Michael McGehee (right), a materials scientist at Stanford University in Palo Alto, California, examines a tandem perovskite cell.

MATERIALS SCIENCE

Perovskite solar cells gear up to go commercial

In tandem with silicon, low-cost photovoltaic crystals make electricity more efficiently

By **Robert F. Service**, *in Boston*

Cheap materials called perovskites are insinuating themselves into silicon solar cells—a first step toward ultimately usurping the reigning cell material. Last week, at a meeting here of the Materials Research Society (MRS), researchers announced that "tandem" cells, in which perovskites are layered on top of silicon and other photovoltaic materials, have achieved record-setting efficiencies at turning sunlight into electricity. Now, researchers are moving fast to surmount the lack of durability and other problems that have hindered the commercialization of perovskites.

"I think perovskites are going to make it to market," says Aslihan Babayigit, a perovskite researcher at Hasselt University in Diepenbeek, Belgium. The progress has been "amazing," adds David Cahen, a materials scientist at the Weizmann Institute of Science in Rehovot, Israel. "Even if all the problems are not solved, most look solvable."

Known since the 1830s, perovskites are a class of crystals with a common 3D structure. It wasn't until 2009 that researchers in Japan first realized their potential as a photovoltaic material. The first perovskite devices converted only 3.8% of light energy into electricity, far less than crystalline silicon, today's dominant commercial technology, which tops out at 25.3% efficiency for the best research cells. (Commercial cells usually vary between 16%–20%.) But researchers tinkered with their perovskite recipes, and the efficiencies of the cells quickly skyrocketed. The record now stands at 22.1%, demonstrated earlier this year by researchers in South Korea.

Tandems, which combine cells optimized to capture different parts of the solar spectrum, can do even better. Silicon, for instance, preferentially absorbs reddish light, whereas perovskites tend to soak up blue and green photons. Slapping a perovskite cell on top of silicon need not cost much because the ingredients are dirt cheap, and the crystals can be grown easily at low temperatures. Tandems also allow perovskites to piggyback on the entrenched silicon industry.

At the MRS meeting, Michael McGehee, a materials scientist at Stanford University in Palo Alto, California, reported that by growing a perovskite on silicon, he and his colleagues had created a tandem cell with an efficiency of 23.6%, better than the efficiencies of either component. Another group led by Christophe Ballif of the Federal Polytechnic School of Lausanne in Neuchâtel, Switzerland, reported in July that a silicon-perovskite tandem with a more complex architecture had reached an efficiency of 25.2%.

Tandems are likely to continue improving for years. Researchers have yet to build in all the finer tricks of the trade, such as optimizing the electricity-carrying layers in the cells and adding coatings that minimize surface reflections. Even with current perovskite materials, over the next couple years silicon-perovskite tandems could reach efficiencies of 30%, McGehee predicts. At that threshold, says Henry Snaith, a physicist at the University of Oxford in the United Kingdom, solar companies will start to add perovskites into their commercial panels, driving further improvements in the materials that could ultimately help them supplant silicon altogether.

At the MRS meeting, some researchers foreshadowed that day. Giles Eperon, a materials scientist at the University of Washington in Seattle, explained that when getting his Ph.D. at Oxford, he made a perovskite that strongly absorbs reddish light—the wavelengths that silicon has specialized in. Partnering with McGehee's group, Eperon layered his red absorber on top of a more

Stronger together

By stacking perovskite solar cells in tandem with others, researchers are nearing the record efficiency of single crystal silicon, the industry's commercial standard. Two-terminal (2T) devices layer the materials into a single cell; four-terminal (4T) devices stack together two electrically independent cells.

SOLAR CELL TYPE	RECORD EFFICIENCY (%)
Silicon (single crystal)	25.3
Perovskite-perovskite (2T)	17
Perovskite-perovskite (4T)	20.3
Silicon-perovskite (2T)	23.6
Silicon-perovskite (4T)	25.2

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GLOBAL HEALTH

AIDS epidemic nears control in three African countries

Massive new surveys show stunning progress

By **Jon Cohen**

Amidst the reams of statistics that pour out on every World AIDS Day on 1 December came one surprising bit of good news this year. Three neighboring, cash-strapped countries in hard-hit southern Africa—Malawi, Zambia, and Zimbabwe—have had remarkable success against the virus, according to the most comprehensive study done to date.

The new study, coordinated out of the Columbia University Mailman School of Public Health and led by epidemiologist Wafaa El-Sadr, collected massive amounts of on-the-ground data by visiting 80,000 randomly selected households in the three countries. The upshot: HIV-infected people in the region are getting treated and sticking with their drug regimen in numbers that have surprised and delighted experts. The survey found that up to two-thirds of HIV-infected people in the three countries have fully suppressed the virus, slashing the rate of new infections. (In the United States, the comparable figure is 30%.) "We're getting very close to the number that shuts down epidemics," says Deborah Birx, who heads the U.S. President's Emergency Plan for AIDS Relief (PEPFAR) in Washington, D.C.

Until now, the most authoritative estimates of new HIV infection rates, or incidence, and prevalence have come from the Joint United Nations Programme on HIV/AIDS (UNAIDS). Those are based on mathematical models that largely extrapolate from clinics and nonrandomized surveys. The UNAIDS estimates do not include the level of virus in each infected person, a key indication of how well interventions are working.

The new population-based HIV impact assessments (PHIAs), which began in 2015 and are funded by PEPFAR, fill that gap. In addition to going door-to-door in cities, teams traveled to the remote countryside, often pulling up to thatch-roofed homes and erecting pop-up tents in which nurses did blood draws. Social scientists also interviewed participants about their health and lifestyle. Blood was assessed on the spot for HIV and syphilis, with counseling and treatment referrals made for anyone in need. Then the teams took the vials back to cities to analyze viral levels. "We have to reach people we haven't reached and know exactly where the crusade is failing," El-Sadr said during a survey in Zimbabwe.

The results, released in press releases and fact sheets, mostly confirm the UNAIDS estimates of HIV's reach in the three countries—which each have a prevalence of more than 10% of the adult population. But they showed an annual rate of new infections in Zimbabwe and Zambia that was substantially lower than expected (see table, below). Peter Ghys, who directs strategic information and evaluation at UNAIDS in Geneva, Switzerland, says his team will incorporate the PHIA data in future modeling estimates.

Across the region, the PHIA results suggest, the rate of new infections has fallen by half since 2003. Data on viral levels point to one factor: At least 86% of people in each country receiving antiretroviral treatment had "fully suppressed" HIV. This means they had such low levels of virus in their blood that the drugs not only are staving off AIDS, but making it highly unlikely that they will infect others. "We were amazed when we saw this," El-Sadr says.

The result helps assuage worries that many infected people in those countries are not sticking with their treatment. PEPFAR surveys of clinics had suggested that more than 20% of people who started treatment ended up dropping it. "We were misled at the program level about retention," Birx says. The PHIA data's high level of viral suppression suggests that instead, "people were moving from one clinic to another and it looked like they were lost to follow-up."

Vital statistics

A new study in southern Africa reveals a lower than expected annual rate of new HIV infections.

COUNTRY	PREVALENCE	NEW INFECTIONS
Malawi	10.6%	0.37%
Zambia	12.3%	0.66%
Zimbabwe	14.6%	0.45%

All three countries have received substantial international assistance for HIV/AIDS prevention and treatment: Since 2004, PEPFAR has invested $4 billion, and the Global Fund to Fight AIDS, Tuberculosis and Malaria has provided $2 billion more. But funding alone does not explain the gains against the virus, Birx says. "These programs and the people implementing them have done an extraordinary job of working with the community and the individual clients."

The new data have important implications for the global push to end HIV/AIDS epidemics by 2030. To achieve that, UNAIDS has set what is known as the 90-90-90 goal for 2020. UNAIDS modeling shows that epidemics will peter out if 90% of infected people know their HIV status, 90% of that group receives antiretrovirals, and 90% on treatment have undetectable viral levels. This translates to undetectable viral levels in 73% of all HIV-infected people in a population—including those who don't know their status and have uncontrolled infections. The PHIA numbers suggest the goal is within reach: Malawi is already at 67.6%, Zimbabwe is at 60.4%, and Zambia is at 59.8%. The preliminary findings are "pretty doggone amazing," Birx says. "This really shows why it is so important to get community-level survey data." ■

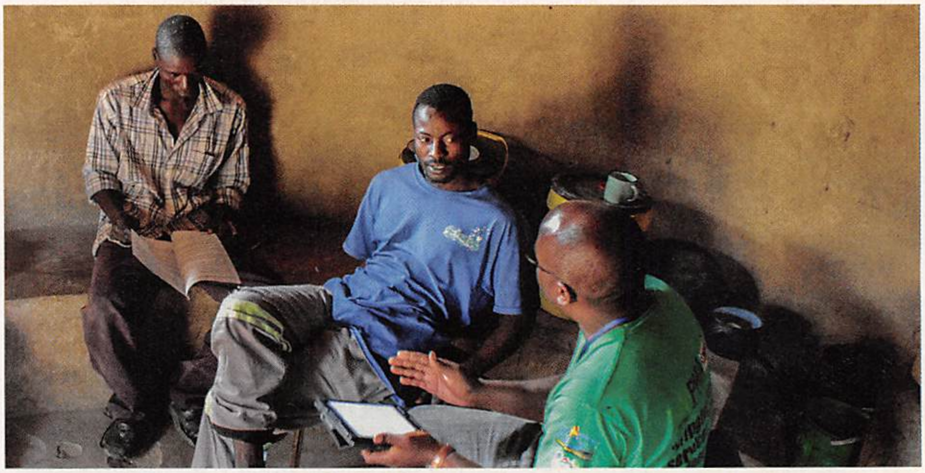

PHOTO: ICAP AT COLUMBIA UNIVERSITY

An HIV survey in Zimbabwe revealed that 86% of treated people are sticking with it.

standard blue absorber, achieving an efficiency of 20.3% in a pure perovskite tandem. Although not yet as good as perovskite-silicon tandems, the perovskite components in the cells are still rapidly improving, whereas silicon has flatlined.

For all their gains in efficiency, perovskites have faced lingering problems. Water vapor, high temperatures, or even prolonged sun exposure can dissolve or degrade perovskites within hours. But at the MRS meeting, McGehee reported exceptional stability for new perovskite recipes that replace an organic component called methylammonium with formamidinium or the element cesium. When encapsulated to protect them from moisture, these cells showed no sign of degradation for 6 weeks, even when exposed to temperatures of 85°C and a relative humidity of 85%, a standard test of durability. "Panels that pass it usually will not fail due to heat and humidity over 25 years outside," McGehee says.

Others are reporting improvements in manufacturing commercial-sized cells rather than the small, bespoke crystals used for setting records. Christopher Case, the chief technology officer for Oxford Photovoltaics (Oxford PV) in the United Kingdom, a perovskite solar cell company launched by Snaith, says the company has scaled up the postage stamp–sized research cells to ones that are 10 centimeters square and that have passed industry durability standards. Last month, the company acquired a former photovoltaic pilot facility in Germany. It is now gearing up to produce perovskite cells atop full-sized commercial silicon wafers, 15 centimeters on a side, Case says. Oxford PV also recently announced that they raised an additional £26 million ($33 million) over the last 18 months from investors, and Case says the company has inked partnerships with several of the top 10 silicon solar cell producers to investigate adding perovskites to their cells. If all goes well, he says, the first pilot products could appear in 2018.

That leaves safety as the major outstanding roadblock to commercialization. The most efficient perovskites contain a highly soluble form of lead, a dangerous neurotoxin that could leach into homes, soil, or groundwater if the cells degrade. Babayigit says there are potential solutions, such as encapsulating the perovskite in protective shells or adding sulfides around the cell, which would bind and quarantine any lead that managed to escape. For now, she says, "it's a heavily underresearched field that needs attention." Given how quickly perovskites are moving to market, it's a safe bet that someone will soon take on the project. ■

BIOMEDICINE

Carbon monoxide, the silent killer, may have met its match

Repurposed molecule saves rodents from gas poisoning

By **Wudan Yan**

On 26 January, Ling Wang and Qinzi Xu, two biomedical scientists at the University of Pittsburgh in Pennsylvania, placed a mouse under a chemical hood, anesthetized it, and hooked it up to monitors. Wang closed the hood and Xu turned on a switch to deliver 3% carbon monoxide (CO)—a concentration so high that it would kill most humans almost immediately—for 4.5 minutes. The mouse's blood pressure dropped precipitously and its heart rate turned irregular. Then, through an intravenous tube, they delivered a molecule their lab had developed. Moments later, the animal's blood pressure began to rise and it recovered. This was a first: There are no known antidotes for CO poisoning.

Given off by engines, heaters, and fireplaces, the tasteless, odorless gas sends more than 50,000 Americans to the emergency room—and kills approximately 500—every year. CO poisons in at least two ways. First, it binds tightly to the hemoglobin in blood and prevents it from delivering oxygen throughout the body. Second, it inhibits the process of respiration in mitochondria, cells' powerhouses. About the best physicians can now offer in cases of poisoning is a treatment developed more than 50 years ago: high-pressure oxygen.

"People have attempted some biochemical tricks to free carbon monoxide from hemoglobin, but they don't really work. That's why we literally have a therapy that's as old as oxygen," says Lance Becker, a physician at the Hofstra Northwell School of Medicine in Manhasset, New York. "So the idea of finding something that might work better, faster, and stronger is very appealing."

That something, described in this week's issue of *Science Translational Medicine*, is neuroglobin—a protein typically found in the brain and retina that protects cells from injury by binding oxygen and nitric oxide—repurposed into a CO scavenger. The Pittsburgh research team, led by critical care physician Mark Gladwin, was originally studying its function when they noticed that isolated neuroglobin molecules almost always had CO, a natural byproduct of hemoglobin breakdown, bound to them. "I thought this was bad news at the time, because we needed to get the CO off the neuroglobin in an extra experimental step," Gladwin said. But when a colleague asked in 2012 whether there was any antidote for CO poisoning, he realized that his lab might already have an answer.

> ***"This agent is phenomenal: It can rip CO right off the hemoglobin ... [It] could be life-saving."***
> **Lindell Weaver**, Intermountain Healthcare

In the mouse study, the group engineered a mutated version of neuroglobin that binds CO 500 times more tightly than it binds hemoglobin. The CO-laden molecules are excreted through the kidneys. When given within 5 minutes of a lethal dose of CO, the neuroglobin saved 87% of mice, the group reports. "This agent is phenomenal: It can rip carbon monoxide right off the hemoglobin," says Lindell Weaver, a doctor who treats patients with high-pressure oxygen at Intermountain Healthcare in Salt Lake City.

Weaver notes, however, that CO poisoning also activates a series of immunological pathways that cause lingering damage to the nervous and cardiovascular systems. "The long-term effects of carbon monoxide are complicated, so just removing [it] might not be enough," he says. "But this agent could be life-saving if it's administered immediately."

Gladwin's team now plans to further explore the efficacy and safety of the neuroglobin in rats, larger mammals, and, eventually, patients. One challenge will be making the neuroglobin scavenger in the amounts needed for use in the field and clinic. The U.S. Food and Drug Administration, Gladwin says, has already promised an expedited review of the treatment given that CO poisoning is a "serious unmet need." ■

Wudan Yan is a freelance journalist based in Seattle, Washington.

SCIENTIFIC COMMUNITY

Curator resigns after sexual misconduct investigations

Long-running case sparks debate about collaboration

By **Ann Gibbons**

Paleoanthropologist Brian Richmond, who allegedly sexually assaulted a research assistant and harassed trainees in a field school, has resigned his prestigious position as curator of human origins at the American Museum of Natural History (AMNH) in New York City, the museum said this week. Richmond will continue to work off-site until 31 December, and will be paid 1 year of salary, as his contract, which included tenure, requires.

Museum spokesperson Anne Canty declined to say if Richmond resigned under pressure, although he has been the subject of repeated investigations over the past 2 years for violating policies on sexual harassment. Earlier this year, Richmond wrote to *Science* that the museum asked him to resign in December 2015, but that he "had never assaulted anyone," and that he had "sincerely apologized" to the assistant (*Science*, 12 February, p. 652). This week he told *Science* that the details of his departure are confidential and stressed that only one formal complaint had been lodged against him. "I plan to focus on my family and the next steps in my career," he wrote in a statement, including "to publish the outstanding discoveries that my colleagues, former students, and I made."

Richmond's case convulsed the field of paleoanthropology (*Science*, 29 April, p. 503), and reaction to the news of his resignation was swift. "Woo-hoo! This is a positive step in the direction of there being consequences for perpetrators," said biological anthropologist Kathryn Clancy of the University of Illinois in Urbana-Champaign. Clancy co-led a high profile survey called SAFE, which reported numerous cases of sexual harassment at field sites (*Science*, 19 April 2013, p. 265). She and other anthropologists hope that the case marks a shift in how their field deals with harassment.

The formal complaint against Richmond was made by the research assistant. She alleged that he sexually assaulted her in his hotel room in Florence, Italy, in September, 2014, after sessions at a scientific meeting. Richmond has said the encounter was consensual. An initial investigation by the museum's human resources staff found that Richmond "had violated the Museum's policy prohibiting inappropriate relationships between supervisors and their subordinates," according to a memo obtained by *Science*. The research assistant was assigned a new supervisor, but she and Richmond both continued to work at the museum.

The American Museum of Natural History investigated curator Brian Richmond for 2 years.

Unhappy with this outcome, the research assistant publicly shared her story at another meeting. This sparked paleoanthropologist Bernard Wood at George Washington University (GWU) in Washington, D.C., to explore Richmond's actions at that university, where Richmond worked until mid-2014, and at the Koobi Fora Field School in Kenya, which was jointly run by GWU. AMNH then did a second investigation, which uncovered allegations that Richmond had sexually harassed students at the field school. Richmond resigned from the field school but continued to work at the museum.

After Richmond refused to resign, the museum last December hired an outside firm, T&M Protection Resources in New York City, to conduct a third investigation. The museum also asked Richmond to work offsite starting in January, according to the research assistant. The results of this third investigation, which concluded when Richmond resigned this week, have not been released. But Canty said the firm also helped the museum revise its sexual harassment policies and provide training for all employees, students and volunteers.

The research assistant, who remains employed by the museum, told *Science* the day after the resignation that she was "just glad it's over and that justice prevailed. The museum did the right thing." Other museum employees echoed that sentiment, saying that the human origins program was without direction during the stressful investigations. The museum plans to eventually hire a new curator of human origins.

Although Richmond co-authored several high-profile papers last year and says he plans to continue publishing, researchers are fiercely divided over whether others should share authorship with him. Last April, at the annual meeting of the American Association of Physical Anthropologists in Atlanta, Clancy and others argued that researchers should stop all collaboration, including joint publication, with colleagues under investigation for sexual harassment or discrimination, or urge such colleagues to withdraw from joint papers. At least one young researcher mentored by Richmond says a journal editor reported recently that some researchers refused to review papers with Richmond's name on them.

But removing Richmond from publications after the work was done would be "plagiarism," says paleoanthropologist David Strait of Washington University in St. Louis in Missouri, a long-time collaborator with Richmond. "I can't agree with removing someone from authorship on a paper that began in good faith before allegations of misconduct became known."

There are no professional standards on how to proceed, notes paleoanthropologist Leslie Aiello of the Wenner-Gren Foundation for Anthropological Research in New York City, but she and journal editors agree that the priority should be to avoid penalizing junior scientists who need to publish their research.

The whole affair leaves Wood, who once mentored Richmond and later encouraged investigation of his actions, with an "overwhelming sense of sadness and some hope." He regrets the harm done to women in science, and hopes the episode "will mark a watershed in all of our efforts to make the scientific workplace welcoming to all." ■

PHOTO: (RIGHT) SEANPAVONEPHOTO/ISTOCK