EQuad News

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E

INQUIRY

INSIGHT

IMPACT

PRINCETON
School of Engineering
and Applied Science

DEAN'S MESSAGE

INQUIRY, INSIGHT, IMPACT

When asked by alumni, colleagues, and corporate partners about what makes Princeton Engineering unique, I point out stories like Bob Prud'homme's. As featured on page 6 of this magazine, Bob started his career immersed in the chemistry of polymers and investigating basic questions about how they assemble themselves. But he was always looking ahead to putting his insights to good use. Today, the Gates Foundation has selected his medicine-encapsulating technology as one of the most promising routes to treating cryptosporidiosis, malaria, and other childhood killers in the developing world.

Bob's example is one of many: At Princeton Engineering, we do fundamental research with a line of sight to societal impact. By fundamental, I mean research that targets root questions, rather than a narrow, short-term problem. It means research that combines curiosity and wonder with a discerning eye toward what roadblocks need to be cleared for innovations that might be 10 or more years away.

It means that, as an organization, we must provide the trust, freedom, and resources for our researchers to do their best work. And we must foster a collaborative culture for creativity to flourish.

Seeing the work of my wonderful colleagues reminds me time and again why that trust and support are well placed. In these pages, you'll find a small sample of people and projects whose impacts reach far beyond their beginnings.

How have attention to fundamentals and long-term impact played a role in your careers? Join us on Facebook, Twitter, and Instagram or stop in to visit and share your stories.

Emily Carter
Dean
Gerhard R. Andlinger Professor in Energy and the Environment
Professor of Mechanical and Aerospace Engineering and Applied and Computational Mathematics

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Photo of Emily Carter by David Kelly Crow

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Following Princeton University convention, undergraduate alumni are indicated by an apostrophe and class year; graduate alumni, whether master's or doctoral, are indicated with a star and class year.

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LEAKS WILL NOT SINK CARBON CAPTURE AND STORAGE

The case for carbon capture and storage — a promising method for reducing greenhouse gases — received a boost recently from a Princeton University study that indicated the procedure would not be prone to significant leakage or high costs related to fixing leaks.

In a paper published in the journal Climatic Change, the researchers concluded that levels of leakage based on simulations at hypothetical subsurface carbon dioxide storage locations, even in a worst-case scenario, would not make the cost of the technology prohibitive in the global energy system.

In carbon capture and storage, carbon dioxide gas, which is released from burning fuels, is captured at a source such as a power plant. The gas is compressed into a dense fluid and injected a kilometer or more below the land surface for permanent storage. While the technology is not yet being used at large scale, advocates believe it is a promising strategy for climate change mitigation while fossil fuels are still being used. A chief worry, however, is whether the gas could leak and return to the atmosphere.

To reach their conclusion, the researchers mathematically simulated the geophysical impacts of carbon storage, which include projections of leaks, in combination with the economic impact of stopping leaks and paying associated fines and penalties.

Hang Deng *15, a former doctoral student at Princeton and the paper's lead author, explained that carbon capture and storage has been researched for years, with many studies focusing on the efficacy of the process and the potential for leakage. But the Princeton team wanted to understand both the level of leakage and the economic implications of any escaping gases.

"That link was not there before, and that is really what has motivated our study," said Deng, who is now a postdoctoral researcher at Lawrence Berkeley National Laboratory. Catherine Peters, chair of Princeton's Department of Civil and Environmental Engineering, said the researchers wanted to answer two questions: Would the technology lead to significant leaks, and would the leaks have an economic impact on commercial adoption of the technology? The answer to both, she said, was no.

The study was done with modeling based on both the geophysical aspects of carbon capture and storage, such as flow through subsurface geological formations, and economic modeling of the global energy market, using an integrated assessment model.

"We studied the worst-case scenarios," Peters said. "And even with the extreme worst-case scenarios, we still found that the CO_2 will be reliably trapped underground when you put it there."

– by John Schoonejongen

A team including Catherine Peters (left), professor and chair of the Department of Civil and Environmental Engineering at Princeton, and former graduate student Hang Deng *15 (right), now at Lawrence Berkeley National Laboratory, have concluded that addressing leaks would not prohibitively increase the cost of efforts to reduce atmospheric carbon through capture and storage. (Photo courtesy of the department)

BIOINFORMATICS POINT THE WAY TO TREATING DEADLY PANCREATIC CANCER

A new study that sifted through an enormous mass of biomolecular data has significantly advanced our understanding of the genetics of pancreatic cancer and opened up promising treatment avenues.

More than 40,000 Americans die each year from this devastating disease, making it the third-deadliest cancer nationwide. Most patients do not show signs of the illness until their cancers have spread elsewhere in the body, and even when caught early, pancreatic cancers do not respond well to treatment.

For the study, researchers analyzed molecular changes in malignant pancreatic tumors from 150 patients. Princeton computer scientist Ben Raphael co-led the computational analysis of the dataset, seeking out genetic differences between normal and cancerous cells. Overall, the findings implicate a small number of genes and broader cellular communication pathways as playing major causative roles in the disease. Encouragingly, the study also revealed that a high number of patients' pancreatic cancers should benefit from therapies recently available or in clinical trials.

"With this study, our overarching motivation is to obtain a full view of the molecular changes that occur in cancerous cells so we can develop better early detection and treatment methods," said Raphael.

The study was undertaken as part of The Cancer Genome Atlas (TCGA), a multi-institute collaboration between the National Cancer Institute and the National Human Genome Research Institute. The project is cataloging the genetic alterations in 33 cancers.

The study identified genomic changes in about 42 percent of pancreatic cancer patients that should be sensitive to current or in-the-pipeline treatments. For example, 8 percent of the study's patients exhibited mutations of genes in the DNA repair pathway. This pathway can be effectively treated with either platinum-based chemotherapy or another class of drugs, poly ADP ribose polymerase (PARP) inhibitors, according to the paper's authors.

This specific finding heralds doctors' long-sought goal of "precision" medicine — therapies tailored to an individual's cancer profile obtained through sequencing DNA and RNA in a tumor, Raphael said. Historically, approaches to cancer treatment have focused on where it occurs in the body — in the lungs, colon, skin, blood, and so forth. That paradigm is breaking down, as clinicians increasingly characterize the genetics of cancers to reveal drug-targetable mutations, irrespective of bodily location.

"Every cancer patient has essentially a unique set of mutations, but those mutations fall into some common themes that we can go after therapeutically," said Raphael.

– by Adam Hadhazy

Ben Raphael, a computer science professor, is a co-author of a study that analyzes genetic contributors to pancreatic cancer and points to promising new treatments. (Photo by David Kelly Crow)

TAKING CONCRETE STEPS TO REDUCE CARBON DIOXIDE EMISSIONS

A Princeton research team led by Assistant Professor Claire White is helping to develop new materials that work as well as cement but drastically cut carbon emissions related to cement production. (Photo by David Kelly Crow)

The hardest thing about concrete might be the challenge of making the ubiquitous material in an environmentally friendly manner. Recent laboratory results at Princeton University indicate that the puzzle of greener concrete may eventually be solved.

Concrete raises climate-change concerns because manufacturing its primary component, Portland cement, is responsible for as much as 8 percent of human carbon dioxide emissions. Even worse from an environmental standpoint, forecasters predict Portland cement production will double within 30 years.

There are possible replacements for Portland cement. One option, alkali-activated materials, could cut cement-related carbon emissions by up to 90 percent. Studies have shown that alkali-activated materials are as strong as Portland cement. But there is little long-term data about the greener cement's durability — a key question for builders.

Researchers at Princeton and other institutions have been working to answer questions about the new cement replacements. Claire White, an assistant professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment, said accurately simulating the long-term durability of concrete is challenging. But the information is critical if industry is to adopt the material.

"One of the reasons that alkali-activated materials are not widely used is a lack of testing standards at a national level," White said.

In recent years, White's research group has used different methods to both measure the long-term durability of cement alternatives and propose ways to eliminate the materials' weaknesses. In one report, her team proposed adding small amounts of zinc oxide nanoparticles to reduce defects that can develop as the material ages.

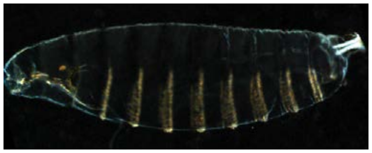
In a more recent article in the Journal of the American Ceramic Society, White's team demonstrated that certain types of alkali-activated cement have lower permeability than Portland cement. High permeability is a critical weakness for any cement because chemicals that intrude into a concrete structure can weaken the concrete as well as corrode the steel used as a reinforcement for most modern buildings.

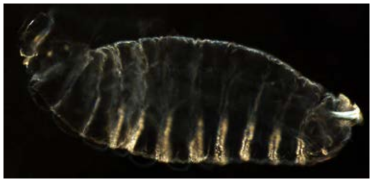
White said the findings are an encouraging step but do not clear the way completely for the new type of cement. While permeability is a key measure of durability, samples with low permeability can suffer from other potential problems, including cracking.

"We want to develop new methods to obtain accurate data on how these materials will perform over time," she said. "This will help with the implementation of sustainable alternatives in the construction industry."

– by William Leventon

EMBRYOS RAPIDLY OUTGROW MOTHER'S GENETIC KICK-START



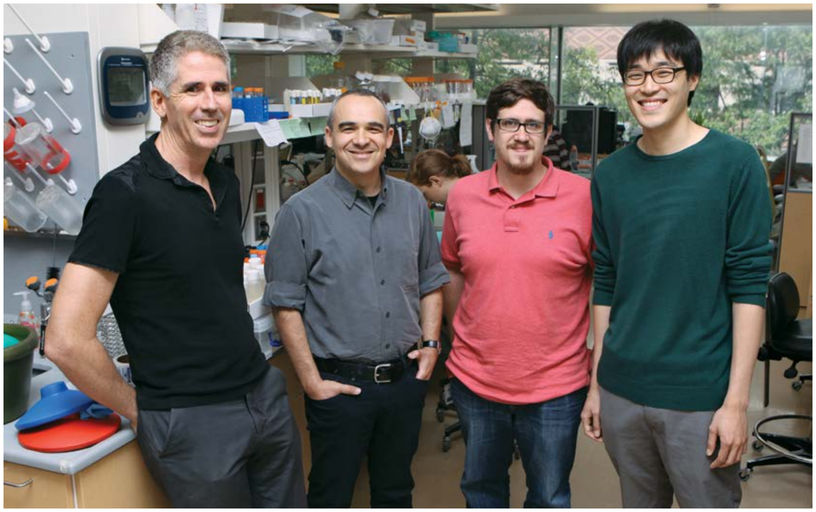


Changes in genetic expression affect the development of fly embryos as shown, with an unaltered embryo at top and mutant version below. (Image courtesy of the researchers)

Humans aren't alone in seeking independence from their parents at an an early age. Birds must fly the nest. Mammals must wean off their mother's milk. Now a study from Princeton researchers sheds light on a similar sort of separation drama that unfolds almost from the moment life begins, long before an animal is born or hatches from an egg.

During early stages of breakneck growth, a developing embryo must begin to make its own building blocks of DNA after it has exhausted the supply from its mother.

The study, published in Developmental Cell, revealed that a mother fruit fly ultimately provides no more than half of the DNA building blocks needed by her rapidly dividing embryos. Those initial, maternal DNA precursors, the researchers further demonstrated, actually put the brakes on a vital enzyme that the embryo needs to crank out precursors by itself. Only after the mother's influence has waned can the embryonic fruit fly transition to self-sufficiency.



From left: Professors Joshua Rabinowitz and Stanislav Shvartsman *99, postdoctoral researcher Robert Marmion, and graduate student Yonghyun Song are examining the steps by which embryos create DNA precursors independent of those supplied by their mothers. (Photo by Frank Wojciechowski)

In addition to illuminating a critical juncture in embryogenesis, the study could lead to new drugs. It highlights the role of the RNR enzyme, which is a key target of chemotherapy.

"The reason we eat chicken eggs for breakfast is because they are loaded with sugars, fats, and proteins deposited by the mother," said Stanislav Shvartsman *99, a professor of chemical and biological engineering and the Lewis-Sigler Institute for Integrative Genomics. "The question we are answering with this study is, at what point do you as an embryo stop relying on what your mother gave you?"

The researchers collected fruit fly eggs at different times after fertilization in the lab. In just two hours, a fly embryo grows from a single, fertilized egg cell into more than 6,000 individual cells — each with a set of DNA-encoded, genetic instructions. An analysis showed that hour-old embryos did not contain enough DNA building blocks to continue meeting the genetic demands of the many thousands of new cells that had yet to form.

Further experiments examined the role of the enzyme — named ribonucleotide reductase, or RNR — known to create the DNA building blocks. Embryos altered so they did not produce RNR could not progress beyond the point when they had depleted the mother's original stockpile. The researchers also engineered a form of RNR that could not be suppressed by the DNA precursors from the mother. Sure enough, when the embryo's RNR was given free rein in this manner, embryo-driven fabrication of DNA precursors exploded fivefold.

– by Adam Hadhazy

VERSATILE PRINTING TECHNOLOGY BUILDS, ERASES ULTRA-TINY STRUCTURES

To build the world's most cutting-edge nanotechnologies, engineers rely on lithography — a printing concept dating from the late 1700s.

Now, engineers from Princeton, the University of California, Los Angeles, and IBM have developed a new nanolithography technique that promises greater flexibility than other methods by allowing engineers to create, analyze, and erase nanoscale structures from a variety of materials.

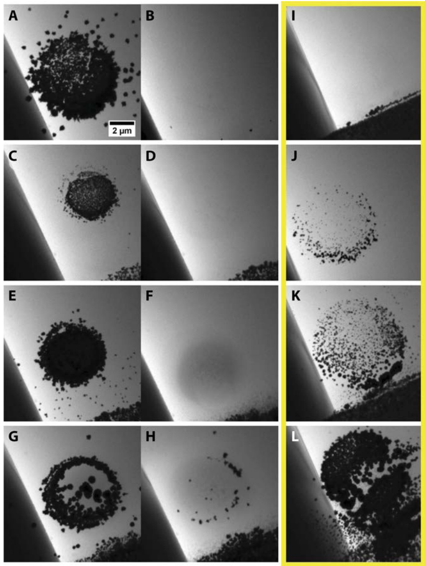
As they reported in the journal Science Advances, the researchers used the technology to build structures less than 10 nanometers in diameter. For reference, a human hair is 80,000 to 100,000 nanometers thick.

"Our new method combines several existing fabrication technologies to produce unprecedented flexibility to use in a variety of metals, build multiple types of nanostructures, and fabricate and erase those structures on the fly," said Daniel Steingart, an associate professor of mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment.

The team based their technique on electron beam nanolithography, which deposits nanoscale structures in layers. The layers are laid down using an electron-sensitive film called a "resist" that changes its chemical makeup when exposed to the electron beam. Areas of the resist that aren't exposed to the beam are etched away, leaving the pattern drawn by the electron beam intact.

The researchers sought to develop a method of electron beam lithography that could build nanostructures without using a resist film. To do this, they combined the beam technology with a technique for using electrical current to grow metals in a solution — a specialty of Steingart's lab, which focuses on battery technology.

In their device, tiny metal electrodes made of gold, nickel, or copper are attached to the wall of a tiny chamber filled with an electrolyte solution. When voltage and an electron beam are applied to the solution, metal ions deposit as nanocrystals on the side of the chamber.



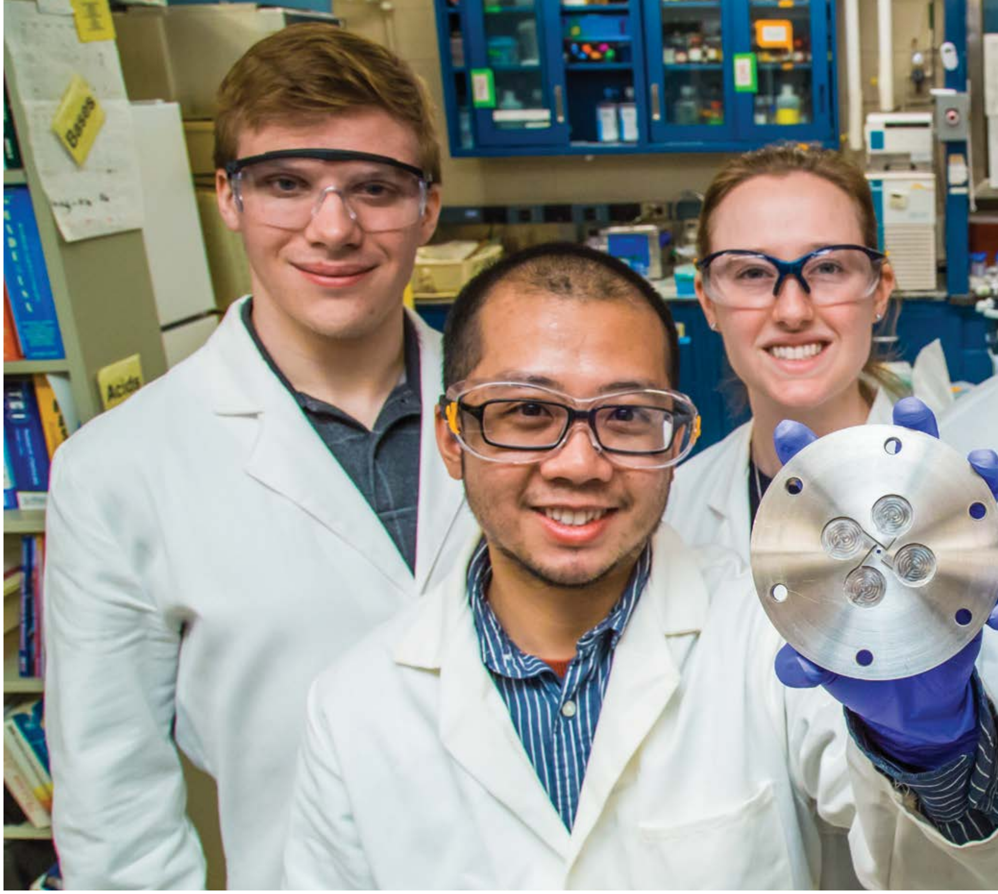
Left: Princeton researchers invented a system for creating ultra-tiny structures that is more versatile than previous methods, including the ability to erase. The first two columns (images A to H) show structures that were created out of minute particles of gold and then erased. Images I to L show how different structures could be created by modulating the time and electrical current of the device. (Images courtesy of the researchers)
Right: Daniel Steingart, associate professor of mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment. (Photo by Frank Wojciechowski)

The researchers can also use the device to erase the nanostructures, another advance over conventional methods.

"We can dissolve a shape previously deposited by scanning slowly over the existing nanostructures or increasing the current to the beam already irradiating a deposit," said Jeung Hun Park, an associate research scholar at Princeton. "The ability to erase a structure adds another factor of control to this technique, making it a highly versatile approach to fabricating nanostructures," Park said.
– by Chris Emery

LIFE-SAVING MEDICINES GROW FROM FUNDAMENTAL CHEMISTRY, WIN GATES' FOUNDATION BACKING

by Wendy Plump

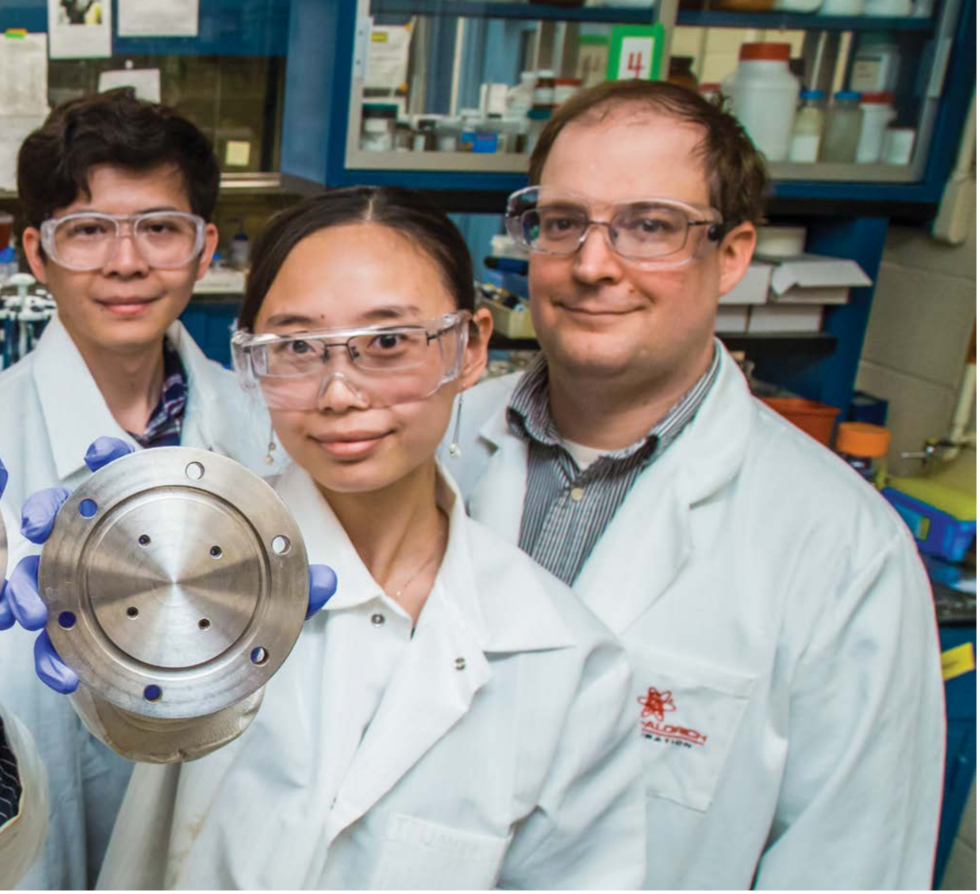


By the time Robert Prud'homme visited the Bill and Melinda Gates Foundation in Seattle two years ago, his technology for encasing medicine in ultra-small particles had already led to new drug delivery approaches for high-value medical applications, including oncology.

But Gates Foundation officials posed a new challenge: They wanted to use the technology to produce pediatric drugs to combat widespread killers in the developing world. That meant the drugs had to be cheap and easy to produce in massive volume, they had to be stable for long periods in hot and humid conditions, and they had to work as a single dose administered by mouth. And, most important, they had to be effective in circumstances in which other drugs had failed. Prud'homme, who has been developing the technology for the last 15 years, said the tasks were difficult but doable.

The Gates Foundation agreed and recently put Prud'homme's method on the fast track for use in developing countries where malaria, tuberculosis, and other life-threatening diseases are endemic. The focus of the effort is the special challenges of developing children's medication.

"We've had to learn all these things about the volume of liquid an infant can swallow, how you administer a drug to children who won't swallow pills, and how color and taste play a role in drug acceptance. So, there's a lot of sociology that goes into it," said Prud'homme, a professor of chemical and biological en-



Researchers in the lab of Robert Prud'homme display equipment used to encapsulate medicines for use in combatting childhood diseases. From left, the team includes: Kurt Ristroph, Ph.D. student; Jack Lu *17; Ellen Dobrijevic '17; and postdoctoral researchers Jie Feng, Joanna Zhang, and Simon McManus. (Photo by David Kelly Crow)

gineering. "We're learning more than we're teaching."

The $1.2 million grant was one of just three awarded by the Gates Foundation in 2016 for novel technologies in global health drug development. The program seeks to deliver therapies fast and cheaply — in this case, at no more than 50 cents a dose — preferably in a powder form that can easily be mixed with water. Prud'homme said the foundation is moving very quickly. Two drugs are undergoing clinical trials and several others are in the pipeline.

The group is finishing preparations to produce the medicine at a WuXi AppTech facility in China. After the Gates Foundation selected WuXi as the manufacturing site, in an unexpected twist, Prud'homme learned that WuXi's head of formulations development is Santipharp Panmai *98, who received his doctorate under Prud'homme at Princeton 20 years ago.

If all goes well, the first of these new formulations would use a 50-year-old leprosy drug to combat cryptosporidiosis, which is the major cause of infant diarrhea in the developing world and leads to infant mortality. The second drug would provide a single-dose treatment for malaria.

The societal questions and life-saving uses now on Prud'homme's mind reflect the mix of fundamental science and practical problem solving that have propelled his career.

His technology, called flash nanoprecipitation, is a method for encapsulating drugs and other therapeutic molecules in nanometer-sized particles. The technique involves shooting a stream of drugs and polymers ▶

Joanna Zhang, Ellen Dobrijevic '17, and Robert Prud'homme work to increase medicines' effectiveness in the developing world. (Photo by David Kelly Crow)

into an opposing stream of water inside a small cavity. Biocompatible polymers — essentially long chains of molecules — are the building blocks of plastics, among other modern materials. Prud'homme's mixture contains polymers that repel water and polymers that are attracted to water. When the streams meet, the water-repelling polymers cluster around the drug molecules, while the water-attracting polymers create small capsules that encompass the other polymers and the drugs. The polymer-drug packages then solidify and precipitate out of the liquid mix.

Developing the technique was challenging. The researchers had to precisely calibrate the flow of the two liquids as well as the size and geometry of the mixing chamber. Most important, they had to select the right mix of polymers to create the tiny capsules.

The flash nanoprecipitation process enhances drugs' stability, which is essential in the developing world where refrigeration and sterile working conditions may be unavailable. In many regions, drugs will have to remain viable after sitting for months in hot warehouses.

Another requirement is scalability. The Gates Foundation wants formulations that can "scale up" from the tiny amounts used in research to the much larger quantities needed for continuous manufacturing. This attribute is "huge" right now, said Hoang (Jack) Lu *17, who was one of nine team members working in Prud'homme's laboratory.

"A lot of other technologies have difficulties in scaling up when you have nanoformulations," said Lu. "When you have small scales in research and design, that's fine. But when you have a compound that you want to make at a large scale then you run into walls."

With Prud'homme's technology, the same process his team uses in his Princeton lab can be adapted for large, continuous manufacturing. "That's where our technology really shines," Lu said. "It reduces costs quite a bit." Flash nanoprecipitation is scalable not only in terms of vessel size, he explained, but in terms of time — the longer the process is run, the more material it produces.

The project includes collaborations with Johns Hopkins University, the University of Tokyo, and the University of Chicago, among others. Lu said the Princeton team is also in regular contact with the TB Alliance and Medicines for Malaria Venture, both Gates-supported initiatives.

Prud'homme's research began with fundamental questions about assembling polymers, but he said that as an engineer he always has interest in possible applications. He said the combination of basic scientific curiosity and an eye for applications created the 15-year path toward a new formulation for drugs.

"If you came purely from the pharmaceutical world you never would have gotten here, and if you came purely from polymer research you would not have gotten here either," he said. "Understanding the engineering fundamentals of how these things assemble was really the key."

As the project moves toward completion, the excitement in Prud'homme's lab is palpable.

"I was so intrigued by this unique opportunity to develop drug formulations, which might quickly go through all human trials with the strong support from Gates Foundation, and be used to save hundreds of thousands of lives in developing countries," said Yingyue (Joanna) Zhang, a postdoctoral researcher in chemical and biological engineering. "This would enable us to fully explore its potential for oral drug delivery to address more unmet medical needs." **E**

CELLULAR INSIGHTS **PROMISE** ADVANCES IN **INDUSTRY** AND **HEALTH**

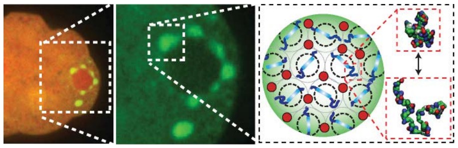
Research focused on physical principles behind formation of structures

by John Sullivan

Clifford Brangwynne's research begins with basics. What makes up the tiny structures in cells? How do they grow? How do they interact?

"You try to answer fundamental questions," said Brangwynne, an associate professor of chemical and biological engineering. "You hope they take you in interesting directions."

Researchers in Brangwynne's lab have moved into very interesting areas. In the past few years, they have explained how tiny structures called organelles grow and function within cells despite the lack of a surrounding membrane. The discovery that many organelles form through phase changes, like dewdrops appearing on grass, has led to a better understanding of cellular function. In one example, the research led the team to a way of understanding the growth of dangerous, solid-like protein aggregates inside the cells. These insights are shedding light on the proteins' role in devastating degenerative neural diseases such as Alzheimer's and ALS.



At left: Membraneless organelles are shown in green around a cell's nucleus in a flatworm embryo. Middle: A zoom-in of the liquid-like organelles. At right: An artist's impression of a tighter zoom, revealing a structure that is permeable only to molecules of certain sizes, shown in red.

"Once you see how those pathological structures may be seeded, immediately you start thinking about ways to inhibit those processes," he said. Brangwynne noted that a great deal of work needs to be done, but if all continues to go well, "potential pathways to therapies are going to emerge in the next few years."

Last year, Brangwynne and his colleagues were able to engineer biological structures within cells. The technique, which also developed from basic research on organelles, opened up a possible path to enhancing certain cellular functions.

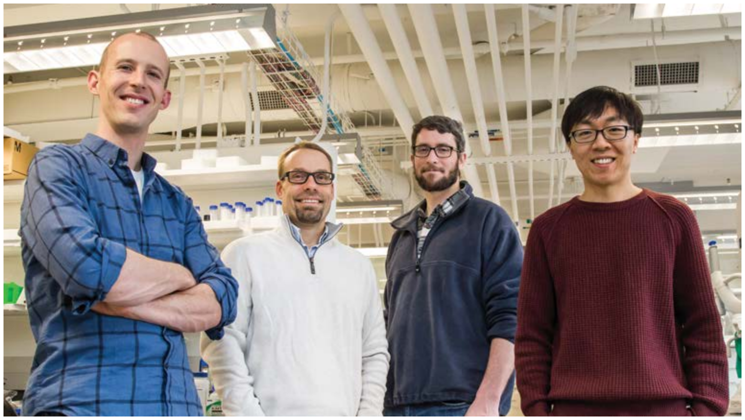
"From a basic ability to engineer structures within cells, we are starting to think about applications," Brangwynne said. One possibility is to use engineered cells in industry for more efficient and faster protein purification, the laborious task of separating pure proteins from other cellular material.

Brangwynne said another possible track is enhanced production of valuable compounds within cells. The lab has already begun to collaborate with Jose Avalos, an assistant professor of chemical and biological engineering and the Andlinger Center for Energy and the Environment, on yeast strains that produce important natural products, such as forms of alcohol that could be used as fuel.

"I have been interested in biology for a long time, but I have been tackling biology through the lens of soft matter and materials physics," Brangwynne said. "Some of the work we have been able to do is enabled by having a different perspective.

"As an engineer, I see that the world has all these problems. So when we make basic discoveries about how cells work, I immediately start to think, 'Why don't we use this to solve some of them?'" **E**

Princeton researchers developed a tool using light to manipulate proteins inside cells to better explore cellular operation and possibly disease development. From left, the researchers are Jared Toettcher, assistant professor of molecular biology; Mikko Haataja, professor of mechanical and aerospace engineering; Clifford Brangwynne, associate professor of chemical and biological engineering; and Yongdae Shin, postdoctoral fellow, chemical and biological engineering. (Photo by David Kelly Crow)



From left: Professor Elie Bou-Zeid, Abdulghafar Al Tair '19, and post-doctoral researcher Maider Llaguno Munitxa have designed a mobile phone app to help people navigate local environmental data in their cities. (Photos by David Kelly Crow)

The NUE mobile phone app puts environmental data at users' fingertips and could ultimately help urban planners.

Navigating the urban environment, smartly

Expertise in heat transport yields tool to help prepare for hotter world

Elie Bou-Zeid's research team has planted environmental sensors around Baltimore and New Jersey and built models to forecast shifting winds in towns and cities. Now, he wants to put that information at the fingertips of smartphone users.

"We made an environmental app for smartphones," said Bou-Zeid, an associate professor of civil and environmental engineering. "It lets citizens navigate and potentially collect environmental data for their cities."

The app, called NUE for Navigating Urban Environments, is designed to turn a smartphone into an environmental navigator. The user points a camera along a street in a participating city, and the app reports the air temperature, local humidity, and air quality for roughly half a kilometer (about four intersections in Manhattan). When fully developed, the app will allow a multitude of cameras to augment and analyze this information.

The app builds on Bou-Zeid's fundamental research into atmospheric flow and heat transfer in local areas, particularly around cities. Bou-Zeid's team developed autonomous sensor boxes that can be attached to vehicles (recently deployed on buses in Seoul, South Korea). The app taps into that sensor data along with other openly available environmental data. Bou-Zeid and postdoctoral researcher Maider Llaguno Munitxa, a co-investigator on the project, think that making these data easily accessible to people is the critical part of the project.

"We want to make citizens aware of the environment in their cities," Bou-Zeid said. "If you engage the citizens, if they care about the environment in the city, that has a value in itself." **– by John Sullivan**

New forms shape solar power

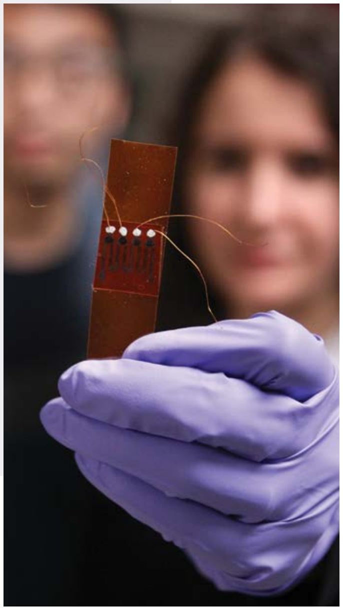
Polymer chemistry yields solar cells, sensors, and smart windows

The common image of solar power involves big, blocky panels bolted to a roof. But in the lab of Yueh-Lin (Lynn) Loo *01, photovoltaics are freed from this cubist form. Some are crinkled, bent, or even used as transparent laminates on windows.

"Much of our research is concerned with these materials' complexity, and how we can control the materials' structure to express different mechanical properties, such as elasticity, toughness, conductivity, and other traits," said Loo, director of the Andlinger Center for Energy and the Environment, Theodora D. '78 and William H. Walton III '74 Professor in Engineering, and professor of chemical and biological engineering. "If you look at steel as an example, it is used for all sorts of different applications. And in each application, from steel wool to steel beams, the metal has different mechanical properties," she said.

Her team's focus on the fundamental characteristics of organic molecules and polymers has led to the development of self-powered smart windows that use transparent solar cells to absorb ultraviolet light, and solar cells with wrinkles and folds that boost light absorption. The work in her lab on conducting materials has also led to uses in medical settings, such as a glucose sensing monitor and an ultra-sensitive temperature sensor.

– by Sharon Adarlo



Right: In the lab of Lynn Loo *01, researchers are shaping photo-voltaics into many different forms. (Photo by Frank Wojciechowski)

Warren Powell '77, a professor of operations research and financial engineering, has developed methods to help make complex choices in fields from shipping to power management. (Photo by David Kelly Crow)

Making better choices, from power to payloads

Mathematical optimization aids many industries

Many scientists' work begins with a question in the lab. Warren Powell '77 had a different start.

"My career began with a dinner conversation," said Powell, a professor of operations research and financial engineering.

At the dinner, in 1982, a trucking executive complained that his company's system for matching loads and drivers assumed they could predict the future. The frustrated executive, with a master's in operations research, stated that, in reality, the problem was "stochastic," meaning inherently unpredictable. Powell saw this as a challenge.

"I have this paper from the 1980s; it has four completely different ways to model the stochastic fleet management problem," Powell said. "All of them bad."

Powell worked at the problem for the next 20 years, applying versions to railroads and massive electrical grids.

"I kept chipping away at it," he said.

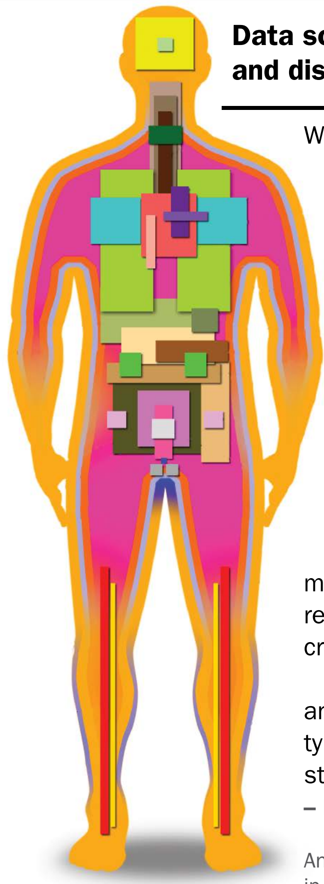
Thirty years, 230 papers, and two books later, Powell has applied his system in many fields, including blood management, spare parts supplies, medical decisions, and power grids balancing the uncertainties of wind and solar energy.

Powell said he is still working on the basic questions. "Even in the last year or so, I have 'aha' moments when I am teaching my grad courses," he said.

His team currently has a new model in production — it matches truck drivers to loads.

– by John Sullivan

Data science provides genomic guide to health and disease



What are the odds that a statistician would work beside doctors at top medical schools?

These days, pretty high.

Barbara Engelhardt, an assistant professor of computer science, specializes in Bayesian statistics, a method of weighting statistical analysis to interpret challenging data. Her research team develops methods to harness biomedical data with machine learning and statistical inference. The result offers doctors a better understanding of disease.

Her team is developing systems to predict the onset of sepsis and other conditions in hospital patients and to better understand the role of genetics in disease. Recently, Engelhardt was a leader of a multi-university consortium that studied genetic expression related to a variety of tissues in the body as a step toward creating a genetic map for healthy tissues.

"The ultimate goal is to understand gene expression and gene regulation in a diversity of different tissue types," she said. "That is absolutely critical to understanding how dysregulation can lead to disease."

– by John Sullivan

An international team of researchers reached a major milestone in decoding the human genome by linking genes to specific tissues and disease processes. Using tissue samples donated from 449 people, the researchers linked nearly 20,000 genes to 44 tissue types, depicted in the schematic image above. (Illustration courtesy of the GTEx Consortium)

Edgar Choueiri *91, a professor of mechanical and aerospace engineering, designs sophisticated audio systems in one lab and spacecraft engines in another. (Photo by David Kelly Crow)

Math marks the path from sonar to cell phones

As a Ph.D. student in the 1970s, H. Vincent Poor *77 helped lead the development of mathematical techniques that allowed radar and sonar to detect objects and estimate their locations.

Then along came cell phones. "I wasn't thinking about communication," said Poor, now the Michael Henry Strater University Professor of Electrical Engineering. "It happened that a new application came up that drew on the same ideas."

Today Poor, with 16 patents, is widely recognized for theoretical foundations that enabled generations of mobile phones, from the 3G networks that first married voice and data through today's emerging 5G system. He is now applying and developing similar tools for a more sustainable and nimble electric grid, cybersecurity, and other uses.

"It keeps evolving," Poor said. "It's a full employment opportunity for someone like me."

– by Steven Schultz

H. Vincent Poor *77 (center), former dean of engineering at Princeton, taught a fall 2017 freshman seminar titled "Princeton and the Dawn of the Information Age" to show the foundational technologies that led to the computer, internet, and smartphone revolutions, all of which had substantial roots at Princeton. (Photo by Sameer Khan/Fotobuddy)

Building sound systems and space engines

One lab is not enough for Edgar Choueiri *91.

The professor of mechanical and aerospace engineering works in two connected laboratories reflecting his research interests in audio technology and spacecraft propulsion. One is filled with researchers designing electric engines that could one day take astronauts to Mars, and the other has a team working on cutting-edge sound systems for Tesla Motors and high-end audio manufacturers. Both teams work on fundamentals, but with an eye toward developing working devices.

"In the past couple of years, we had three papers in Physical Review Letters but at the same time you can go to the Apple Store and find a Princeton-IP-enabled 3-D audio product on the shelf," he said.

Choueiri, a former director of the program in engineering physics, said Princeton has a knack for attracting scientists "who also like to build things."

"My father was an engineer, and my mother taught physics," he said. "I could not make up my mind."

– by John Sullivan

Making many networks work as one

With no central authority, the network of networks that makes up the internet manages to connect more disparate groups of people than anything else in history.

Of course, the internet's storied lack of rules is an illusion. Volumes of technical standards undergird the system like the plumbing beneath Manhattan. One of the people who best understands this backbone is Jennifer Rexford '91, chair of the Department of Computer Science, and a former member of the Federal Communications Commission's Open Internet Advisory Committee.

Rexford's research examines the most efficient and stable way to transfer information through networks. Her work on the Border Gateway Protocol helped define methods to manage traffic among the tens of thousands of independent networks that make up the internet.

"You need to harness the rational behavior of each network acting in its self-interest," said Rexford, the Gordon Y.S. Wu Professor in Engineering. "But you also need to deploy technology to defend against bad actors who don't care if the internet is safe or stable."

– by Aaron Nathans

Jennifer Rexford '91, the Gordon Y.S. Wu Professor in Engineering, has helped create the standards that allow the many networks that make up the internet to work together smoothly. (Photo by David Kelly Crow)

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