Technology of Materials (PRISM), said the new laboratory has been designed to meet the standards of the most exacting equipment available. In fact, the new structure is so stable that PRISM will be moving its most sensitive equipment into the Andlinger Lab, and Novembre is part of a group advising the project's designers on technical requirements.

The University is currently raising funds to purchase equipment, some of which will be designed specifically for use at Princeton. But equipment is only part of the equation. For the center to fulfill its goals, people with the right mix of expertise will need to collaborate on breakthroughs that lead to new energy technologies.

Emily Carter, the center's director, said a tremendous advantage held by Princeton is the ability to draw upon researchers from a wide variety of fields — more than 90 faculty members in 16 departments are currently doing research related to energy and the environment.

Although the Andlinger Lab will not be ready for a few years, the center is already fostering energy and environment research at the University. Upcoming Highlight Seminar topics range from wind energy to liquid fuels made by bacteria.

"Every one of these problems is not going to be solved by isolated research; they are going to be solved by teams of people," said Carter, who is the Gerhard R. Andlinger Professor in Energy and the Environment and a professor of mechanical and aerospace engineering and applied and computational mathematics.

Plans for collaboration reach beyond the University. Carter said the center will work with corporate affiliates on research and with government leaders on policy. The goal is for the world "to look to us for talent, but also for ideas."

"We need to train the next generation of leaders in this field, not just in science and engineering, but across the board," she said.

Photo by Bentley Drezner

James Miller of Sandia National Laboratories delivered a talk as part of the Andlinger Center's Highlight Seminar Series, which brings leaders in energy research to Princeton to share their work. Miller discussed ideas for using solar energy to convert carbon dioxide to hydrocarbon fuels in a type of reverse combustion.

With 'Power in a Box,' students win national competition

Converting a standard shipping container into a sustainable source of energy for remote or disaster-torn regions, a team of Princeton University students took top honors in an 18-month national competition that culminated on the Washington, D.C., Mall in April.

The students, working through a course called "Engineering Projects in Community Service" (EPICS), won a $90,000 grant from the U.S. Environmental Protection Agency to further develop and implement their project. The students' submission includes solar panels and a 40-foot-tall wind turbine that telescopes out of the container. Dubbed by the students "Power in a Box," it is designed to replace diesel-powered generators in areas cut off from other power sources.

The students are now using their grant money to build a more powerful version of the system, to work with the company Access:Energy to bring it from village to village in Kenya, and demonstrate how Power in a Box could be replicated with local materials. **–Steven Schultz**

Photo by Catherine Peters

A team of Princeton undergraduates set up their "Power in a Box" invention on the Washington, D.C., Mall on the second day of a competition sponsored by the U.S. Environmental Protection Agency.

Breakthroughs promise more powerful diagnostics, earlier disease detection

Princeton engineers recently reported medical technologies that promise far more sensitive diagnostics, as well as wireless detection of infections from within the body.

Million-fold improvement

In one finding, a team of nanotechnology experts devised a method for making a standard laboratory test up to 3 million times more sensitive to signs of diseases such as cancer and Alzheimer's, as well as other biological markers.

The breakthrough involves a common biological test called an immunoassay, in which disease-fighting antibodies are tagged with fluorescent molecules. When added to samples such as blood or urine taken from patients, these glowing antibodies attach themselves to biomarkers associated with diseases and technicians measure the intensity of the light. The brighter the glow, the more of the biomarker is present. However, if the amount of biomarker is too small, the fluorescent light is too faint to be detected.

The Princeton researchers tackled this limit on detection by fashioning nano-sized glass and gold structures that dramatically improve the transmission of light. Added to the standard glass vials used in immunoassays, these structures enhanced biomarker detection 3 million-fold. That means the enhanced immunoassay is sensitive to biomarker levels up to 3 million times smaller than what a conventional immunoassay can detect.

"You can have very early detection with our approach," said Stephen Chou, the Joseph C. Elgin Professor of Engineering, who led the research team. "Furthermore, the new assay is very easy to use, since for the person conducting the test there will be no difference from the old one — they do the procedure in exactly the same way."

Chou is now conducting tests to compare the sensitivity of the enhanced test to a conventional immunoassay in detecting breast and prostate cancers. He also is collaborating with researchers at Memorial Sloan-Kettering Cancer Center in New York to detect proteins associated with Alzheimer's disease at a very early stage.

Tooth tattoo

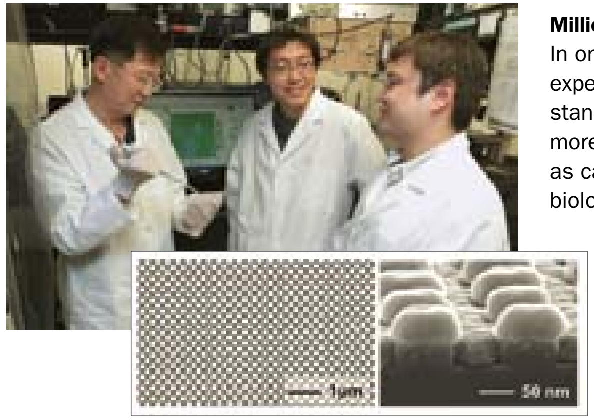
In separate research, a cross-disciplinary team of engineers used silk strands pulled from cocoons and gold wires thinner than a spider's web to create a removable tattoo that adheres to dental enamel and may be able to monitor a patient's health with unprecedented sensitivity.

"This is a real-time, wireless response from a sensor that can be directly interfaced with a variety of biomaterials," said Michael McAlpine, assistant professor of mechanical and aerospace engineering. He said the system not only has the ability to supply fast results, but is able to detect very small amounts of bacteria.

The researchers created the tattoo by bundling the silk and gold with graphene — an extremely thin sheet of carbon in which atoms are arranged in a honeycomb lattice. The material's unique properties allowed the researchers to construct a small, flexible device able to detect bacteria at a much higher sensitivity level than traditional methods. In tests, the researchers detected a single E. coli bacterium, which is roughly 2 millionths of a meter in length.

By combining the graphene array with a small antenna, the detection can be picked up by a remote reader device that is small enough to be held in a user's hand. **–SS and John Sullivan**

Photo by Frank Wojciechowski



Professor Stephen Chou (left) demonstrates how biological samples are added to an immunoassay test. Graduate student Fei Ding (middle) and postdoctoral researcher Liangcheng Zhou (right) were part of a team that demonstrated a 3 million-fold improvement in the test using a nano-sized device (inset) made of gold and silicon.

Photo by Frank Wojciechowski

Graduate student Manu Mannoor (left) worked with Assistant Professor Michael McAlpine (right) to "tattoo" a tooth with a biosensor capable of detecting minute amounts of bacteria. The team demonstrated a slightly bulkier version of the device on a cow tooth (inset).

Schmidt Fund awards support transformative technologies

A nitrogen sensor that can monitor environmental change, a "no-frills" quantum computer and a laboratory small enough to fit inside a single cell were the three Princeton University technologies selected this year to receive support from the Eric and Wendy Schmidt Transformative Technology Fund.

Established in 2009 by Google Executive Chairman Eric Schmidt (BSE '76) and his wife, Wendy, the $25 million endowment fund supports the development of new technologies that could enable significant scientific and technological advances.

"Through the generosity of Eric and Wendy Schmidt, we are able to support projects that have the potential to change the way we live through innovative research," said A.J. Stewart Smith, dean for research and the Class of 1909 Professor of Physics. "The Schmidt Fund enables initiatives that show great promise while accepting that cutting-edge research carries some risk. The three projects are inspiring and imaginative, and have tremendous possibilities for making profound advancements in our knowledge of the world around us."

The environmental-change sensor, a novel method for measuring nitrogen, is being created by Gerard Wysocki, an assistant professor of electrical engineering, and Daniel Sigman, the Dusenbury Professor of Geological and Geophysical Sciences. Nitrogen and compounds containing it — such as fertilizer and many pollutants — play a critical role in the environment, but monitoring the natural cycles and the effects of human activities on those cycles has been difficult. The team is using their $700,000 Schmidt fund grant to develop a method called Faraday rotation spectroscopy to measure isotopes of nitrogen — forms of the element that vary slightly in mass — to track how nitrogen cycles through organisms, soil, fresh water, the ocean and the atmosphere.

The quantum computer project, involving the promising yet extremely difficult-to-realize field of quantum computing, is led by Andrew Houck and Hakan Türeci, both assistant professors of electrical engineering. Although quantum computing has the potential to perform calculations currently impossible to address with today's computers, Houck and Türeci are not attempting to build a general-purpose quantum computer, but are working instead on a stripped-down version that can answer only certain types of questions.

With a $350,000 award from the Schmidt Fund, the researchers plan to construct their computer using building blocks known as circuit quantum electrodynamics elements, in which each piece of information is coupled with a device for transmitting signals. Houck and Türeci would wire together these elements to make a computer capable of simulating the quantum behavior of light particles, or photons, and providing key insights into basic energy science.

The "nanolab" is being developed by Haw Yang, associate professor of chemistry. Tools for exploring the internal workings of the cell tend to involve breaking the cell membrane and studying the contents piecemeal. Yang envisions a laboratory so tiny that it can enter the living cell and observe it from within. With a $700,000 award from the Schmidt Fund, Yang aims to build this "nanolab" to report on conditions such as pH level, temperature and electric field. Scientists and clinicians would be able to steer the nanolab to investigate different regions within the cell. The nanolab also could provide therapy by dispensing therapeutic reagents or destroying a diseased area.

A campus-wide competition is conducted each year to evaluate Schmidt Fund applicants. The reviewers, who include internal referees and external consultants, look for quality and innovativeness as well as a technology's potential to significantly influence a field. The request for proposals for next year's awards will be issued this September. **–Catherine Zandonella**

Photo by Frank Wojciechowski

Gerard Wysocki

Photo courtesy of the John D. and Catherine T. MacArthur Foundation

Daniel Sigman

Photo by Frank Wojciechowski

Andrew Houck

Photo by Brian Wilson

Haw Yang

It's in the bag:
Course gives students tools to manage fledgling enterprises

It's nearly the end of the semester and students in Derek Lidow's class are giving their best pitch on why he should buy their shopping bags.

Some come with slick videos and PowerPoint presentations. Others give live demonstrations of their products' special qualities. One group designed a compostable paper bag containing a seed insert so customers could plant the whole thing in the ground.

Like all the assignments in Lidow's new class called "Entrepreneurial Leadership," this final exercise was designed to give students a taste of the real business world as beginning entrepreneurs. They work in teams to research markets, design a product, identify manufacturers and set a price.

Lidow (BSE '73), the James Wei Visiting Professor for Entrepreneurship at Princeton's Keller Center for Innovation in Engineering Education, brings his experience as an entrepreneur and executive into the classroom. He was the founder, president and CEO of iSuppli, now IHS iSuppli, which provides data analysis for the global electronics industry and was sold to the IHS Company in 2010. Prior to that, Lidow was the CEO of International Rectifier Corp., a power semiconductor company.

The course is envisioned as complementing "High-Tech Entrepreneurship," the popular course taught by Ed Zschau, a visiting lecturer and electrical engineering professor. While the subject matter of Zschau's course could be compared to childbirth, Lidow said, his course is about "early child rearing" and teaches students how to grow a company. "That's a more perilous venture for entrepreneurs. Less than 10 percent grow their companies to the point where it's self-sustaining," he said.

Lidow's students discuss business school case studies and work in teams on assignments such as one in which teams compete to construct 60 designs out of sets of interlocking cubes. By the end, students have worked in three different teams on 24 assignments and read 1,500 pages of cases and books.

Shortly before the semester ended, Lidow shocked the class by interrupting the bag-design project with a surprise assignment to read the 320-page book, "Reinventing the Wheel," and write an essay about it in five days.

"You could feel the air get sucked out of the room and there were 50 pairs of dagger eyes looking at me," Lidow chuckled. There was a method to his madness: teaching students crisis management. After the initial panic, students organized themselves. Two teams divided the work among 10 students so each read just 30 pages and then combined their summaries.

A major aim of the course is for students to gain insights into their own leadership abilities. Students wrote a final paper on their personal leadership strategy and analyzed how they would use their strengths and compensate for their weaknesses as business leaders.

Tony Xiao, a graduating senior who majored in economics, said the course offered a methodical look into the stages of an entrepreneurial business and is helping him as he starts a software company. "It's like having a user manual or a playbook at the same time you're playing the game," he said. **–Jeanne Jackson-DeVoe**

Derek Lidow (left), Princeton's James Wei Visiting Professor of Entrepreneurship, leads a course that uses case studies and hands-on exercises to help students understand and build the leadership skills required to grow a small venture into a mature company. In one of the last assignments, students had to work as a team to design a shopping bag for a company and pitch their idea to Lidow. From left, undergraduates Coraline Griffie, Chenyu Zheng, Alexander Chan, Shu Haur Tang and John Monagle present their concept.

Photo by Denise Applewhite

H_2O
WATER IN OUR WORLD

For anyone looking for warnings about climate change, a good place to go would be just north of Las Vegas to Lake Mead. On a visit in 2008, I observed that the rock walls circling the lake were whitewashed with salt deposits for about 100 feet above the reservoir's blue mirror surface. That chalky band marked the normal water level and, after about a decade of sparse precipitation, Lake Mead was critically low.

James Smith is the chair and professor of the Department of Civil and Environmental Engineering and the director of the Program in Geological Engineering. He is also an associated faculty member in the Princeton Environmental Institute, the Department of Geosciences and in the Program in Atmospheric and Oceanic Sciences.

Photo of Lake Mead from visibleearth.nasa.gov; photo of J. Smith by Frank Wojciechowski

Water in our world, continued from page 7

It is likely to get worse. Climate model projections show that droughts will become more common in the Southwest as we move into the 21st century, and some projections indicate that the reservoir will no longer meet the region's water needs in as few as 25 years. At Lake Mead, the writing is on the wall for anyone who cares to look.

Lake Mead, created by the Hoover Dam, was one of the engineering marvels of the last century. (It is also one of the few named after the engineer who helped create it, Elwood Mead.) It truly made the desert bloom. Rapid growth in the American Southwest has relied on Lake Mead and the other Colorado River reservoirs for both water and power. The city of Las Vegas and much of Southern California could not have developed without it.

At the School of Engineering and Applied Science, we are working on a new generation of solutions to make better use of the water that our society depends upon. Our engineers are monitoring water use in areas ranging from the African savannah to downtown Baltimore. We are flying through the upper atmosphere to measure the impact of water on a changing global climate and wading deep into wetlands to evaluate the impact that pollution has on water quality. Our work encompasses details as tiny as droplets on a goose feather and as massive as hurricanes sweeping across the Atlantic.

With groundbreaking research such as Ignacio Rodriguez-Iturbe's work on the virtual water trade, Pablo Debenedetti's analysis of water at the molecular level, and Eric Wood's projections of continental drought, Princeton has much to be proud of. But we plan to do more in the future.

One way we would like to do this is to increase our collaborations with other leading scientific organizations. Princeton has historic ties to the nation's foremost climate modeling group, the Geophysical Fluid Dynamics Laboratory (GFDL), which is part of the National Oceanic and Atmospheric Administration. Located on Princeton's Forrestal Campus, the laboratory's scientists are the U.S. government's primary climate modelers and develop the projections that will guide our future policies. Scientists from GFDL also teach at Princeton, providing key courses in climate and atmospheric sciences. We would like to increase that collaboration, perhaps through jointly appointed faculty members and researchers.

We also plan to continue to work with colleagues throughout the University. Advances in water policy will be explored through collaborations with colleagues at the Woodrow Wilson School of Public and International Affairs. The water-energy nexus will present an emerging research agenda through the Andlinger Center for Energy and the Environment. The broad challenges of providing water for society's use, while maintaining quality of land, air and water, will be a continuing area of interaction with the Princeton Environmental Institute.

As engineers and scientists, we now face a challenge every bit as great as those facing the men who dug the first footings for the Hoover Dam back in 1931. Finding better ways to use water — to save it, to clean it and to work with it — will be our Hoover Dam. And the future of our country will depend on our work no less than it has depended on the waters of Lake Mead. E

Lake Mead, whose water level has been below the historical drought level since 2000, presents a stark example of shifts in water resources.

Opposite: Professor James Smith (left), an expert in the hydrology of extreme floods and the atmospheric dynamics of storms, worked with former Princeton postdoctoral researcher Gabriele Villarini (center) and geosciences lecturer Gabriel Vecchi (right) to predict the frequency of hurricanes as oceans warm and some types of pollution are reduced.

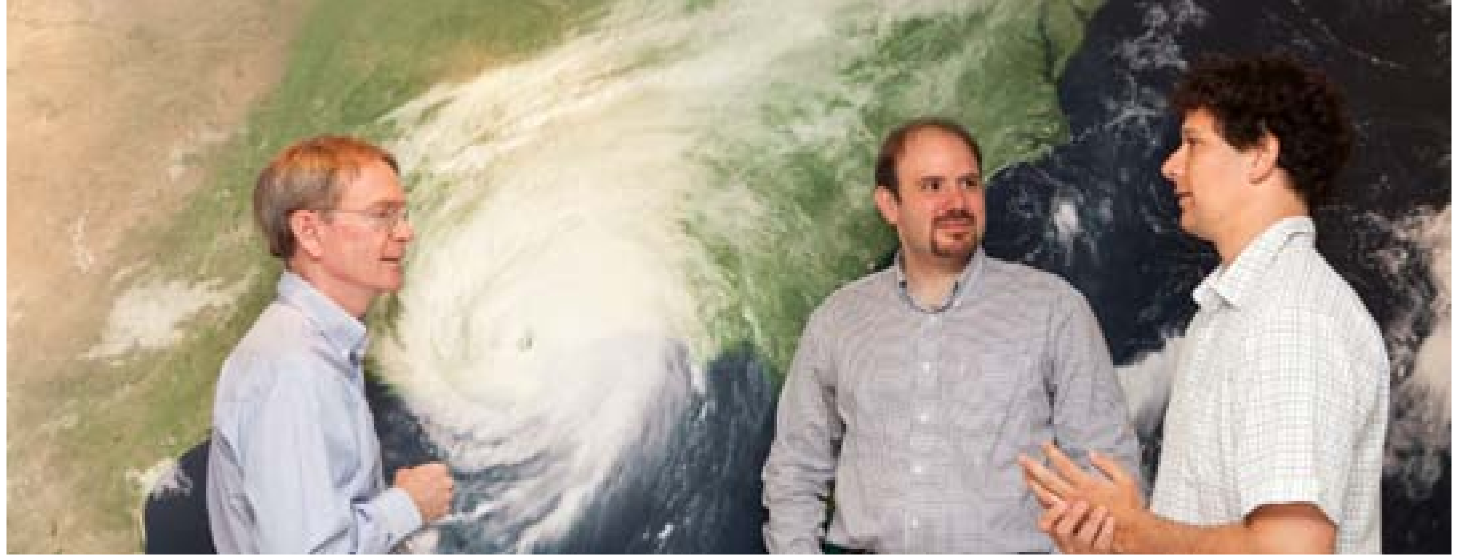


Photo by Denise Applewhite

GLOBAL CHANGES MEAN COMPLEX FUTURE FOR TROPICAL STORMS

By John Sullivan

Tropical storms in the Atlantic are likely to increase as the Earth's climate warms in the first half of this century, but not for the reason that many people think.

By analyzing storm patterns over the past century, researchers at Princeton and the Geophysical Fluid Dynamics Laboratory (GFDL) found that the increase will be caused by changes in the levels of aerosols in the atmosphere rather than an increase in greenhouse gases.

In a recent report in the journal Nature Climate Change, Gabriele Villarini, a research scholar in the group of Princeton Professor James Smith, and Gabriel Vecchi of GFDL analyzed the impact that changes in aerosol levels are likely to have on storm formation. Aerosols are particles suspended in gas. In the atmosphere, aerosols can be naturally occurring, such as clouds or dust, or they can be a result of pollution.

In recent decades, countries have taken steps to reduce air pollution, particularly aerosols. That is good from the public health standpoint — pollution by aerosols contributes to a number of health problems. But aerosols also affect climate. High concentrations of aerosols can cause thicker clouds, which result in regional cooling. Conversely, a drop in aerosol concentration due to pollution control results in warming.

The researchers found that because aerosols tend to be distributed regionally, rather than globally like greenhouse gases, changes in aerosol levels can cause regional differences in sea-surface temperatures. Such temperature differences are directly connected to the generation of tropical storms in the Atlantic. If the tropical Atlantic sea-surface temperature is warmer than the overall tropical mean state, there will be a greater number of storms.

While aerosol reduction heightens regional differences, global warming is likely to drive an overall rise in ocean temperature. In a series of scientific papers over the past several years, Smith, Villarini and Vecchi presented mathematical models that use data ranging from old weather logs to modern satellite transmissions and concluded that the relatively uniform increases in sea surface temperatures brought on by global warming will not significantly increase the number of tropical storms in the Atlantic.

"If you just look at the rise in sea surface temperature, you would be frightened to death," said Smith, chair of the Department of Civil and Environmental Engineering. "But it isn't the temperature that is critical, it is the relative temperature."

However, the researchers pointed out that their work does not make any projections about whether storms will become more severe as a result of climate change.

"This analysis does not bear any information on whether the strongest storms are going to get stronger," Villarini said. "You cannot extrapolate anything about that."

Villarini said the researchers initially assumed that the aerosols' effect would be similar to that of greenhouse gases. However, Vecchi, a climatologist and a visiting research scholar in Princeton's atmospheric and oceanic sciences program, began to analyze the decrease in aerosols, and the climate models showed a substantial impact.

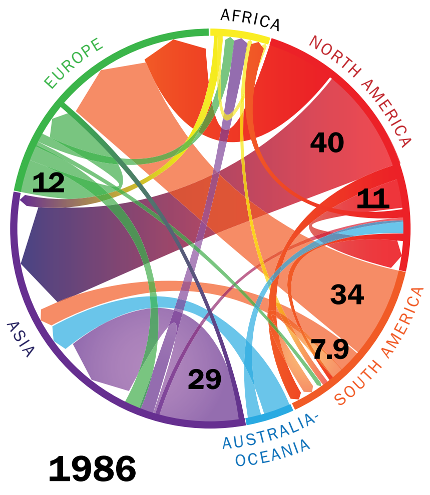
"The story became more and more interesting," said Villarini, now a professor at the University of Iowa.

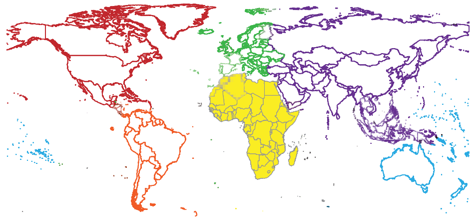
The unintended impact in cleaning up the aerosols shows the complexity of dealing with the changing climate. Villarini said the public health impact, as well as the benefit for the Earth's ozone layer, is clearly a substantial benefit of the policy.

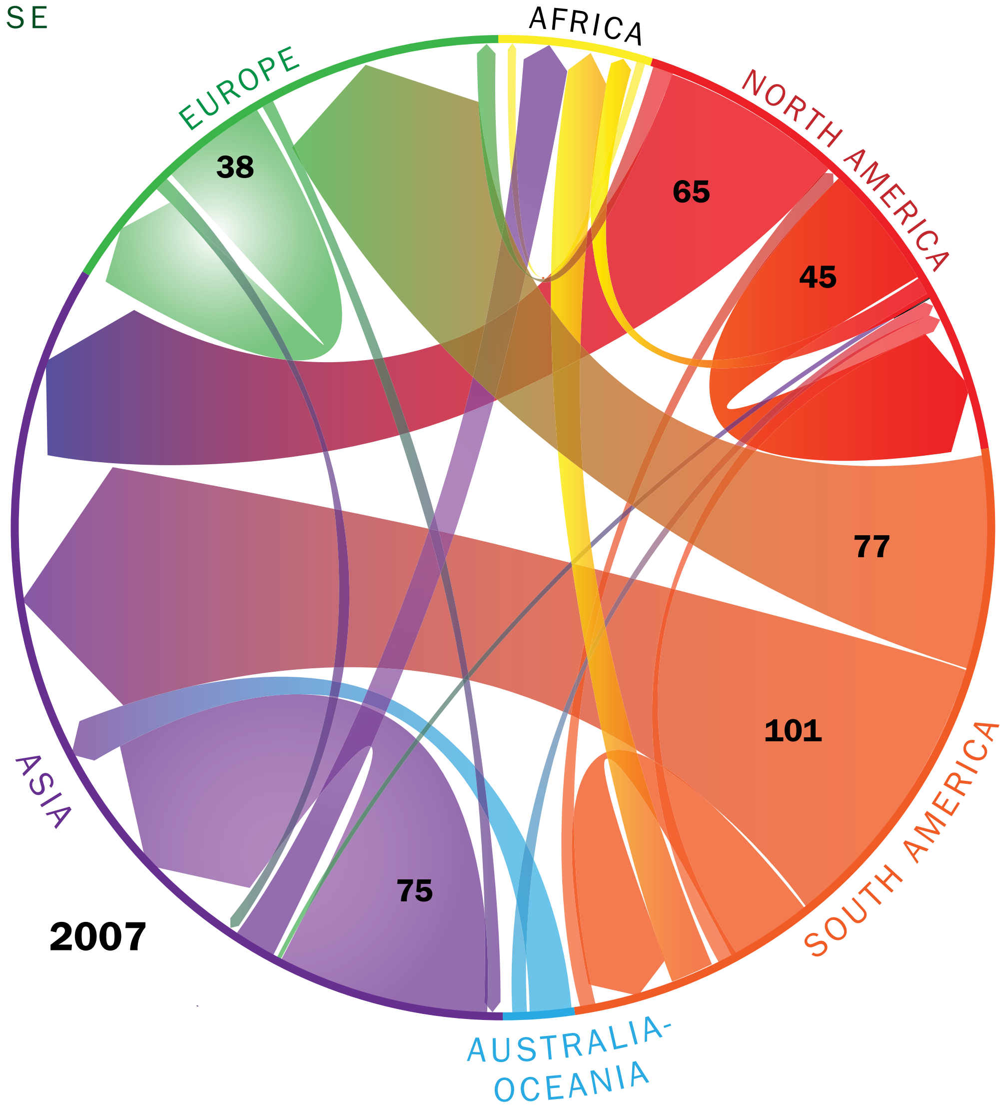
"The impact of the reduction in aerosols is multifaceted," he said. "The impact is not only on the tropical cyclone, it has impact on the absorption and scattering of light and radiation and changes in precipitation patterns. Plus it has impacts on human health. All of these are elements to keep in mind." E

'VIRTUAL WATER TRADE' HAS REAL IMPACTS

EATING HABITS IN CHINA SPUR GLOBAL SHIFT IN WATER USE







Graphic created using network visualization software by Martin Krzywinski et al. and adapted from an illustration appearing in Proc. Natl. Acad. Sci USA

Professor Ignacio Rodriguez-Iturbe (opposite page) and colleagues found that trade in "virtual" water expanded drastically from 1986 to 2007. The diagrams above illustrate the volume of water used to produce internationally traded goods and where those goods traveled. The thickness of the arrows indicate the relative volume of virtual water trade. The sizes of the largest flows are indicated by the black numbers, as measured in cubic kilometers of water.

By John Sullivan

A decade ago, a shockwave raced through the world's agricultural markets. China opened its borders to foreign-grown soy.

Ranchers in Argentina plowed under their pastureland and Brazilian farmers opened new acreage for planting. Almost overnight, the economies of those countries changed.

Why did this happen? And why does it make sense to grow food and ship it around the world rather than raise crops close to home?

A Princeton-led research team has found that one of the primary answers is water. ▶

"Trade in food is, essentially, trade in water," said Ignacio Rodriguez-Iturbe, the James S. McDonnell Distinguished University Professor of Civil and Environmental Engineering. "The food trade is a trade of virtual water between countries that have the water and countries that don't."

Roughly 80 percent of the world's freshwater use is devoted to agriculture. As countries such as China stretch their water supplies, they turn to countries with more abundant water supplies for food. In an article published on April 17 in the Proceeding of the National Academy of Sciences, the researchers reported that the volume of water associated with trade in food has doubled over the past 22 years.

"You see the impact of globalization on water usage," said Carole Dalin, a graduate student in civil and environmental engineering at the School of Engineering and Applied Science.

For the most part, the impact has been a relatively good one. In many parts of the world, water is a scarce resource, so the international trade allows regions with a surplus of water to devote that abundance to growing food that would be far more expensive and water-intensive to grow in drier regions. Even with the attendant transport costs, Dalin said, food trade has increased the efficiency of global water use.

Changes in Asia, and China in particular, had the greatest impact overall, Dalin said.

"When we looked at the global network, we saw that Asia was the region that increased imports the most," she said. "Looking even closer, at the national scale, we saw that China became the biggest importer in the world. They started importing in the 1990s and there is really a jump after 2000."

One of the main reasons for the shift was a change in people's diet in China, she said. As the Chinese increased their consumption of meat, their demand for agricultural products changed. That led to a massive increase in demand for crops used to feed livestock, such as soy. The expansion of Chinese imports — including opening its markets to imported soy in 2001 — was large enough to shift economies around the world, primarily in Latin America.

Between 2001 and 2007, China's virtual water imports more than doubled, and 90 percent of that was due to imports of soy products, the researchers found "This is driving agricultural expansion in South America, particularly Brazil and Argentina," Dalin said.

Latin American farmers not only increased their production, but also increased their efficiency in water use over the period, which contributes to global water conservation. But the change is not without problems. The demand for exports has led to deforestation in South America as farmers seek to open new acreage to cultivation.

Still, the virtual water trade may offer a type of safety valve as the countries of the world use trade to make up for regional shortfalls in food production that are likely to occur as climate change increases the incidence of droughts.

"International trade, which is not typically driven by concerns about water, could be one method to adapt to climate change," Dalin said. **E**

Photo by Laura Pedrick

PLANS FOR DAMS ON MEKONG RIVER COULD SPELL DISASTER FOR FISHERIES

By John Sullivan

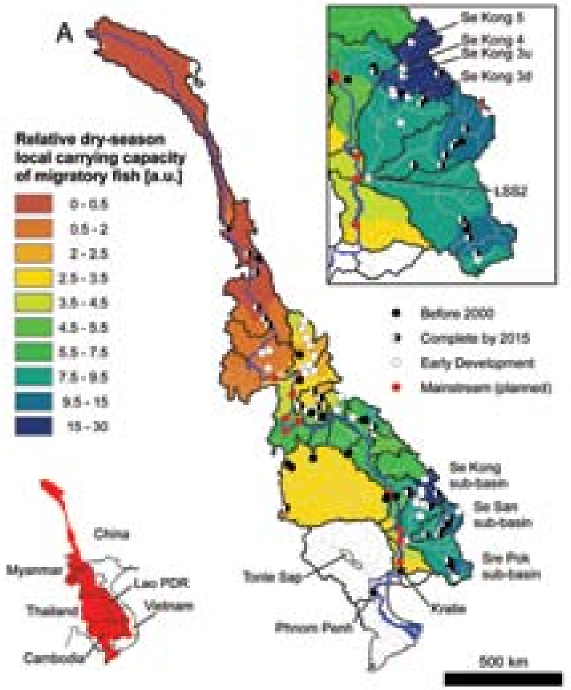
A massive expansion of hydropower planned for the Mekong River Basin in Southeast Asia could have a catastrophic impact on the river's fishery and millions of people who depend on it, according to a new study by researchers including scientists from Princeton University.

The researchers analyzed a number of scenarios for dam construction along the river and its tributaries. In an article in the Proceedings of the National Academy of Sciences (PNAS), they found that, in the most extreme cases, about a quarter of the migratory fish in the Lower Mekong Basin could be lost. The researchers warned that ecological damage is not the only concern. The Mekong River Basin, home to 65 million people, is the world's largest inland fishery, with about two-thirds of the residents depending on subsistence fishing for their diet.

Guy Ziv, the paper's lead author and a former Princeton researcher, said the importance of the river as a food source makes the impact of development "a major food security concern."

The construction is being driven by the increasing power needs of the expanding economies of Southeast Asia. Dams constructed in Laos, as currently planned, would provide power not only for that country, but also for Thailand and Vietnam. ▶

Graphic by PNAS/Guy Ziv et al.



Princeton researchers and their colleagues found that a massive hydropower proposal for Southeast Asia's Mekong River Delta could be detrimental to populations of migratory fish, a food staple for the region's 65 million people. The researchers suggest that governments reconsider constructing proposed dams (indicated on the map above) on Mekong tributaries that support large fish populations; on the map, blue indicates the highest capacity of migratory fish a tributary can support.

Plans for dams on Mekong River, continued from page 11

The researchers recognized the importance of power to the region, and that hydropower offers many advantages over other sources such as fossil fuels. But they said governments in the region should carefully consider the tradeoffs before continuing with the dam projects.

"Large rivers of the world are fundamentally important ecosystems," said Ignacio Rodriguez-Iturbe, the James S. McDonnell Distinguished University Professor of Civil and Environmental Engineering at Princeton and one of the authors. "Frequently, the urgent need for hydropower generation leads to a neglect of crucially important considerations like biodiversity and fish resources when planning the construction of dams along the rivers."

The PNAS report offers an opportunity to consider these tradeoffs as well as a set of possible solutions that the researchers said would minimize the impact on the river's fish for different levels of energy production. The researchers delivered a series of recommendations regarding which dams were most damaging so that countries in the regions can make informed choices. In particular, the researchers recommended against building dams on tributary rivers, which tended to be the most imprtant for the survival of migratory fish.

"We are not saying you should not build dams," Ziv said. "We are saying that you should build to minimize the impact."

Ziv is a research scientist at Stanford University who wrote the paper while working at Princeton. His co-authors are Simon Levin of the Department of Ecology and Evolutionary Biology at Princeton; Rodriguez-Iturbe of the School of Engineering and Applied Science at Princeton; Eric Baran of the WorldFish Center in Phnom Penh, Cambodia; and So Nam of the Cambodian Fisheries Administration. The research was supported by the James S. McDonnell Foundation, the AXA Research Fund, Mitsui-Bussan and the government of Japan.

The Mekong, which runs through Southeast Asia from Tibet to the South China Sea, is one of the world's most diverse fish habitats. The researchers identified 877 species of fish in the Lower Mekong Basin, including 103 migratory species that would be affected by dam construction.

"The Mekong is one of the richest spots in the world," said Levin, the George M. Moffett Professor of Biology at Princeton. "It is a diversity hotspot."

Ziv said the researchers felt their report was a positive one overall. If the countries in the region can work together, they potentially could generate a large amount of energy without doing a tremendous amount of damage to the river, he said.

"You can reach a pretty large level of energy production without losing a lot of biomass," he said. "However, our results suggest that there are some dams that you can and should avoid." **E**

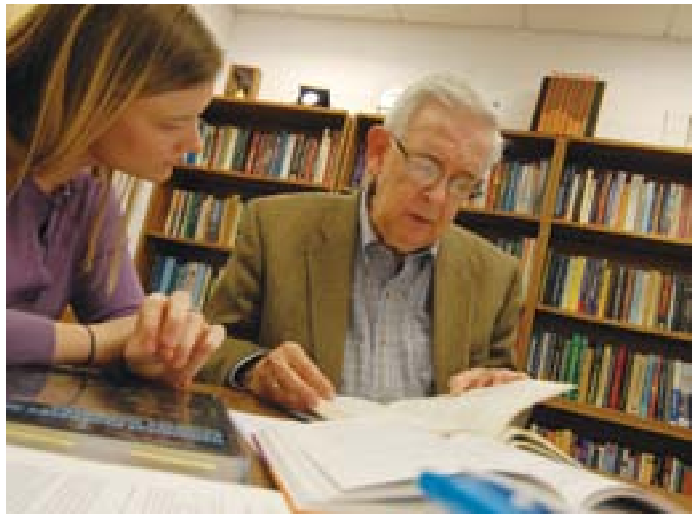


Photo by Laura Pedrick

Ignacio Rodriguez-Iturbe (right) studies the interaction of water and ecosystems, including the role of water systems in biodiversity and international trade. Here he speaks with graduate student Megan Konar.

Photo courtesy Mark Zondlo

Graduate student Minghui Diao recently flew to Antarctica and back on a research plane as part of her work with Assistant Professor Mark Zondlo to understand the interaction of water vapor, climate change and cloud formation. Shown here on the research plane during a stop in in New Zealand, Diao helped gather previously unavailable data on gas concentrations at varying altitudes.

CUTTING THROUGH CLOUDS TO REVEAL WATER'S ROLE IN CLIMATE

By John Sullivan

Mark Zondlo and his research team frequently find themselves 45,000 feet above the Earth looking for water vapor in the upper reaches of the atmosphere.

From a seat in a National Science Foundation (NSF) research jet, the engineers can search a slice of the sky for pollutants and gases that play a role in climate change. Zondlo, an assistant professor of civil and environmental engineering, said that water plays a greater role in climate change than many people imagine.

"If we want to understand where the Earth's climate is going in the future, we have to understand water vapor," Zondlo said. "It is the dominant greenhouse gas."

Zondlo said that even small increases in water vapor enhance the effect of other greenhouse gases by as much as 30 percent. Much of his research in recent years has focused on how water in the upper atmosphere affects clouds, one of the most difficult aspects for climate models to predict.

"We are trying to understand the mechanisms for it — how does water get transported up there, how do clouds form?" he said.

Last September, Zondlo and his co-researchers participated in the final flights of the HIAPER Pole-to-Pole Observation (HIPPO) mission, an NSF project that used a specially modified jet to take atmospheric measurements from the Arctic to the Antarctic. The mission gave researchers a clearer picture of gas concentrations at varying altitudes and provided the first global insights into ice-cloud formation.

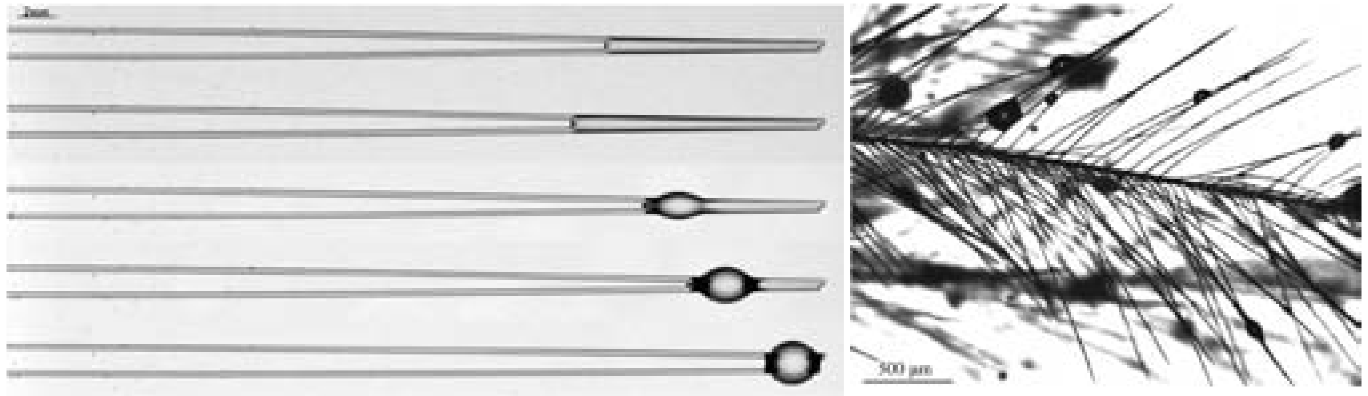
"From a water vapor perspective, HIPPO was very important," Zondlo said. "You can measure it through satellites, but you can't measure it at cloud scales like you can with the aircraft."

Zondlo and his team are now part of a new series of flights over the Rocky Mountains and the American Midwest called the Deep Convection Clouds and Chemistry Experiment. That project, under the auspices of the NSF and NASA, will look at how thunderstorms lift pollutants into the upper atmosphere.

"We are looking at thunderstorms over Colorado, the Great Plains and over the Gulf Coast states," he said. "We are trying to look at different sources for the air and how they impact the climate above."

After that project, Zondlo's team is off to Thailand where they will examine polluted conditions high over Southeast Asia.

"Changes in the upper atmosphere drive the climate of the Earth," he said. "That's where water vapor has its biggest impact." **E**



Images courtesy of Camille Duprat and Suzie Protière

LESS IS MORE: STUDY OF TINY DROPLETS COULD HAVE BIG APPLICATIONS

By John Sullivan

Under a microscope, a tiny droplet slides between two fine hairs like a roller coaster on a set of rails until — poof — it suddenly spreads along them, a droplet no more.

That instant of change, like the popping of a soap bubble, comes so suddenly that it seems almost magical. But describing it, and mapping out how droplets stretch into tiny columns, is key to understanding how liquids affect fibrous materials, from air filters to human hair. That knowledge could allow scientists to better describe why water soaks into some materials, beads atop others and leaves others matted and clumped.

To help get those answers, an international team of researchers led by scientists at Princeton University made a series of close observations of how liquid spreads along flexible fibers. They were able to construct a set of rules that govern the spreading behavior, including some unexpected results. In a paper published in Nature, the researchers found that a key parameter was the size of the liquid drop.

"That surprised us," said Camille Duprat, the paper's lead author. "No one had thought about volume very much before."

Duprat, a postdoctoral researcher in the Department of Mechanical and Aerospace Engineering, said the research team was able to determine drop sizes that maximized wetting along certain fibers, which could allow for increased efficiency in industrial applications of liquids interacting with fibrous materials — from cleaning oil slicks to developing microscopic electronics. The team also discovered a critical drop size above which the drop would not spread along the fibers, but would remain perched like a stranded roller coaster car.

"If in any engineering problem you can learn an optimal size above which something does not happen, you have learned something very important about the system," said Howard Stone, a co-author of the paper and Princeton's Donald R. Dixon '69 and Elizabeth W. Dixon Professor in Mechanical and Aerospace Engineering.

Stone said the team conducted a series of experiments observing how liquid spread along different types of fibers. The plan was to make broad observations and derive a governing theory from the experiments.

"We had a lot of results and at some point we started having these meetings trying to understand what we had," he said. "We realized the way to think about it was in the way of critical sizes."

Besides Duprat and Stone, the researchers included Alexander Beebe, a Princeton junior majoring in mechanical and aerospace engineering, and Suzie Protière, an associate scientist at the University of Pierre and Marie Curie in Paris. The research at Princeton was conducted with support from Unilever. **E**

Above left: A study led by Princeton engineers shows that the size of oil droplets determines whether they spread along flexible glass fibers. Smaller droplets stretch along the fibers (top two examples), but larger droplets sit immobile between the glass rods.

Above right: The researchers conducted similar studies of oil droplets on goose feathers, and also found that the size of the droplets determines whether they form clumps. The finding could prove important for cleaning waterfowl after accidental spills.

PROBING WATER'S MOLECULAR MYSTERIES YIELDS PRACTICAL INSIGHTS

By John Sullivan

Pablo Debenedetti studies water at the smallest possible scales — zooming in on molecule-to-molecule interactions — but the implications for large industrial processes and many scientific fields could hardly be greater.

Take water quality. Debenedetti and Sankaran Sundaresan, both Princeton engineers, are attempting to find a clean, new way to desalinate water by using hydrates, or crystalline solids in which hydrocarbon molecules are trapped in water cages. When hydrates form in seawater, these water cages are salt-free, so the researchers are trying to use them to draw pure water from the ocean. The work, supported by a Princeton University Grand Challenge and Project X grants, could lead to a relatively low-cost and low-energy method of providing needed drinking water.

"There is a sense of urgency about water that has accelerated in recent years," said Sundaresan, a professor of chemical and biological engineering. "It has led us to take a look at new options."

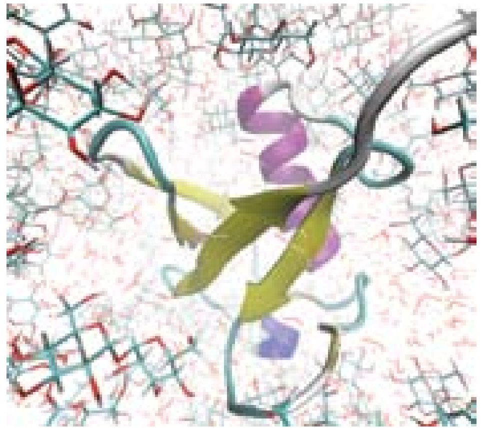
Princeton engineers also are examining how water behaves when squeezed between waterproof surfaces at the molecular level. Understanding the process would provide key insights for the design of self-cleaning materials and the preservation and storage of certain pharmaceutical compounds. The expulsion of water at the molecular level also is thought to play a key role in the folding of proteins — the process by which proteins assume their shape and function in the cells of all living things.

In a recent paper in the Proceedings of the National Academy of Sciences, Debenedetti and postdoctoral researcher Sumit Sharma found that the most important factor in determining the speed at which this squeezing process can occur is the distance between the surfaces. The researchers found that a small cavity spanning the space between the surfaces had to form before the water would evaporate, and the ease with which this cavity could form depended sensitively on the space between the surfaces. Debenedetti said that the difference of as little as a single angstrom (one ten-billionth of a meter) could change the chance of drying one hundredfold.

"The key finding is that the rate at which water is expelled is enormously sensitive to the size of the cavity," said Debenedetti, the Class of 1950 Professor in Engineering and Applied Science and vice dean of the School of Engineering and Applied Science.

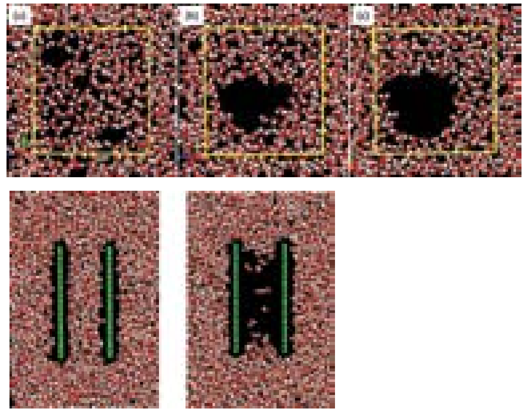
It is possible that water expulsion could be a controlling factor in how fast certain proteins, called globular proteins, adopt their biologically active shape, but further research will be required to explore that question.

"This type of research is very fundamental," Debenedetti said. "The general problem is to predict the substance's observable properties starting from the molecular level." **E**



Protein image courtesy of Harold Hatch

Simulation image courtesy of Sumit Sharma



Researchers in the lab of Pablo Debenedetti are gaining fundamental insights into how water moves away from oils or other "hydrophobic" molecules. In this simulation above, the researchers determined the rate at which water molecules (red and white) move away from oil molecules (green or yellow) and how much energy is required to move them. These insights are useful in determining how proteins (left) fold into the shapes that give them their unique functions.

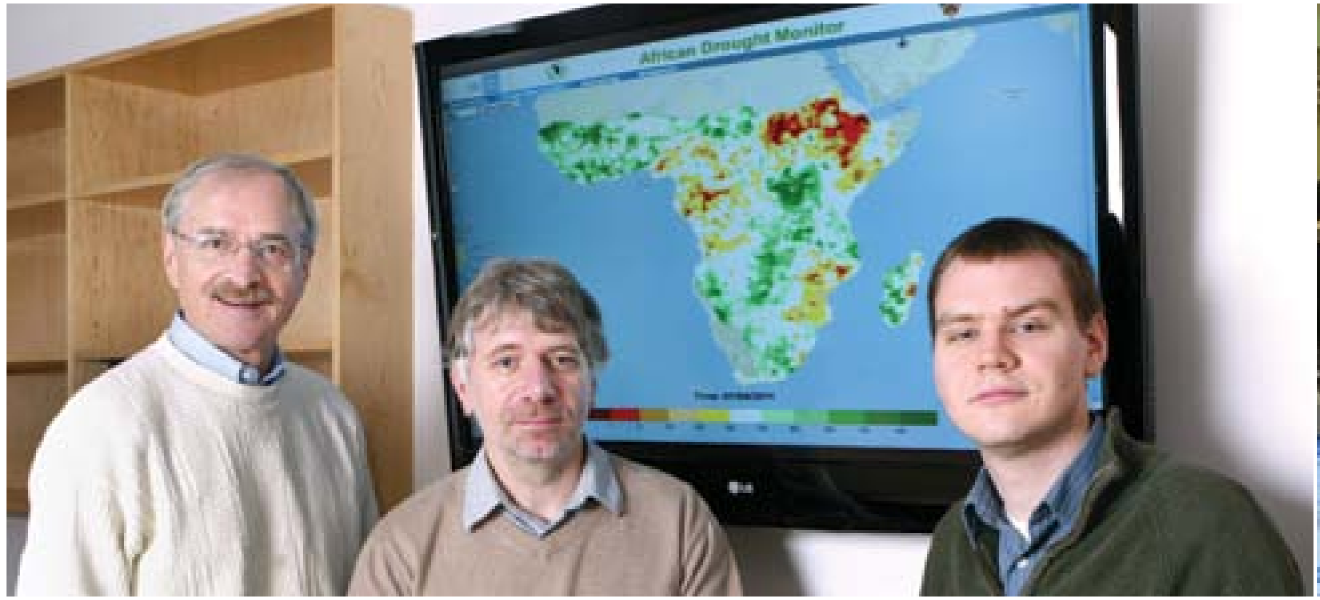


Photo by Frank Wojciechowski

Photo by Justin Sheffield

Opposite: Engineering school researchers (from left) Eric Wood, Justin Sheffield and Nathaniel Chaney created a computer model to track drought in remote or war-torn regions of Africa that are difficult for ground-based observers to reach. Left: Wood (by windows at right) speaks with scientists at the AGRHYMET research center in Niamey, Niger. The Princeton team recently installed the drought monitor at AGRHYMET and is scheduled to deploy the system in Kenya later this year.

TRACKING DROUGHT TO AID DISASTER RELIEF

By John Sullivan

Drought is often the precursor to disaster, but getting leads on its stealthy approach through remote or war-torn areas can be so difficult that relief agencies sometimes have little time to react before a bad situation becomes a calamity.

The problem is that there is often no easy way to get data about water supplies in these areas — water monitoring stations don't exist, or they don't work, or their locations are simply too dangerous. Groups such as AGRHYMET, an intergovernmental hydrology, agricultural and food-security agency based in Niger, often have to rely on far-flung observers, often volunteers, to obtain the information manually.

"AGRHYMET conducts the drought monitoring for the whole of West Africa from Cape Verde and Mauritania to Chad and Nigeria," said Abdou Ali, a senior scientist with the organization. "Many areas of this region are drought prone. The ground-based data is not enough and even when the data exists, the transmission system is very weak."

But researchers at Princeton University have come up with an approach to help overcome those problems using satellite data and historical records to track drought conditions as they emerge. Experts believe their monitoring project, installed in February at AGRHYMET's research center in Niamey, Niger, may go a long way in addressing problems related to drought that have long plagued Africa.

"Water scarcity is a critical issue," said Eric Wood, the head of the Princeton team and director of Princeton's Program in Environmental Engineering and Water Resources. "What are the signatures in weather and climate that precede a drought? What takes you out of drought? If you don't have the objective monitoring, you can't do the predictions."

Because data is not available for many areas of the continent, the researchers use a mathematical model to simulate the water cycle and, from this simulation, determine when specific regions enter into drought. They combine patterns simulated from decades of climate records with current temperature measurements and with precipitation data from satellites. Essentially, the model maps the landscape and provides a likely estimate of hydrological conditions based on current inputs and historical patterns.

"The most important thing it gives you is spatial patterns," said Justin Sheffield, a research scholar in civil and environmental engineering. "You can say this region is in drought and it has been in drought for the past several months."

Putting those patterns together can be critical for agencies preparing to respond to famines or other crises spawned by drought. They may get very accurate reports from some regions, but a lack of information can make it difficult to respond to other areas.

"The difficulty often is connecting all the dots," said Frank Catania, deputy director of humanitarian response for the aid organization Oxfam America. "You are seeing things in one area, but other groups are seeing other things in other areas. Who puts all that data together?"

Drought and floods account for 80 percent of deaths and 70 percent of economic damage caused by natural disasters in Africa, according to a 2007 report by the United Nations.

More recently, drought has led to widespread famine in East Africa, and there is concern about drought-related hunger in the Sahel region, the band of savanna that runs along the southern edge of the Sahara desert.

"Consistent, quantitative information on emerging drought regions is absolutely essential," Sheffield said.

Support from the United Nations and NASA

A conversation at a 2006 international conference on the hydrological impacts of climate change led to a working arrangement between the Princeton team and the United Nations Education, Scientific and Cultural Organization (UNESCO).

"Africa is a priority for UNESCO, so it fits very well into the strategy to make sure that we have a system in place to have an early warning on drought," said Siegfried Demuth, chief of hydrological systems for UNESCO's Division of Water Sciences. "We are looking to provide the knowledge base, the tools, with which countries can be better prepared."

Demuth said the drought monitor will also help countries plan for long-term water management, whether that involves water-supply projects or irrigation for agriculture. The ability to track water supplies over the long run — decades rather than years — can be critical to building reservoirs, planning for growth or for selecting crops.

Demuth said a priority for UNESCO was developing a tool that African researchers could refine and expand. To that end, the Princeton researchers have designed the system so that people using it can fine-tune its accuracy by comparing the model's results with data taken from ground stations in their region, and can use the data for related research such as crop monitoring or climate change assessments.

"The hope is that we are going to build and expand on the idea through our African collaborative research network, which is supported through the University's Council for International Teaching and Research," said Wood, the Susan Dod Brown Professor of Civil and Environmental Engineering.

Wood said it was important for the project's future that African researchers develop ways that the model can best suit local needs. He said the workers in the field also will be able to suggest ways to improve the model and to provide data that will lead to further refinement of its accuracy.

"We want the feedback," he said. "We have the technology, the knowledge, to do this but what we need to know is how useful this is for people on the ground."

The goal is to distribute information widely that can help people deal with water shortages before they become disasters.

"There may be another jump between what we are producing and what is really useful for people on the ground, but that is what we are relying on our collaborators for," Sheffield said. "That is the kind of thing that interests me — turning this into a practical tool that can help save lives and prevent people from going hungry." E

Photos courtesy of Peter Jaffe

MICROBES AND MARSHES: MIX OF CHEMISTRY AND BIOLOGY HELPS CLEAN UP WATERS

A team of Princeton engineers researching plant growth and greenhouse gases in the Meadowlands marshes of New Jersey included (directly above, from left) graduate students Luke MacDonald and Hagar ElBishlawi, Professor Peter Jaffe, graduate student Jeffery Paull and Professor Klaus Holzapfel of Rutgers University. ElBishlawi (above right) stands at one of the Meadowlands research plots. In another project in southern New Jersey (top left, from left), postdoctoral researcher Shan Huang and graduate student Alyce Egner are working with Jaffe to understand a novel mechanism by which soil microbes clean agricultural pollutants from water.

By John Sullivan

In the course of studying water and its impact on communities, Peter Jaffe and his students have waded through the marshes of New Jersey's Meadowlands and worked with villagers in India to remove toxins from their drinking water.

Their travels represent the wide range of interests that Jaffe, a professor of civil and environmental engineering, has pursued in water-related research.

In India, fluoride contamination in well water is common in parts of the country. In small amounts, fluoride helps prevent tooth decay, but too much fluoride can deform teeth and bones. Jaffe's group found a way to use apatite, a phosphate compound, to filter out the fluoride and leave the well water safe for residents. And, because phosphorous is good for plants, the old filtering material can be re-used as fertilizer.

Closer to home, Jaffe and a team of researchers from Rutgers and the Meadowlands Environmental Research Institute have embarked on a project to measure how environmental conditions, including plant growth, affect the amount of greenhouse gas emitted by the wetland. The researchers hope their work will allow for better control of marsh gases such as methane, a powerful greenhouse gas. Plants are thought to help balance these emissions and, among other things, the research will examine the impact of two of the most common plants in the Meadowlands: cordgrass (spartina) and the invasive common reed (phragmites).

The Meadowlands work is similar to other projects that Jaffe has undertaken. In recent years, his research teams have looked at how wetlands recover from long-term pollution, and have examined methods to reduce concentrations of toxic metals in the environment.

Jaffe and his students also are working on a project, funded by a Princeton Project X grant, that could offer a promising method to counter widespread environmental damage caused by nitrogen compounds in water. These compounds enter waterways in fertilizer from agricultural runoff and have created massive dead zones in fresh water and coastal regions in which plants and fish cannot survive.

Jaffe and his students analyzed wetland sediment samples from the Assunpink Wildlife Management Area in New Jersey and uncovered indications of a novel mechanism by which iron-reducing microorganisms convert ammonium in runoff to harmless nitrogen gas, which returns to the atmosphere. Currently, the team is attempting to understand the process better with the hope of using the organisms or a similar chemical mechanism to clean up threatened waterways. E

Photo by Denise Applewhite

DEVISING A 'SILVER BULLET' FOR MEASURING WATER USE BY PLANTS

Princeton alumna Ida Posner (BSE '12) worked with a research team led by Kelly Caylor (right), an assistant professor of civil and environmental engineering and director of the Princeton EcoHydrology Lab, in an effort to find better ways to measure the water use in an ecosystem.

By John Sullivan

A skilled gardener can intuit how much water tomatoes and carrots need, but precisely quantifying a plant's actual water use can be tricky.

Although the measurement is critical for understanding how ecosystems are affected by drought, development or climate change, there is no easy way for scientists to verify estimates of water use. Right now, scientists have to use expensive, bulky laboratory equipment to analyze samples and directly track how much water plants are using. But if recent Princeton graduate Ida Posner's senior thesis project works the way she hopes, that could all change.

Posner (BSE '12) has developed a technique to simplify and reduce the cost of water vapor measurements. For her senior thesis project, Posner built a small, cylindrical device that could lead the way for scientists to quickly and efficiently measure plant water use.

Working in the Engineering Quadrangle's hydrology lab, Posner was part of Professor Kelly Caylor's research team looking for better ways to measure the water use in an ecosystem.

"There is an urgent need for better guidance regarding the management of water for use in dry-land agriculture and the response of rangelands to rainfall variability in semi-arid regions," said Caylor, assistant professor of civil and environmental engineering and director of the Princeton EcoHydrology Lab. "Any advice or additional insight to these issues depends critically on being able to routinely and accurately characterize the water use of plants."

To track how much water plants use, the researchers measure isotopes present in water vapor emitted by a plant — a process called transpiration. The proportion of isotopes, variations of elements determined by the number of neutrons in an atom, is affected by how the water vapor formed.

"The isotopic signature of water gives it a fingerprint that you can use to trace water through the ecosystem," Posner said.

Water vapor created by plants through transpiration has a distinct isotope composition, but this measure is often skewed by organic contaminants that are emitted by the plants. It's possible to remove or account for these contaminants, but that requires laboratory equipment unsuitable for field use. Posner's task was to create a cheap and practical filter to remove these chemicals without disturbing the sample.

In testing her device, Posner first extracted water from a basil plant in Caylor's Princeton laboratory by mashing up a sample and freeze-drying the water. (Another of Caylor's students, Alice Suh (BSE '12), worked on a special clamp that can directly collect emitted water vapor. Suh, also a civil and environmental engineering major, developed the device as part of her senior thesis project as well.)

Posner then had to remove the impurities without damaging the sample. To do that, she made a special filter that operates like a car's catalytic converter. Essentially, she took a 5-inch stainless steel pipe and filled it with aluminum pellets coated with a thin layer of platinum. She attached air hoses at both ends of the pipe so she could stream the water vapor through. The platinum breaks down the organic contaminants, which then remain inside the pipe. The vapor emerges from the other end ready for analysis. In the field, Posner's pipe assembly would be attached to a suitcase-sized device that measures the isotopes.

Caylor said if Posner's technique works "we will be able to quickly and routinely assess the isotopic composition of plant water use in field settings."

Currently, laboratory approaches for removing the contaminants that skew the test are not suitable for field use. "So Ida is really working on a silver bullet — a method of removing contaminants that can be used either in the field or in the lab." E

HSIEH '77 HONORED FOR CRITICAL ROLE IN CAPPING GULF OIL SPILL

Photo courtesy of Patrick Campbell/University of Colorado

Engineering alumnus Paul Hsieh (left) delivers a talk at the University of Colorado after earning national recognition for making the calculations that allowed the final capping of the Deepwater Horizon oil spill (below).

Photo courtesy of USGS

By John Sullivan

There is pressure, and there is pressure.

Paul Hsieh (BSE '77) mostly deals with the physical type, the stresses and forces of underground water and rock. Understanding that type of pressure is a daily task for Hsieh, a hydrologist at the U.S. Geological Survey (USGS) in Menlo Park, Calif.

But after the Deepwater Horizon oil rig exploded in April 2010, Hsieh learned about pressure of an entirely different kind. Engineers worked for 87 days to cap the stricken well and staunch the oil flowing into the Gulf of Mexico. But no one was sure whether the plan would work, or create an even greater disaster.

For the answer, the federal government turned to Hsieh.

"The well was lined by pipes called casing, and the fear was that the explosion had damaged the well so that the oil could leak out of the casing," he said.

The escape of oil, called an underground blowout, could have led to multiple ruptures on the seabed and place the disaster beyond control. A working group of scientists, reporting to Secretary of Energy Steven Chu, decided to use the well's pressure to determine whether the blowout was likely.

"If the pressure was high, that would be a good indication," Hsieh said. "If the pressure was low it would indicate the oil was leaking out of the well and there was a danger of an underground blowout."

As a researcher with the USGS, Hsieh helps develop computer models to predict the flow of underground water and potential contaminants. Part of the modeling deals with estimating the interaction between water and rock structures deep underground — a feature uniquely suited to the Deepwater Horizon recovery.

Hsieh said he has been fascinated with the subject since he spent a summer as an undergraduate studying the aquifer on Eastern Long Island under George Pinder, a professor of civil engineering, at Princeton.

"I spent a summer on the South Fork on a project looking into potential salt water intrusion into the water resources, and I loved the work," he said.

Hsieh started work at USGS after graduating with his bachelor's degree in civil engineering. Except time spent earning his doctorate from the University of Arizona, he has been there ever since.

Rear Adm. Kevin Cook, director of prevention policy at the U.S. Coast Guard, has called Hsieh's work on the Deepwater Horizon recovery "a game-changer" and said it provided confidence to finally close the well. Hsieh and his co-workers also provided the official calculation of the amount of oil that spilled from the well. For his work, Hsieh was named the 2011 Federal Employee of the Year by the Partnership for Public Service.

Hsieh stepped in ready to run his evaluation after workers clamped down the cap at Deepwater Horizon. The pressure readings were mixed — too high to clearly indicate a leak but too low to be absolutely sure that the well was sound.

"Most people were leaning toward reopening the well because the risk of an underground blowout was unacceptable," Hsieh said.

Hsieh had limited time to perform the analysis — the longer the well remained capped, the greater chance of a blowout. He stayed up all night running the numbers. His results were clear: The well would hold.

For the next two weeks, the scientists worked around the clock checking the well and refining the simulation.

"As time went on, the monitoring showed no sign of a leak," Hsieh said. "It all ended well." **E**

UNLOCKING THE MYSTERIES OF THE DEEP SEA

By Teresa Riordan

At least three Princeton Engineering alumni — all in the Seattle area — are engaged in exploring the mysteries of the deep sea.

• As a research scientist and senior engineer at the University of Washington, **Andy Stewart** (Ph.D. '12) works on a variety of projects, such as basic research in dynamics and control of autonomous systems (typically underwater vehicles), and designing and building a high-definition video camera for streaming live footage from a hydrothermal vent as part of the National Science Foundation's decades-long Ocean Observatories Initiative.

Stewart also is working on instruments — five of which are set to be deployed this summer — that sit in the ocean at depths of nearly 15,000 feet and measure water velocity using the Earth's magnetic field.

"What we do is essentially build a circuit out of some saltwater pathways and record voltage potential between known locations in the flow," he reports. "My main contribution has focused on a mechanism that switches polarity in this circuit. It requires mechanically switching a seawater pathway inside the device and must function under very high external pressure."

Stewart credits his research with **Naomi Leonard** (BSE '85), the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering, as having prepared him well. "Having a strong background in fundamental theory is critical when you're cooking up projects that push limits," he says. "The experience I gained working in Naomi's lab with the underwater vehicle test bed gave me the skills I'm now using to develop the next generation of ocean-science technology."

• **Stockton Rush** (BSE '84) is co-founder and CEO of OceanGate Inc., a provider of manned deep-sea submersibles that aims to expand the capabilities of research and academic institutions, government agencies and commercial businesses. OceanGate is developing a manned submersible that can reach depths of 6,000 meters, which it says will dramatically change the way we access the deep sea. The project, in collaboration with the University of Washington's Applied Physics Lab, is leveraging advances in material science, electronics and aerospace technology.

• Bezos Expeditions, founded by Amazon.com CEO **Jeff Bezos** (BSE '86), is attempting to recover the five F-1 rocket engines that, firing in concert, launched NASA's historic Apollo 11 mission. After they burned for just a few minutes, the F-1s plunged back to Earth into the Atlantic Ocean. Using state-of-the-art deep-sea sonar, the Bezos Expeditions team has located the Apollo 11 engines, which are lying 14,000 feet below the surface. The expedition plans to attempt to raise one or more of them from the ocean floor. Writing on the expedition website, Bezos expresses hope that the engines will be put on public display should any be recovered. "NASA is one of the few institutions I know that can inspire 5-year-olds," he writes. "It sure inspired me, and with this endeavor, maybe we can inspire a few more youth to invent and explore." **E**

Photo courtesy of Andy Stewart

Photo courtesy of OceanGate

Photo courtesy of NASA

Above right: Recent alumnus Andy Stewart is developing a series of devices similar to the one shown here for measuring water velocity deep in the ocean.

Center: Alumnus Stockton Rush sits atop a submersible vehicle he is developing with his ocean exploration company OceanGate.

Right: The Apollo 11 moon mission dropped booster stages of the rocket back to Earth; Jeff Bezos, engineering alumnus and founder of Amazon.com, is leading an effort to retrieve the rocket pieces from deep in the Atlantic Ocean.

Faculty members elected to National Academies


Photo by Frank Wojciechowski

Pablo Debenedetti, the Class of 1950 Professor in Engineering and Applied Science and vice dean of the School of Engineering and Applied Science, has been elected to the National Academy of Sciences, one of the highest honors given to scientists in the United States.

Debenedetti, is an expert in the thermodynamics and statistical mechanics of liquids, glasses and biomolecules. He has advanced the understanding of the relationship between the molecular structure and the physical properties of fluids and amorphous solids such as glass. His research into the properties of proteins in low-water environments has led to advances in the use of proteins in pharmaceutical applications, both through increasing proteins' stability as well as improving the delivery of small particles of proteins through the upper respiratory tract. Debenedetti has also explored, theoretically and computationally, the behavior of water at the molecular level. That research includes examining how water droplets spread along different surfaces and how ice forms in clouds (see story, page 15).


Photo by Denise Applewhite

Kai Li, the Paul M. and Marcia R. Wythes Professor in Computer Science, was elected as a member of the National Academy of Engineering, one of the highest professional honors among engineers.

Li was selected for his contributions in the fields of data storage and distributed computer systems.

His breakthrough design of a data-compression technique called deduplication allowed the industry to build new disk-based storage systems. The new systems are able to store far more backup and archival data than traditional approaches; they also allow for the electronic transfer of data to remote sites for disaster recovery. Before that, such data were mostly stored on tapes that had to be physically transported to remote sites, a much more cumbersome and expensive method.

In the field of distributed computer systems, Li pioneered techniques that allow users to program using a shared-memory programming model on clusters of computers. His work on connecting a cluster of servers together efficiently to act as a single higher-power server contributed to the industry communication standards now in place for such computing. More recently, Li has been working with colleagues at Princeton to develop methods to efficiently manage and analyze the vast amount of data generated by increasingly sophisticated research in fields ranging from genomics to neuroscience.

Thanos Panagiotopoulos and **Ignacio Rodriguez-Iturbe** were elected to the American Academy of Arts and Sciences, one of the nation's most prestigious honorary societies.

Panagiotopoulos, the Susan Dod Brown Professor of Chemical and Biological Engineering, develops theoretical models and computer simulations to understand and make better use of the properties of fluids and other materials. Much of his work involves large-scale numerical calculations on parallel supercomputers and clusters of workstations.

Rodriguez-Iturbe is a pioneer of the field of ecohydrology, the study of the movement of water through landscapes and ecosystems. His work addresses the dynamic interactions of water with climate, soil and vegetation at a wide range of scales. In recent years, he has been a leader in the study of "virtual water trade," a framework for tracking how global trade redistributes water resources (see story, page 10).

Faculty Awards

Department of Chemical and Biological Engineering

Clifford Brangwynne, assistant professor
2012 Searle Scholar

Pablo Debenedetti, vice dean, Class of 1950 Professor in Engineering and Applied Science
Fellow, *American Association for the Advancement of Science*

Lynn Loo (Ph.D. '01), professor
2012 AIChE Owens Corning Early Career Award
2012 Young Global Leader, World Economic Forum

Rodney Priestley, assistant professor
Howard B. Wentz, Jr. Faculty Award
Young Investigator, Air Force Office of Scientific Research

William Russel, Arthur W. Marks '19 Professor of Chemical Engineering
Fellow, American Association for the Advancement of Science

Department of Civil and Environmental Engineering

Peter Jaffe, professor
Fellow, American Geophysical Union

Erik Vanmarcke, professor
2012 Alfred M. Freudenthal Medal, American Society of Civil Engineers

Department of Computer Science

Sanjeev Arora, Charles C. Fitzmorris Professor in Computer Science
2011 ACM-Infosys Foundation Award

David Blei, associate professor
Young Investigator, Office of Naval Research

Mark Braverman, assistant professor
CAREER award, National Science Foundation

Jennifer Rexford (BSE '91), professor
Member, Open Internet Advisory Committee, Federal Communications Commission

Department of Electrical Engineering

Mung Chiang, professor
Fellow, IEEE
IEEE Kiyo Tomiyasu Award
2012 IEEE INFOCOM Best Paper Award

Stephen Chou, Joseph C. Elgin Professor of Engineering
Fellow, Optical Society of America

Jason Fleischer, associate professor
Fellow, Optical Society of America

Bede Liu, professor
Foreign member, Chinese National Academy of Sciences

Sharad Malik, George Van Ness Lothrop Professor in Engineering
Ten-Year Most Influential Paper Award, International Conference on Computer-Aided Designing

Naveen Verma, assistant professor
Alfred Rheinstein Junior Faculty Award

Gerard Wysocki, assistant professor
Early Career Award, U.S. EPA

Department of Mechanical and Aerospace Engineering

Emily Carter, Gerhard R. Andlinger Professor in Energy and the Environment
Doctor Honoris Causa, Ecole Polytechnique Federale de Lausanne

Naomi Leonard (BSE '85), Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering
Fellow, Society for Industrial and Applied Mathematics

Michael McAlpine, assistant professor
2012 DARPA Young Faculty Award

Richard Miles, Robert Porter Patterson Professor of Mechanical and Aerospace Engineering
Plasmadynamics and Lasers Award, American Institute of Aeronautics and Astronautics

Marlan Scully, lecturer with the rank of professor
2012 Frederic Ives Medal/Jarus W. Quinn Prize of the Optical Society

Lex Smits, department chair, Eugene Higgins Professor of Mechanical and Aerospace Engineering
Fellow, American Association for the Advancement of Science

Department of Operations Research and Financial Engineering

Ramon van Handel, assistant professor
NSF CAREER award
E. Lawrence Keyes, Jr./Emerson Electric Company Faculty Advancement Award

Robert Vanderbei, department chair, professor
Fellow, Society for Industrial and Applied Mathematics

Faculty members lauded for teaching and mentoring

A flair for creating innovative courses and a dedication to mentoring students earned three Princeton Engineering faculty members recognition at the close of the 2011-12 academic year.

Maria Garlock, associate professor of civil and environmental engineering, received the President's Award for Distinguished Teaching at the University's Commencement exercises June 5. Garlock's research blends structural engineering and art, a combination she has used to create dynamic courses and projects for students. One course brought students to Chicago to study tall buildings, while a project had students create models of works by structural artist Félix Candela that were then exhibited at the Princeton University Art Museum.

"I admire her insights as a mentor, her enthusiasm as a teacher and her drive as an individual," wrote one graduate student in nominating Garlock for the award. "Education to her is a holistic combination of teaching, research and mentoring."

Stephen Lyon, professor of electrical engineering, received the Distinguished Teaching Award from the School of Engineering at Class Day exercises June 4. During the past 20 years, Lyon has collaborated with other faculty members to create six entirely new courses, each bringing innovative approaches and important new topics into the curriculum. A course he developed on optoelectronics — devices that combine light and electricity to process information — in 1993 has been passed on to other faculty members and continues to be a flagship course today. Lyon also was an integral part of the creation of the schoolwide course, "An Introduction to Engineering," which involves topical, hands-on engineering projects for freshmen. Lyon currently serves as the faculty coordinator for the course.

Ramon van Handel, assistant professor of operations research and financial engineering, was honored with a Graduate Mentoring Award by the McGraw Center for Teaching and Learning at the Graduate School's Hooding ceremony June 4. Van Handel has taught classes on topics including stochastic processes, stochastic calculus and stochastic methods for quantitative finance.

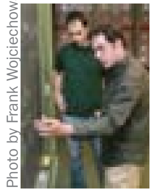
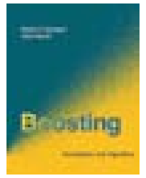


Photo by Frank Wojciechowski

"By treating me more as his colleague than his student, Ramon has been extremely successful in building a rich and fertile environment in which I feel free to speak out about whatever ideas I have," wrote one student. "Ultimately, however, if I were to be asked what really makes Ramon stand out as a true mentor to me, the answer would lie in the fact that he is passionate about his students, about their creativity and their ability to find their own way."

Faculty Books

Hisashi Kobayashi, the Sherman Fairchild University Professor of Electrical Engineering and Computer Science Emeritus, "Probability, Random Processes, and Statistical Analysis: Applications to Communications, Signal Processing, Queueing Theory and Mathematical Finance" (Cambridge University Press, 2012), with Brian Mark and William Turin.



Robert Schapire, professor of computer science, "Boosting: Foundations and Algorithms" (MIT Press, 2012), with Yoav Freund.

Independent consultant Frank Ryle (center) leads students through project management exercises as part of an engineering class. The pilot initiative was created in part to improve safety and help avoid accidents for students using tools and machine shops for hands-on projects.

Photo by Denise Applewhite

In designing robots, students learn to drive a project

by Jeanne DeVoe

Students in a session of Dan Nosenchuck's mechanical design class last semester put aside the tools they were using to build a sophisticated robot and picked up a pad of sticky notes.

The students plastered a wall with the notes, each small paper corresponding with a project milestone. They led Nosenchuck along the wall, describing each activity they planned to accomplish before their May 15 deadline when the teams had to send their robots on a search-and-rescue mission as a final test. To pass, the robots were required to retrieve a medical kit, travel along a zigzagging corridor and deliver the kit to a light representing an injured person.

While the robots ultimately succeeded, the broader goal of the course was to teach students to safely manage their projects under deadline pressure, said Nosenchuck, an associate professor of mechanical and aerospace engineering. Because students in design courses sometimes work with potentially hazardous tools, the University is introducing time-management techniques to further laboratory safety — if students can better pace themselves, they can avoid the last-minute crunch that can lead to accidents.

The initiative, being tested as a pilot, was the brainchild of Dale Grieb, the director of administration and services and the safety coordinator at the engineering school. Grieb first proposed additional emphasis on project management in the aftermath of a 2011 accident at Yale that killed a student working late in a machine shop.

Grieb worked with the Office of Environmental Health and Safety to establish policies at Princeton requiring better lighting, limited hours and more supervision in the machine shops. But she worried that pressure to meet deadlines could lead to unforeseen hazards.

"Design courses using tools are not courses you can cram for," Grieb said. "They have to be planned out."

Grieb proposed enhancing the safety component of design courses to Nosenchuck, who embraced the plan. Grieb planned to teach several sessions but was diagnosed with pancreatic cancer shortly before the program started.

Nosenchuck and Grieb invited project management expert Frank Ryle, of Princeton-based PMPulse, to introduce students to the principles of project management. Ryle had the students use the sticky notes to break their massive projects into smaller components with realistic deadlines. The notes' visual presence on the wall helped ensure that team members know exactly what they are supposed to do.

Ryle, a consultant who has worked with companies in 22 countries, said this kind of visual planning is crucial. "They see all the work and the time they have to do it," he said.

Reviewing the students' sticky notes, Nosenchuck emphasized the time commitment. "Is there anything you can do to give yourself a buffer?" he asked one team. Students said the concentration on planning helped them avoid last-minute work and ensure that work was evenly divided among team members. Phyllis Schafly, a junior, said detailed planning helps students anticipate risks before they arise.

"You know exactly what could go wrong," she said.

Note: Dale Grieb, the administrator whose 41 years of service to Princeton culminated in the project profiled in this article, died May 22. Princeton Engineering mourns the loss of a person whose passion for improving processes and building partnerships has enhanced the work of countless faculty members and students.

Class Day 2012

The 2012 Class Day ceremonies, which took place June 4, include recognition of graduating seniors for their achievements in academics, service and athletics. The winners were among the 217 recipients of bachelors of science in engineering degrees in the class of 2012.

Mary Catherine Bartlett
Chemical and biological engineering
The Lore von Jaskowsky Memorial Prize

Stephanie Chen
Civil and environmental engineering
The Tau Beta Pi Prize

Peter Davison
Mechanical and aerospace engineering
The J. Rich Steers Award

Atray Dixit
Mechanical and aerospace engineering
The Lore von Jaskowsky Memorial Prize

Matthew Edwards
Mechanical and aerospace engineering
The Jeffrey O. Kephart '80 Prize in Engineering Physics
The Prism-Newport Award in Photonics

William Herlands
Electrical engineering
The Calvin Dodd MacCracken Senior Thesis/Project Award

Steven Kim
Operations research and financial engineering
The J. Rich Steers Award

Emily Lancaster
Computer science
The Tau Beta Pi Prize

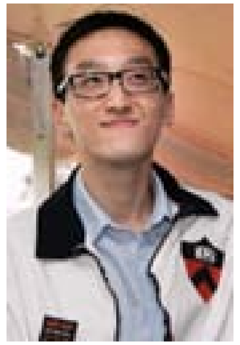
Ilina Mitra
Electrical engineering
The Lore von Jaskowsky Memorial Prize

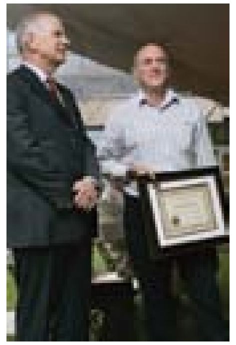
Brandon Podmayersky
Computer science
The James Hayes-Edgar Palmer Prize in Engineering

Leo Shaw
Chemical and biological engineering
The PRISM-FEI Award in Materials Characterization

Ravi Yegya-Raman
Operations research and financial engineering
Class of 1916 Cup
The George J. Mueller Award

Michael Yaroshefsky
Operations research and financial engineering
The Elgin Prize
The Class of 1901 Medal





Top: Dean H. Vincent Poor (center left) and distinguished teaching award winner Stephen Lyon (center right) stand with the recipients of awards at the engineering school's 2012 Class Day event. Second row, from left: Leo Shaw, Mary Bartlett, Poor and Lyon. Third row, from left: Ravi Yegya-Raman, Michael Yaroshefsky being congratulated by Dean Kathleen Deignan, Stephanie Chen. Bottom photo: Nicole Hantman, Jesse Adams, Matthew Edwards, Robert Klein, and Nicole Rafidi.

Photos by Frank Wojciechowski

Clockwise from top: Nihar Madhavan, a sophomore, collects a water sample outside La Pitajaya. Members of the Engineers Without Borders team in La Pitajaya: from left, graduate student Daniel Wright; sophomore Andres Parrado; senior Nicole Businelli; senior Emily Moder; and sophomore Nihar Madhavan. Village residents will operate and maintain the system. Andres Parrado and village resident.

Photos courtesy of those pictured

Students help bring fresh water to remote Peruvian village

By John Sullivan

Established in 2004, Princeton Engineers Without Borders has completed projects such as a solar-powered library in Ghana and a sanitation system in Peru. The chapter draws students from all majors and is supported by the Keller Center for Innovation in Engineering Education, the Princeton Environmental Institute and the Princeton Institute for International and Regional Studies.

The Andes village of La Pitajaya, Peru, is so isolated that when a team of Princeton students walked in for a visit last winter, they used a road that residents built by hand so their children could travel to school.

The students, with the Princeton chapter of Engineers Without Borders, were there to scout the area for their newest project: building a pipeline to bring drinking water to La Pitajaya's 150 residents. According to the students, the residents had no source of clean water, and sickness was common in the community.

"They are taking drinking water from an irrigation canal," said Emily Moder, a senior majoring in civil and environmental engineering and one of the project leaders. "There is a lot of mining and agriculture in the area, so the water is pretty polluted."

The project is no small undertaking. To reach potable water, the engineers will have to construct a pipeline across more than two miles of the Andean foothills to draw water from a mountain spring to the people in La Pitajaya. One of the primary purposes of the students' trip, last January, was to obtain water samples from several different springs for testing.

"We have several source options and, ideally, we are going to choose one that does not require heavy treatment," said Daniel Wright, a third-year graduate student in civil and environmental engineering who is serving as a project adviser. He said the water source is at a higher elevation than the village. "The idea is to have it be a gravity-fed system."

Moder said the site they are considering lies near an existing irrigation canal that passes by La Pitajaya. The canal should offer a relatively easy route for the pipeline, which the engineers plan to bury to avoid damage from rockslides.

About 30 students are now involved in the project, and most of the actual construction will be performed by the villagers or local workers. If all goes according to plan, work will begin this summer and the students hope to have the water system functioning by August. As part of the project, the village will set up a water committee that will determine water rates and make needed repairs.

"This is something they want really badly," Moder said. "They have been very helpful and capable in making it happen."

Below: Students from the Princeton chapter of Engineers Without Borders gathered with villagers from La Pitajaya, Peru, to start preliminary work on a new drinking-water system. Upper right: The students shared meals with Pitajaya residents. Lower right: A GPS unit shows the students reaching an altitude of 7,000 feet.

Students from the Princeton chapter of Engineers Without Borders gathered with villagers from La Pitajaya, Peru, to start preliminary work on a new drinking-water system.

Scan the QR code (left) to watch students discuss their work in Peru (http://bit.ly/KNhNF4).

With an average of 4 to 5 graduate students per faculty member, Princeton Engineering offers graduate students opportunities to take leading roles in major projects. The work being done by the students on these page represents just a slice of the research under way in the school's six departments. A common theme is that their work seeks to answer fundamental questions in their fields while creating technologies of broad value to society.

Anna Hiszpanski

CHEMICAL AND BIOLOGICAL ENGINEERING

ADVISER
Lynn Loo (Ph.D. '01), professor

PREVIOUS INSTITUTION
Caltech

RESEARCH
Focusing on an area sometimes called "plastic electronics," Hiszpanski designs, synthesizes and characterizes organic, electrically active compounds for use in thin-film transistors. These materials could ultimately lead to large-area, flexible video displays. In addition, Hiszpanski is interested in renewable energy and has been incorporating these compounds as light-harnessing components in plastic photovoltaics, which are large flexible sheets that convert sunlight to electricity. Formerly a Rutgers/Princeton Nanotechnology for Clean Energy IGERT Fellow (an interdisciplinary training program funded by the National Science Foundation), she currently holds a National Defense Science and Engineering Graduate fellowship.

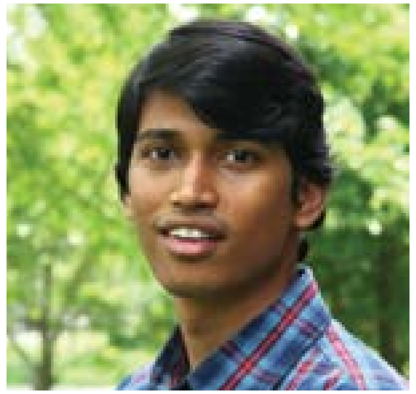
Stephen Good

CIVIL AND ENVIRONMENTAL ENGINEERING

ADVISER
Kelly Caylor, assistant professor

PREVIOUS INSTITUTION
Carnegie Mellon (B.S.); Michigan Technological University (MSE)

RESEARCH
As a member of the Environmental Engineering and Water Resources program, which is offered jointly by civil and environmental engineering and geosciences, Good's research seeks to answer a fundamental question: How much water in a given landscape is used by plants and how much is lost to evaporation from soil? To make these measurements, he is helping develop new techniques that use natural variations in stable-isotope levels combined with cutting-edge laser spectroscopy. This work will allow for more accurate measurement and will strengthen understanding of hydrologic systems as well as establish strategies for maximizing the productive use of limited water resources.



Anirudh Badam

COMPUTER SCIENCE

ADVISER
Vivek Pai, associate professor

PREVIOUS INSTITUTION
Indian Institute of Technology

RESEARCH
Badam's research aims to increase the energy efficiency and performance of modern data centers that power large-scale websites. Servers in such data centers have typically relied on random-access memory (RAM) for performance. High-capacity, high-speed RAM, however, is costly in terms of initial expenditure and electricity consumption, and can limit the scalability of websites. New memory technologies like NAND-Flash are fundamentally more energy efficient and more scalable in size, but are not as easy for programmers to use. Badam aims to bridge this gap and help programmers embrace new memory technologies to deliver fast, energy-efficient and high-performance data centers. This work has earned Badam recognition as one of Princeton's inaugural group of Siebel Scholars.

Jiasi Chen

ELECTRICAL ENGINEERING

ADVISER
Mung Chiang, professor

PREVIOUS INSTITUTION
Columbia University

RESEARCH
Chen is focusing on optimizing video transmission over wireless networks. Her work addresses the increasing practice of service providers charging users for accessing high-bandwidth content such as videos on their mobile devices. She is using a combination of mathematical optimization, machine learning and profiling of the user's consumption patterns to help users maintain a high-quality experience while staying within their data quota. In addition to this work, Chen's research interests include wireless sensor networks, ultra-wideband radio and medical EEG sensors.

Darren Pais

MECHANICAL AND AEROSPACE ENGINEERING

ADVISER
Naomi Leonard (BSE '85), Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering

PREVIOUS INSTITUTION
Saint Louis University

RESEARCH
Pais studies emergent collective behavior of groups in biology and in robotics. His dissertation will contribute to the understanding of the evolutionary mechanisms for cooperation and tradeoff management in biological collectives, as well as the design of decision-making protocols for robotic groups. Among specific group behaviors that Pais studies are collective predator pursuit and prey evasion, and collective migration. Pais has been the recipient of several prizes and fellowships, including a Wu Fellowship, the Crocco Award for Outstanding Teaching and the Graduate School's Harold Dodds Honorific Fellowship.

Warren Scott

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

ADVISER
Warren Powell (BSE '77), professor

PREVIOUS INSTITUTION
Rice University

RESEARCH
Scott focuses on using optimization techniques to improve the efficiency of energy use. Specifically, he is using techniques of approximate dynamic programming pioneered by Powell to help large consumers of electricity navigate increasingly complex energy markets. Based on Scott's work, companies could balance their use of energy from variable sources such as wind, solar and electricity purchased on the highly volatile spot market, while meeting energy needs that vary over time, often with some level of uncertainty. His research addresses the surprisingly difficult challenge of using advanced energy storage techniques efficiently to smooth out variations in supplies, demands and prices.

Photos of A. Hiszpanski, J. Chen, D. Pais and W. Scott by Frank Wojciechowski. Photo of S. Good is courtesy of S. Good and photo of A. Badam is by Steven Schultz.

Alumni honored for innovation and leadership

All photos courtesy of those pictured except where noted

Jeff Bezos (BSE '86), founder of Amazon.com, and **Jeffrey Ullman** (Ph.D. '66), professor emeritus of computer science at Stanford University, were elected to the American Academy of Arts and Sciences.

Bezos earned a bachelor's in electrical engineering and computer science from Princeton, and went on to become founder and CEO of the world's largest online retailer, Amazon.com. In 2012, Baron's magazine included him in its annual list of the World's Best CEOs.

Ullman received his Ph.D. in electrical engineering in 1966 and continued at Princeton as a faculty member before moving to Stanford. His research interests include database theory, database integration, date mining and education using the information infrastructure.

George Heilmeier (Ph.D. '62) won the 2012 Charles Stark Draper Prize from the National Academy of Engineering "for the engineering development of the Liquid Crystal Display (LCD) that is utilized in billions of consumer and professional devices." Heilmeier worked for RCA's Sarnoff Research Center, where he pioneered LCDs and later became head of the Defense Advanced Research Projects Agency and then president, CEO and chairman of Bellcore, now Telcordia, a New Jersey-based research and development company.

The Consumer Electronics Association inducted **Eli Harari** (Ph.D. '73) into its Hall of Fame in October 2011 and selected **Robert Briskman** (BSE '54) to be inducted in October 2012. Harari, co-founder and former CEO of California-based SanDisk Corporation, was elected for his leadership in developing flash memory storage solutions. Briskman, technical executive of Sirius XM, was selected for his pioneering work in satellite radio.

Kef Kasdin (BSE '85) was named by Greentech Media to a list of Top 10 Women in Biofuels. Kasdin is CEO of Proterro, Inc., a New Jersey-based company developing a non-plant-based feedstock of sugar for commercial-scale production of biofuels and chemicals.

John Seinfeld (Ph.D. '67) won the 2012 Tyler Prize for Environmental Achievement for advancing scientific understanding of air pollution. Seinfeld, the Louis E. Noel Professor of Chemical Engineering at the California Institute of Technology, was cited for "groundbreaking work leading to the understanding of the origin, chemistry and evolution of particles in the atmosphere."

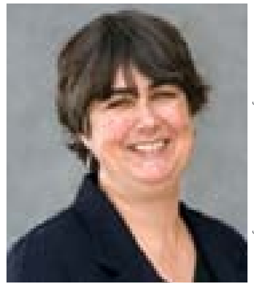


Photo courtesy of Tufts University

Diane Souvaine (Ph.D. '84), professor of computer science at Tufts University, was elected a 2011 fellow of the Association of Computing Machinery for her work in computational geometry and "for service on behalf of the computing community." Souvaine currently serves on the National Science Board, which advises the president and Congress on policy related to science and engineering research.

Lisa Jackson honored for work as EPA administrator

Photo by Denise Applewhite

Princeton University awarded its James Madison Medal, the University's highest honor for alumni who earned graduate degrees, to Lisa Jackson, administrator of the U.S. Environmental Protection Agency.

Jackson, who earned a masters degree in chemical engineering at Princeton in 1986, accepted the award and delivered a talk at the University's annual Alumni Day event Feb. 25.

In her address, Jackson noted that while she originally had planned to pursue a medical career, she said she realized there were other ways to help people. "I was thinking about being a doctor because I wanted to help people by treating them when they got sick," Jackson said. "I came to realize that — if I studied chemical engineering and started to work to protect our environment — I could help people by making sure they didn't get sick in the first place.

"Coming here set the trajectory for my entire life," she said of Princeton. "This university is where I had the opportunity to fully immerse myself in what became one of the greatest passions of my life — the exploration of science." –Ian Cahir

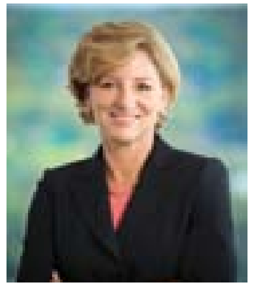
Scan the QR code (left) to watch Lisa Jackson deliver a talk after receiving Princeton University's Madison Medal in February (http://bit.ly/OzZlyw).

Engineers take leadership positions

Sabah Hamad al-Sabah al-Binali (BSE '92) has joined Shuaa Capital as vice chairman of its credit finance unit, Gulf Finance Corp. Al-Binali will contribute strategies to help the Dubai-based firm implement a plan for growth that includes diversification of its credit portfolio and geographic expansion starting with Saudi Arabia.

Kenneth Citron (BSE '87) joined the auction house Christie's as chief information officer and international managing director for e-commerce. Citron is responsible for integrating technology platforms across its world-wide business units and directing development of the company's e-commerce channel.

Chris Dietemann (BSE '75) was named president of Polar Corp.'s Quality Trailer Products Co., a Texas-based manufacturer and distributor for light and heavy-duty trailer-truck components.



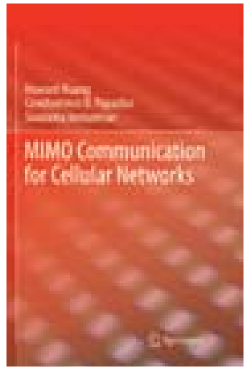
Sherilyn McCoy (MSE '82), formerly senior executive at Johnson & Johnson, was named CEO of Avon Products. McCoy has responsibility for developing and implementing a strategy to restructure the company and increase sales in key markets, including the United States, Brazil and Russia.

Joel Rood (BSE '80) was appointed CEO of CalStar Products, a Wisconsin-based company that develops and manufactures masonry products that are produced with low energy requirements and low carbon dioxide emissions. Previously, Rood was an executive at James Hardie Corp. and CertainTeed Canada, both manufacturers of building supplies.

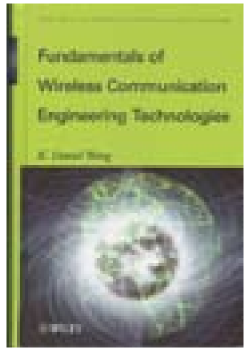
Dan Tuck (MSE '82). Zephyr Photonics, a Nevada-based research and development company, has appointed Dan Tuck as its new general manager and vice president of component operations. Zephyr serves the U.S. Department of Defense and the aerospace, industrial, energy and intelligence industries.

Alumni books address wireless communications

K. Daniel Wong (BSE '92), President of Daniel Wireless, LLC, "Fundamentals of Wireless Communication Engineering Technologies" (Wiley 2012).



Howard Huang (Ph.D. '96), distinguished member of technical staff at Bell Labs, part of Alcatel-Lucent, "MIMO Communication for Cellular Networks (Information Technology: Transmission, Processing and Storage" (Springer 2011).



HAPPY 50th, EQUAD!

In October 1962, Princeton University dedicated its newly built Engineering Quadrangle, and in the past 50 years the engineering neighborhood has experienced tremendous growth.

HOYT LABORATORY
2013 – UNDER RENOVATION

Hoyt Lab, designed by New York-based Davis, Brody & Associates (now Davis Brody Bond) for the Department of Chemistry, is now being renovated to support research on biological engineering and human health.

FRIEND CENTER
2001 – CONSTRUCTED

The Friend Center for Engineering Education is a thriving campus hub. Designed by Henry N. Cobb of the renowned New York-based architectural firm Pei Cobb Freed & Partners, it houses the spacious and light-filled Engineering Library and hosts classes in both engineering and the liberal arts.

SHERRERD HALL
2008 – CONSTRUCTED

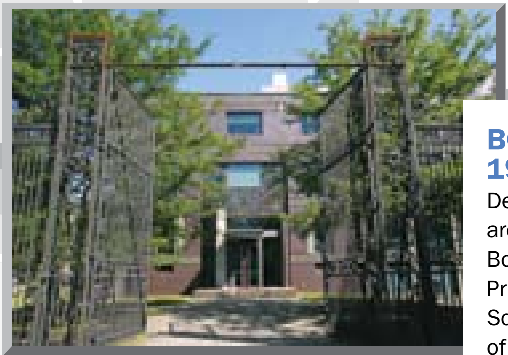
Designed by the Los Angeles-based firm Frederick Fisher and Partners, Sherrerd Hall is home to the Center for Information Technology Policy, which explores digital technologies in public life and is a joint venture between the School of Engineering and Princeton's Woodrow Wilson School of Public and International Affairs. Sherrerd Hall also is home to the Department of Operations Research and Financial Engineering.

COMPUTER SCIENCE BUILDING
1989 – CONSTRUCTED

New York-based architects Kliment & Halsband designed this building for the Department of Computer Science. The Flemish bond pattern at the top floor on the west side of the Computer Science Building contains a gargoyle of the computer age — the famous CS puzzle "p=np?" stated in binary brickwork.

ENGINEERING QUADRANGLE
1962 – CONSTRUCTED

Designed by architect Stephen F. Voorhees (A.B. 1900), the Engineering Quadrangle has been the central building of Princeton's School of Engineering and Applied Science for 50 years. The EQuad building is home to four departments — civil and environmental, chemical and biological, electrical, and mechanical and aerospace engineering — as well as the Keller Center for Engineering Education, established in 2005 to educate leaders for a technologically driven society.



BOWEN HALL
1993 – CONSTRUCTED

Designed by Princeton-based architect Alan Chimacoff, Bowen Hall is home to the Princeton Institute for the Science and Technology of Materials. PRISM was founded to address long-term global and societal challenges through fundamental understanding and innovation in materials science.

ANDLINGER CENTER
2015 – PROJECTED FOR DEDICATION

The corner of Olden and Prospect streets is the future site of the new Andlinger Center for Energy and the Environment, established with the support of a $100 million gift from international business leader Gerhard Andlinger. Designed by Tod Williams Billie Tsien Architects, the center is building on Princeton's strengths in environmental science, materials science and policy to develop sustainable sources of energy.

Photos of the Friend Center, Sherrerd Hall, and Computer Science building by Frank Wojciechowski. Photos of the EQuad and Bowen Hall by Bentley Drezner. Photo of Hoyt Laboratory by Chris Lillja.

Rendering of the Andlinger Center courtesy of Tod Williams Billie Tsien Architects.