close to 4 gigabits per second operating on just 5 milliwatts of optical output power and using high-bandwidth photodiodes at the receiver. With a simple lens to enhance the distance, they can send data 10 meters at up to 1.1 Gb/s, and soon they will increase that to 15 Gb/s, Haas says. The 802.11ad Wi-Fi standard for the 60-gigahertz radio band reaches just under 7 Gb/s, so Li-Fi would more than double that rate.

They're also using avalanche photodiodes to make better receivers. In an avalanche photodiode, a single photon striking the receiver produces a cascade of electrons, amplifying the signal. Haas's team at the Li-Fi R&D Centre has created the first receiver chip for Li-Fi with integrated avalanche photodiodes on CMOS. The 7.8-square-millimeter IC houses 49 photodiodes.

Separately, the Fraunhofer Institute for Photonic Microsystems, in Dresden, Germany, had announced plans to demonstrate a Li-Fi hot spot in November (after press time) at the Electronica 2014 trade show in Munich. Frank Diecke, who leads the team developing Li-Fi at Fraunhofer, says that the system would most likely use infrared light and is aimed at industrial users rather than consumers. The hot spot was set to be a point-to-point link with a data rate of up to 1 Gb/s.

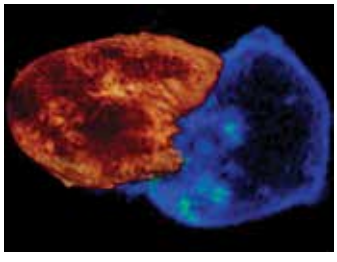
"You can have more or less the same data rate as over a USB cable," Diecke says. "That's very challenging for most wireless technologies, like Wi-Fi and Bluetooth." Another advantage, says Diecke, is that the latency of Wi-Fi—the time between when a signal is sent and when it's received—is measured in milliseconds, whereas Li-Fi's latency is on the order of microseconds. In industrial applications, where data has to flow between sensors, actuators, and a control unit, low latency and high data rates would make Li-Fi useful in places where Wi-Fi is not. "We don't want to replace Wi-Fi," he says. "That's not our goal."

But Diecke says Li-Fi could complement existing communications technologies, including Wi-Fi and gigabit Ethernet. For now, his group is not focusing on combining it with general lighting, as Haas proposes.

A group of European academic researchers and networking companies is aiming for the consumer market, though. The group is working on a project called Advanced Convergent and Easily Manageable Innovative Network Design (ACEMIND) to develop ways to manage local networks in homes and small businesses. ACEMIND includes a number of demonstrator projects to test different technologies, including Li-Fi. Dmitris Katsianis at the University of Athens, who is a participant in ACEMIND, thinks Li-Fi might be in practical use within the next five years. "Li-Fi has the advantage of being useful in electromagnetically sensitive areas such as in hospitals, aircraft cabins, and power plants," he says.

Haas is counting on a much bigger market. He expects LEDs to evolve past just being light sources, much the same way the cellphone evolved from a communications device to a mobile computer. "In 25 years, every lightbulb in your house will have the processing power of your cellphone today," he says. "It will in the future serve illumination as just one of many purposes." —Neil Savage

LIFE IN ACTION



This month Eric Betzig, of the Howard Hughes Medical Institute, is expected to fly to Stockholm to receive his share of the 2014 Nobel Prize in Chemistry for expanding the frontiers of microscopy. It seems he just couldn't leave those frontiers alone. Betzig (an engineer by training) and his collaborators have come up with a brand new microscopy trick. Called lattice light-sheet microscopy, it generates extraordinarily sharp 3-D images and videos of live organisms at scales ranging from single molecules to early-stage embryos. (Here it's showing an immune system cell [left] attacking an invader.) It works by illuminating the biological sample using a thin sheet of light that's manipulated by an ultrafast LCD to create a lattice of high and low intensity.

See the full story at http://spectrum.ieee.org/betzig1214

BETZIG LAB/HHMI

MEXICO'S RENEWABLES REVOLUTION CREATES TENSION

Demand for wind energy brings opportunities to engineers but angers some locals

Men died in gun battles over the installation of windmills in the state of Oaxaca, Mexico, three years ago. Opponents argued that energy companies misled them and that community leaders rented out collective lands without consulting everyone they should have. Today, protests continue, but the growth of wind farms and other renewables seems assured: Mexico boasts almost 2 gigawatts of installed wind power capacity and plans to install perhaps another 12 GW by 2022. All that clean energy is a big change for this country, which is the world's ninth-biggest oil producer and perhaps the 11th biggest emitter of carbon dioxide.

Yet at a conference in the city of Oaxaca de Juárez in August 2014, audience members asked the state's renewable energy coordinator, Sinaí Casillas Cano,

MARK STEVENSON/AP PHOTO

WINDY WELCOME: In 2009, people gathered in Oaxaca for the inauguration of a US $550 million wind farm. The benefits of Mexico's renewables boom have been uneven, triggering protests.

what benefit the foreign-built windmills had brought. Few of the farmers who have rented their land to wind companies are qualified—or needed—to maintain the multimegawatt windmills. The benefits will arrive unevenly as Mexico races to reform its fast-growing energy sector, experts say. Better-educated Mexicans will win the first jobs, and industrial power buyers will be the first to see their electricity bills fall, according to energy strategist Eduardo Reyes of PricewaterhouseCoopers, in Mexico City.

Casillas won applause from the crowd, saying, "Oaxaca needs to keep construction and maintenance jobs here." But to do that, Mexico needs to train engineers capable of working with—and someday competing with—the foreign firms that are leading the renewable energy boom here.

The country has now begun to mobilize its workforce. In October, the federal government launched a national program for energy-job training. The government predicts that the overall sector's job demand will grow from about 20,000 jobs in 2015 to 50,000 by 2018, with about one-fifth of those for people with bachelor's degrees or higher levels of training. It will provide educational grants to up to 60,000 technicians, engineers, and postgraduates.

The country's universities have already ramped up a response as well. In 2011, the National Autonomous University of Mexico (UNAM) launched a new major in renewable energy engineering. "Our graduates have a very high potential of finding jobs in the private sector and in government," says the program's director, Octavio García Valladares. The UNAM program has been stable at around two dozen students per class since 2012, and there are now 22 such programs nationwide.

Still, such efforts have a long way to go, says electrical engineer Santiago Barcón, a columnist for *Energy Hoy* in Mexico City. Unlike in the United States, where competition among companies has created a deeper, if sometimes redundant, talent field, Mexico's history of monopoly means that fewer people have experience in each niche of the energy marketplace. And it will take a decade to get fresh graduates up to speed, Barcón says. The result will be a short-term salary bubble in the energy sector, he predicts.

PricewaterhouseCoopers expects "clean" energy production to triple from 53 terawatt-hours in 2012—around a fifth of Mexico's generation—to 160 TWh by 2024. That gain will be thanks to a 2012 law requiring electricity generators to produce or buy 35 percent of their energy from clean sources. "Clean" in this case includes certain natural-gas plants, but large contracts for non-fossil-fuel energy are proliferating: Wind projects announced this year outside Oaxaca include a 66-megawatt, US $120 million farm in Esperanza and a 252-MW, $650 million project near General Bravo. The country's first utility-scale solar plant, a 39-MW, $100 million facility in La Paz, opened in March. Also, a major constitutional reform of the country's energy sector and regulations enacted this past August make it easier for producers to reach buyers.

Those projects should help unstick the country's stagnant economy, but it may take a long time for benefits to reach Mexicans in the poorest parts of the country, such as the Isthmus of Tehuantepec, where the first major wind farms were installed and gun battles broke out. To counter accusations that foreign wind companies took advantage of illiterate people with little basis for judging their offers, the companies have begun to invest in social development programs.

At the August conference, Claudia Toledo Matus, a corporate-responsibility representative for the Spanish energy company Acciona, said the company's goal was to spend 5 percent of its budget on social development over the 20-year life of the project. Yet in the first four years, Acciona spent only one-tenth of 1 percent of its Oaxaca wind budget on social programs, or around $913,000, according to Toledo. "We have to revise it every year to decide how to allocate it," she says, but she did not provide a schedule for spending the remaining $78 million.

UNAM's García and others criticize Mexico's government for its delays on reforming the renewable energy sector, too. "Unfortunately, the energy reform approved in Mexico barely mentions renewable energies," he says. Government officials will turn their attention to clean energy next, said Megan Reilly Cayten, coauthor of an August Atlantic Council report on the reform, during a conference call: "The issue has essentially been punted to the fall," she says. By *IEEE Spectrum* press time, no new rules had been established. The government will need to resolve issues such as how to assign clean energy credits and how to ensure that renewables can compete with ever-cheaper natural-gas generation on the new electricity grid.

Mexico's first university class of renewables engineers, due to graduate next year, had better study hard: They will arrive in a fast-changing market for their skills. —LUCAS LAURSEN