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COVER STORY

The future of low-cost solar cells

Perovskite and other emerging photovoltaic technologies grab headlines. But will they ever come to market?

By ***Mitch Jacoby***

The colors of the SwissTech Convention Center come from dye-sensitized solar cells integrated into the facade in panels made by Solaronix.

Credit: Solaronix

Located 150 million km from the sun, Earth receives just one-billionth of the sun's colossal power output. But even that tiny fraction—some 120,000 trillion W—showers Earth with more energy in one hour than all the energy consumed

In brief

Emerging photovoltaic technologies based on dye-sensitized solar cells, organic compounds, perovskite materials, and quantum dots garner intense coverage in the science press. These types of solar cells sit in the spotlight because they promise to be less expensive and well suited to many more applications than conventional silicon solar cells, which currently claim about 90% of the

C&EN ...ans in an entire year.

solar-cell market. Read on to find out which of these emerging technologies are well on their way to market and what technical challenges are holding up the others.

The sun's gargantuan outpouring of free and non-carbon-emitting energy has driven scientists for decades to develop photovoltaic devices—solar cells—that catch sunlight and convert it directly to electricity. Today, as the push toward renewable energy intensifies, the solar power industry is manufacturing and installing solar modules worldwide at record-setting numbers.

The vast majority of those solar panels—about 90%—are based on silicon. But because silicon photovoltaics are a mature technology, they are rarely the subject of photovoltaics stories that appear so frequently in the science press. Instead, the spotlight has been shining for several years on a number of emerging photovoltaic technologies that are stimulating intense R&D effort in academia and industry.

These developing technologies, which include dye-sensitized solar cells, organic photovoltaics, perovskite photovoltaics, and inorganic quantum dot solar cells, enjoy rock-star status. The reason is, compared with traditional silicon solar cells, the emerging ones promise to be less expensive, thinner, more flexible, and amenable to a wide range of lighting conditions, all of which make them suitable for a host of applications beyond rooftop and solar-farm panels—silicon's bailiwick.

But where do these emerging photovoltaic technologies stand today? Are they confined to university research labs? Are they being developed by technology incubators and start-up companies?

In the pages that follow, C&EN aims to answer those questions, giving a handful of examples, rather than an exhaustive list, of the dozens of companies working to commercialize these technologies and the technical challenges they face in bringing products to market.

Today's silicon-dominated photovoltaics market is abuzz with statistics showing how fast photovoltaic power is growing and how much power modern panels generate.

For example, solar panel installations on American homes generated, on average, 85% of the electricity needed to power those homes in 2015, says Nick Liberati, communication manager of Boston-based EnergySage, a matchmaking service supported by the Department of Energy that pairs potential solar customers with installation companies.

And solar's quick-paced growth is expected to continue for decades in response to growing global energy demands. In a report published last year, the Energy Information Administration (EIA) predicted that, in the next 25 years, renewable energy sources such as solar and wind will supply roughly 50% of the new energy capacity in the U.S.

Despite solar energy's rapid growth and shiny-looking future, the overall fraction of power currently generated by photovoltaics is tiny. EIA estimates that in 2015, solar energy accounted for just 0.6% of the total quantity of electricity generated in the U.S. Coal and natural gas each supplied 33% of the total, leaving the rest to come from nuclear, hydropower, and other renewables, mainly wind power.

One of the main reasons for solar energy's strong growth is the falling prices of silicon photovoltaics. But the emerging photovoltaic technologies promise to be even less expensive, proponents say.

Conventional silicon cells require ultra-high-purity silicon—on the order of 99.999% pure—and the cells are made via energy-intensive crystal growth and vapor deposition methods. Further adding to their costs, "silicon solar cells use 1,000 times more light-absorbing material than dye-sensitized solar cells and perovskite cells," says photovoltaics pioneer **Michael Grätzel <http://lpi.epfl.ch/graetzel>** , a chemistry professor at the Swiss Federal Institute of Technology, Lausanne.

Because silicon doesn't absorb sunlight strongly, silicon cells contain a relatively thick layer of silicon, which is brittle and therefore must be supported on a rigid, heavy piece of glass, adding cost and limiting applications.

In contrast, emerging photovoltaic cells are made from an assortment of inexpensive materials, including organic polymers, small molecules, and various types of inorganic compounds. And unlike silicon cells, the emerging ones can be fabricated on flexible supports via inexpensive solution-phase techniques common in plastics manufacturing, such as high-speed roll-to-roll printing.

A key factor contributing to the low price of emerging photovoltaics is the ability to produce the modules as large rolls of thin film via high-speed processes.

Credit: Infinity PV

Historically, the lower price tag on emerging photovoltaics has gone hand in hand with significantly lower performance. In terms of power conversion efficiency—a ratio of light energy in to electrical energy out—dye-sensitized solar cells, organic photovoltaics, and quantum dot cells started at just a few percent and have climbed slowly over the years to roughly 12%, where they sit today. The value for silicon cells is much higher, in the range of 20–25%.

For example, the National Renewable Energy Laboratory (NREL), which is regarded internationally as the official verifier of efficiency records for research solar cells, puts today's top-performing multicrystalline silicon cell at just more than 21% efficient. The record for the more expensive and less common single-crystal silicon cell sits at 25%.

State-of-the-art gallium arsenide-based solar cells boasting efficiencies as high as 46% sit at the very top of the NREL list. But those cells are highly specialized photovoltaic research devices that come with steep price tags.

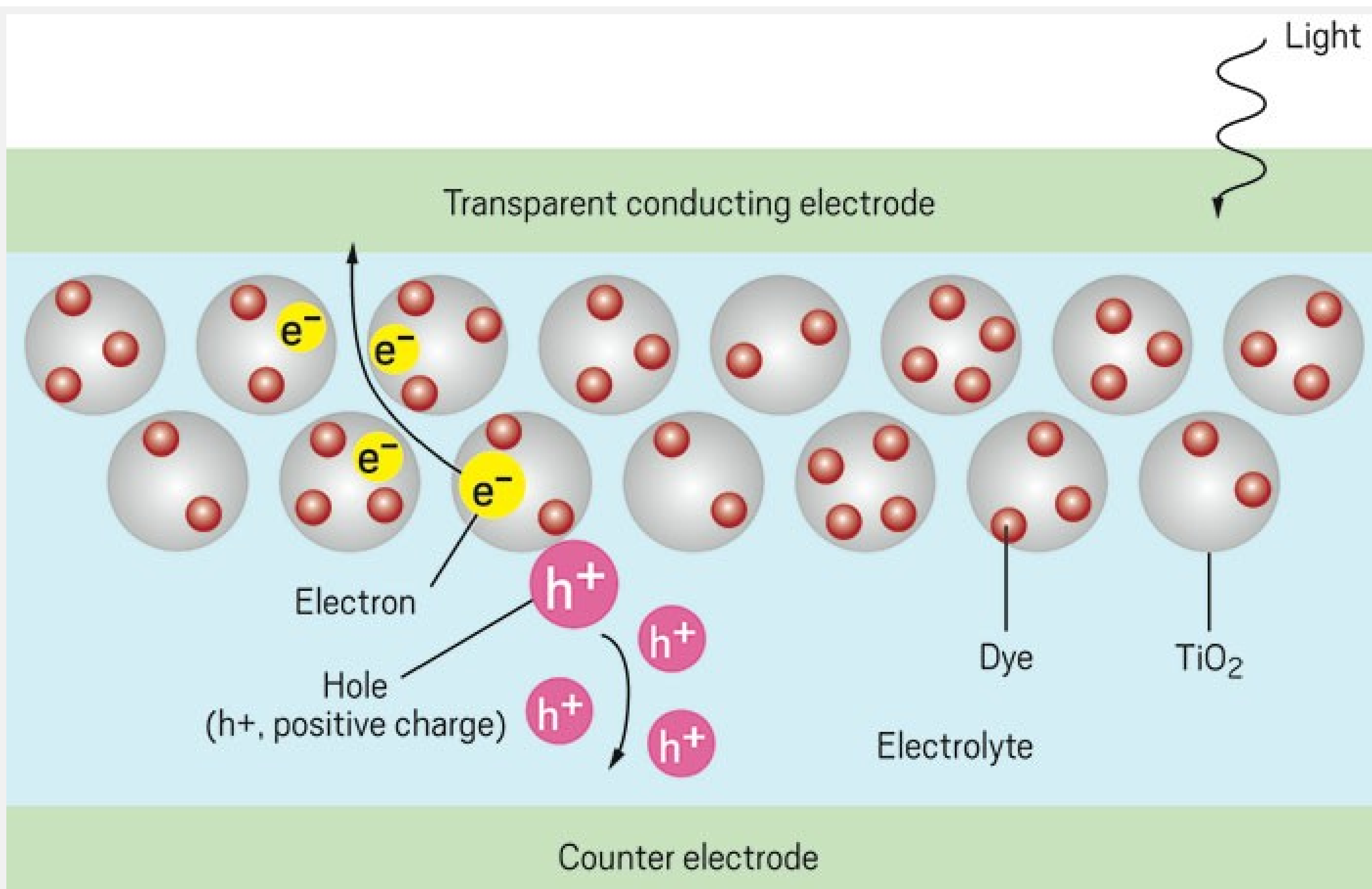
Although the efficiencies of most other emerging photovoltaic technologies sit well below silicon, one type of cell may soon give silicon a run for its money. The current perovskite photovoltaic record holder, according to NREL, clocks in at just more than 22%. But as described below, some technical challenges must be overcome before **perovskite cells <http://cen.acs.org/articles/92/i8/Tapping-Solar-Power-Perovskites.html>** will be commercialized on a large scale. As for the other emerging photovoltaic technologies, many companies are betting that the devices' low price will provide customers with more than enough bang for their buck to offset low efficiencies.

Reflecting on these emerging photovoltaic technologies, "I'm more optimistic now than ever," says the University of Notre Dame's **Prashant V. Kamat <http://www3.nd.edu/~kamatlab/>** , who has been active in the area since the 1970s. He stresses that even if the emerging technologies don't become photovoltaic blockbusters that replace silicon cells, "they will likely lead to offshoot technologies and niche applications."

Dye-sensitized solar cells

Maximum certified efficiency: 11.9%

Commercial status: advanced demonstration, some products for sale



Dye-sensitized solar cells: How they work

Light transmitted by the transparent electrode of a dye-sensitized solar cell is absorbed by a dye (red), which coats TiO_2 nanoparticles (gray). The process forms electron-hole pairs (e^-/h^+). Electrons travel through the TiO_2 layer to one electrode as holes travel through an electrolyte (blue) to the other electrode, generating electric current.

Credit: Adapted from *Small*

In the early 1990s, chemistry professor Michael Grätzel of the Swiss Federal Institute of Technology, Lausanne, and coworker Brian C. O'Regan demonstrated that an appreciable quantity of electricity can be generated from sunlight by means of an inexpensive and easily produced device. Their work touched off a wave of dye-sensitized solar-cell (DSSC) research and led to the founding of several start-up companies.

All photovoltaic devices generate electricity through a series of light absorption, electronic excitation, and charge separation events. Unlike in conventional solar cells, where these events occur in a single layer of silicon, in DSSCs the events occur in separate molecular layers.

DSSCs feature a porous network of disordered titanium dioxide nanoparticles that are coated with light-harvesting dye molecules and are typically surrounded by a liquid-phase electrolyte. Photons captured by the dye—generally a ruthenium complex—generate pairs of negatively charged electrons and positively charged electron vacancies called holes. The charges separate at the surface of the nanoparticles: Electrons are injected into and transported through the TiO_2 layer to one electrode, and positive charges migrate via the electrolyte to the opposite side of the cell.

In the years after the early DSSC studies, several companies jumped into the photovoltaics business. The efficiencies of DSSCs were much lower than those of silicon cells. They still are. But the combination of their low cost, low weight, flexibility, thinness, and ability to transmit light means that DSSCs could be used for applications outside of silicon's reach.

One hot application is building-integrated photovoltaics. The idea is that solar panels can be built into various parts of a building's shell, not just the rooftop, which is the preferred spot for silicon panels because they work best in direct sunlight. DSSC panels, however, work well in diffuse light. For that reason, thin sheets of translucent DSSCs can be sandwiched between panes of glass, turning ordinary windows, skylights, and glass facades into electricity generators.

Several companies are commercializing DSSC technology, including South Korea's Dongjin Semichem. According to the firm's vice president and chief technology officer, Kyusoon Shin, the company has been "building up, tuning, and operating" an automatic pilot production line for glass-based DSSC modules since 2012. It currently has the capacity to produce tens thousands of modules per year.

Shin emphasizes that in addition to the panels' energy-saving appeal, their aesthetics are attracting architects, construction materials companies, and window manufacturers. For now, the company's panels can be found at three demonstration sites in South Korea, Shin says. He adds that two more installations are scheduled for the first half of 2016.

DSSCs also power small electronic devices. One application gaining a lot of attention is the so-called internet of things, which refers to a network of appliances, vehicles, and other objects that are fitted with sensors and other electronics to enable them to collect and transmit data.

The electronics need continuous power, and rather than supplying the power via hardwiring or batteries that need to be replaced or recharged, companies are gearing up to supply it with small DSSC panels. These devices outperform ones made from silicon in terms of their ability to generate electricity from indoor light.

G24 Power, in Newport, Wales, is making DSSC panels for similar applications. The company offers a number of products for sale today under the trade name **GCell <http://gcell.com/shop>** , including a DSSC-powered Bluetooth-enabled wireless keyboard.

In the coming months, GCell plans to start shipping **DSSC-powered beacons <http://www.ibeacon.solar/products>** that broadcast Bluetooth signals. The devices can be used in many ways, for example, to direct game-day attendees from the entrance of a sports stadium to ticketed seats via cell phone communication.

Although companies have been working to develop DSSCs since shortly after the seminal reports in the early 1990s, researchers continue to work to improve them. One shortcoming of early designs is that the liquid electrolyte, typically an organic solution of the iodide/triiodide (I^-/I_3^-) redox couple, is corrosive, volatile, and prone to leaking. And it can react with the dye, all of which limit long-term stability.

Seeking to improve the design, Northwestern University researchers replaced the liquid electrolyte with a novel semiconducting inorganic solid: fluorine-doped cesium tin iodide ($CsSnI_{2.95}F_{0.05}$). The team **reported in 2012 <http://cen.acs.org/articles/90/web/2012/05/Solid-Solar-Cell-Solution.html>** that the solid avoided the corrosion and reactivity problems and led to cells with conversion efficiencies of around 10%.

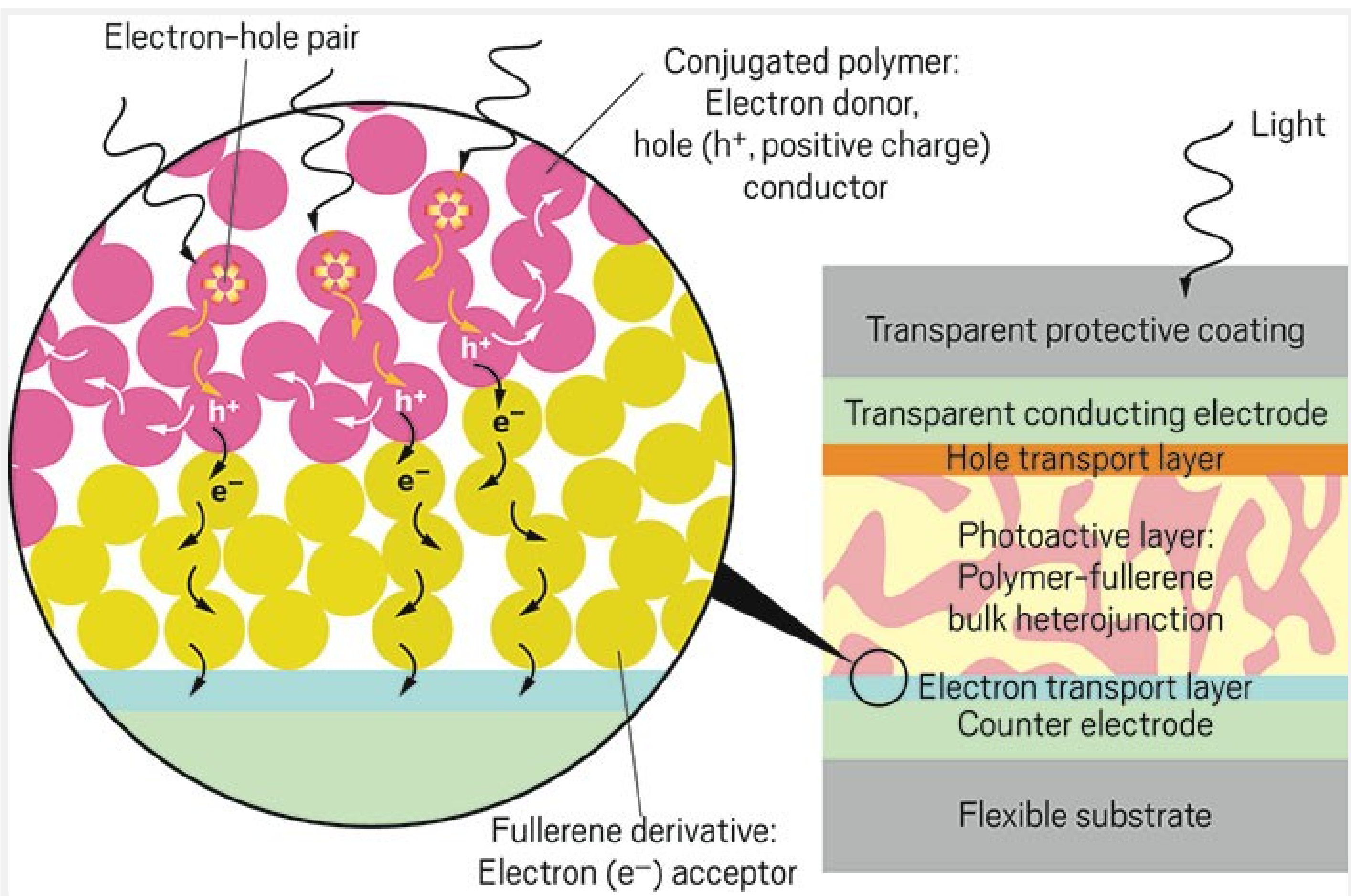
Other potential DSSC improvements come from new pairings of dye and redox couples. Grätzel's group, for example, found that pairing a **zinc porphyrin <http://cen.acs.org/articles/89/i45/Better-Dye-Yields-Better-Solar.html>** dye with a cobalt(II/III) bipyridine electrolyte led to efficiencies that surpassed the common ruthenium-iodide systems.

Solar-cell manufacturers, like all high-tech companies, keep the key details of their product improvement strategies quiet. They admit openly, however, that implementing a lab finding in a manufacturing process usually takes years.

Organic photovoltaics

Maximum certified efficiency: 11.5%

Commercial status: advanced demonstration, some products for sale



Organic solar cells: How they work

Light shining on an organic solar cell passes through transparent layers and stimulates electron-hole pairs (e^-/h^+) in a photoactive layer (enlarged area is a bulk heterojunction). Upon reaching an interface between a conductive polymer (pink, electron donor) and a fullerene (yellow, electron acceptor), the pair splits. Positive charges hop via nanosized polymer domains to one electrode, and negative charges migrate through the fullerene to the other one, thereby generating electric current.

Credit: Adapted from Konarka Technologies

Organic photovoltaic devices rely on a mixture of light-sensitive polymers or small molecules and fullerene-like compounds to absorb light and set their electricity-generating events in motion. The compounds are typically blended in a nanoscale network known as a bulk heterojunction that sort of resembles a coarsely stirred mixture of peanut butter and jelly. That arrangement mediates efficient charge separation by providing a large area of contact between the organic molecule (an electron donor) and the fullerene (an electron acceptor).

As with other emerging photovoltaic technologies, organic photovoltaic modules are thin, lightweight, and flexible, making them well suited to being placed on the outsides of buildings and on irregularly shaped products, such as fabrics for backpacks and tents.

“2018 is our mass production target year.”
—**Thomas Bickl,** vice president, Heliatek

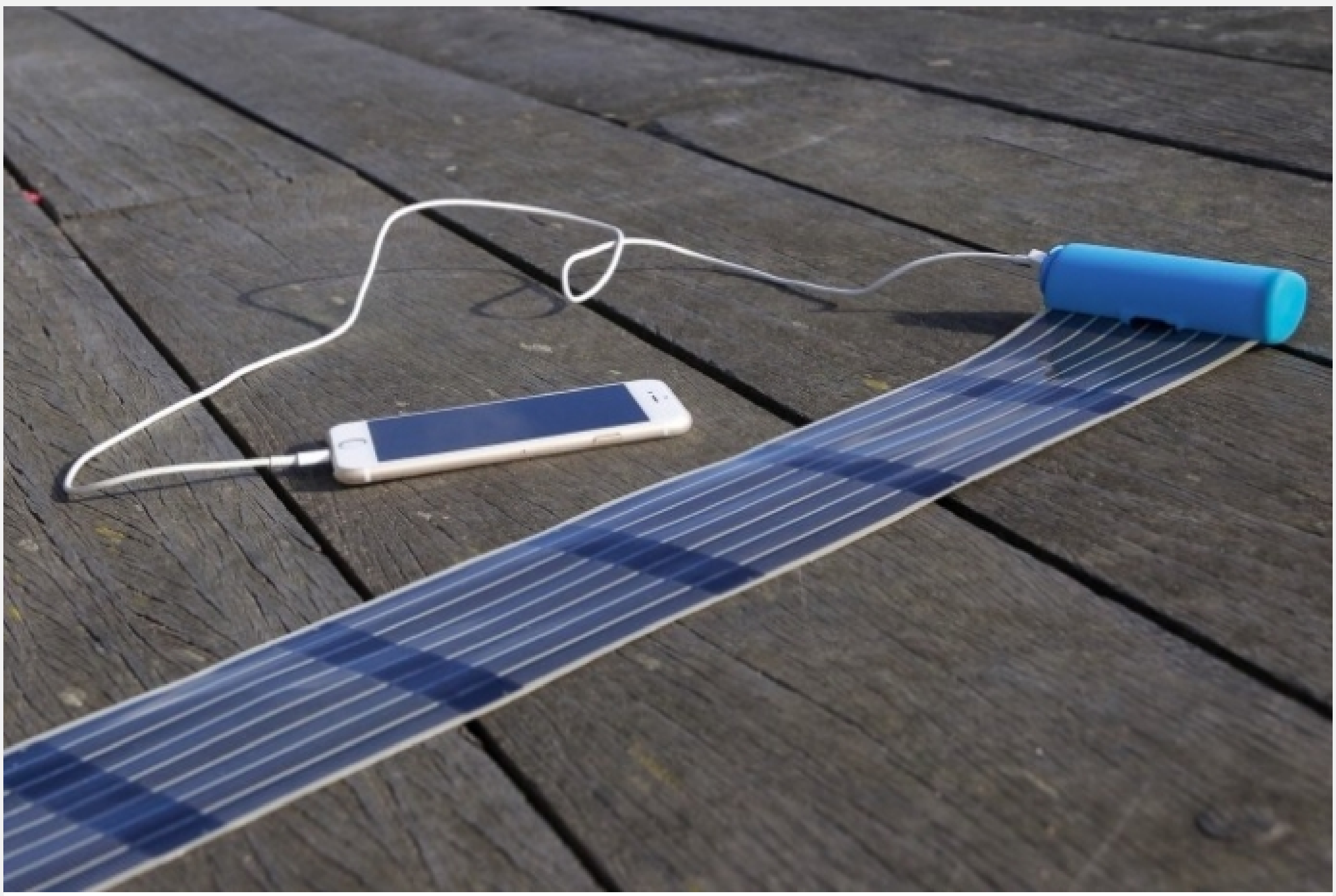
Several companies are actively pursuing these applications. Dresden, Germany-based Heliatek, for example, has several pilot projects under way that highlight the firm’s ability to integrate foil-like organic photovoltaic modules into building facades made of glass, concrete, and metal.

These thin organic solar-cell panels can be integrated into cement and metal portions, not just glass, of a building facade.

Credit: Heliatek

Thomas Bickl, Heliatek’s vice president for sales and product development, notes that the company’s current photovoltaic module production capacity is roughly 10,000–20,000 sq meters per year. That area is on the order of just one warehouse-sized building, he notes. But Heliatek is gearing up quickly to produce more. “Everything we are doing today is aimed to making us market-ready in 2018. That’s our mass production target year.”

InfinityPV is a Danish organic photovoltaics start-up company founded by **Frederik C. Krebs <http://www.dtu.dk/english/Service/Phonebook/Person?id=3454&tab=2&qt=dtupublicationquery>** of the Technical University of Denmark. Infinity currently sells solar cells and modules for educational use, testing, and manufacturing analysis. Krebs and coworkers **caught the media's attention <http://cen.acs.org/articles/91/i4/Supersized-Polymer-Solar-Cells.html>** in 2013, when they developed a large-scale roll-to-roll printing technique and used it to make a record-setting string of 16,000 organic solar cells connected in series. InfinityPV also makes a solar charger for phones. The device features a hand-sized case with a retractable organic photovoltaic panel and a built-in lithium-ion battery.



Unfurl this thin, flexible organic photovoltaic panel and charge your phone or battery indoors or out, then roll it back up for storage.

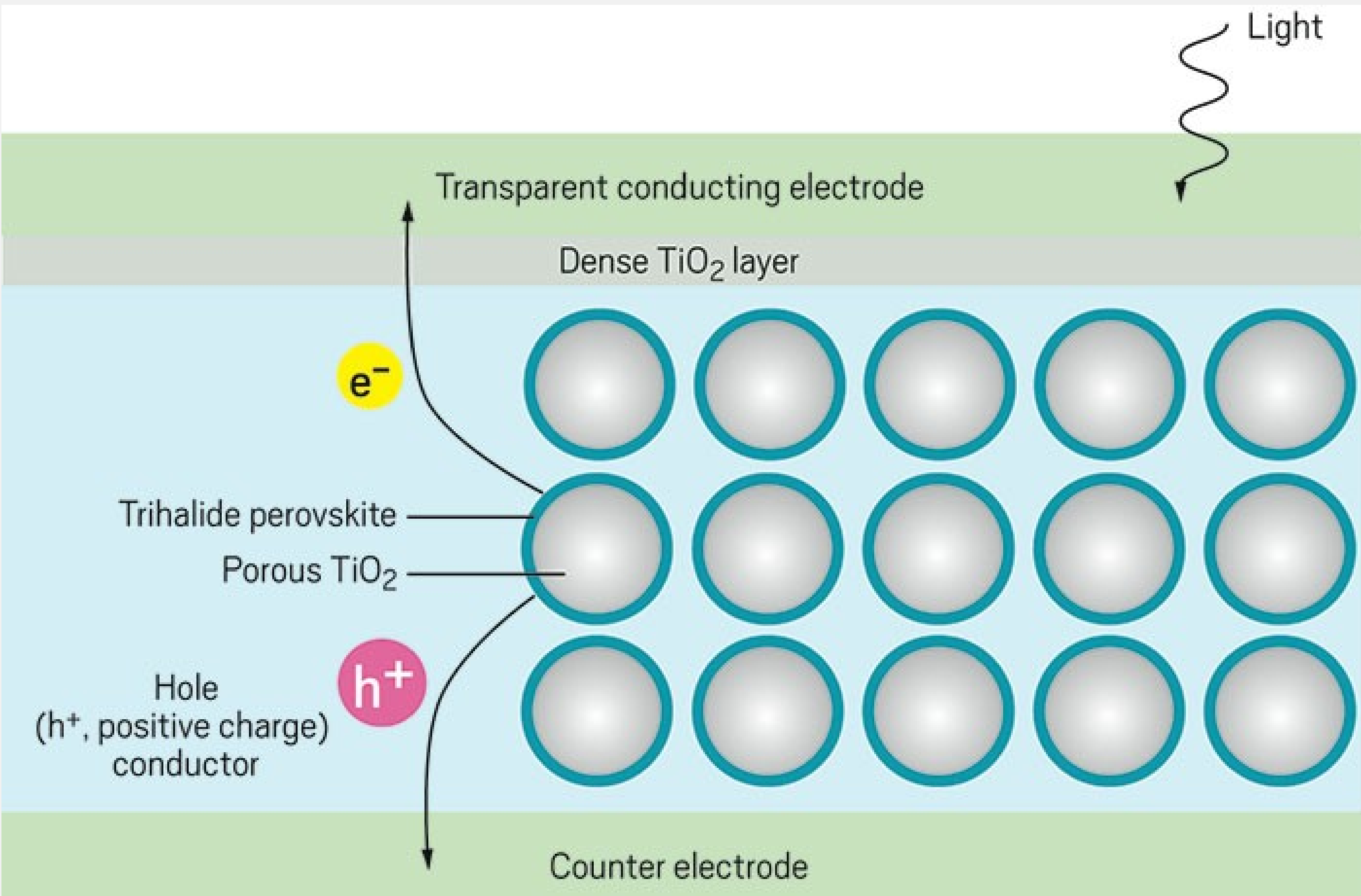
Credit: Infinity PV

Bickl says the key hurdle to boosting the commercialization of organic photovoltaics is financial, not technical. Heliatek's pilot projects prove that the products work well and are reliable, he says. But the cells' low-cost advantage can only be attained when the components and the modules are produced at a much larger scale than Heliatek's current capacity. To reach that scale of manufacturing—a minimum of 1 million sq meters per year—the company must attract new investors, which requires adding pilot-scale demonstrations to build investor confidence. All of those steps take time, he says.

Perovskite solar cells

Maximum certified efficiency: 22.1%

Commercial status: development, no products



Perovskite solar cells: How they work

Light passing through the transparent electrode (green) of a perovskite solar cell onto a layer of a photosensitive perovskite material (blue) stimulates excitations called electron-hole pairs (e^-/h^+). The charged particles separate and diffuse through the charge-conducting layers to their respective electrodes, thereby generating electric current.

Credit: *J. Phys. Chem. Lett.*

Perovskite solar cells have attracted more attention in the past few years than all other types of emerging photovoltaic technologies because they are proceeding on an unprecedented trajectory. Unlike the other emerging technologies, which debuted at very low efficiencies and crept up slowly over several years to the 10% range, perovskite solar-cell efficiencies soared in just a couple of years to more than 22%.

These devices use compounds with the perovskite crystal structure and stoichiometry to absorb light. $(CH_3NH_3)PbI_3$ is the most studied example. Scientists remain unsure why positive and negative charges generated by photoexcitation in these types of cells reach their respective electrodes so efficiently. Yet the remarkable rate of progress caused photovoltaics researchers in academia and industry who were working on other technologies to switch to perovskites or at least add the topic to their priority list. And several new companies, such as Oxford Photovoltaics, a start-up launched by University of Oxford physicist Henry J. Snaith, a leading figure in perovskite photovoltaics, and Warsaw-based Saule Technologies have also entered the perovskite photovoltaics race.

Perovskite solar cells made simply

Simple Setup

As shown in this footage, ordinary lab equipment is all that's required to make perovskite solar cells.

Credit: C&EN

Several companies sell chemicals and materials for perovskite solar-cell R&D, but it seems that, so far, none has perovskite modules for sale. And very few companies have demonstrated modules publicly. Saule Technologies claims to have a working prototype perovskite module that can power small electronic devices.

e at the proving-the-technology stage," Snaith says, adding that it will be "at least 12 months" until Oxford Photovoltaics will begin demonstrating perovskite modules. He adds that Oxford's plan is to mate perovskites with silicon to produce tandem cells for rooftop panels. Studies show that, compared with pure silicon cells, tandem perovskite-silicon cells absorb a larger fraction of the solar spectrum and thereby outperform conventional rooftop silicon panels.

Real commercialization of perovskite photovoltaics is unlikely to happen until the 2019–21 time frame, according to Tyler Ogden, a market analyst with Boston-based Lux Research. Ogden just published a report analyzing the **rise of perovskites <https://portal.luxresearchinc.com/research/report_excerpt/21422>** and the role academic researchers will continue to play.

One key challenge for perovskite commercialization is stability. The light-sensitive material in these devices dissolves in the presence of water and decomposes at high temperature, according to Jao van de Lagemaat, principal scientist and center director at the National Renewable Energy Lab.

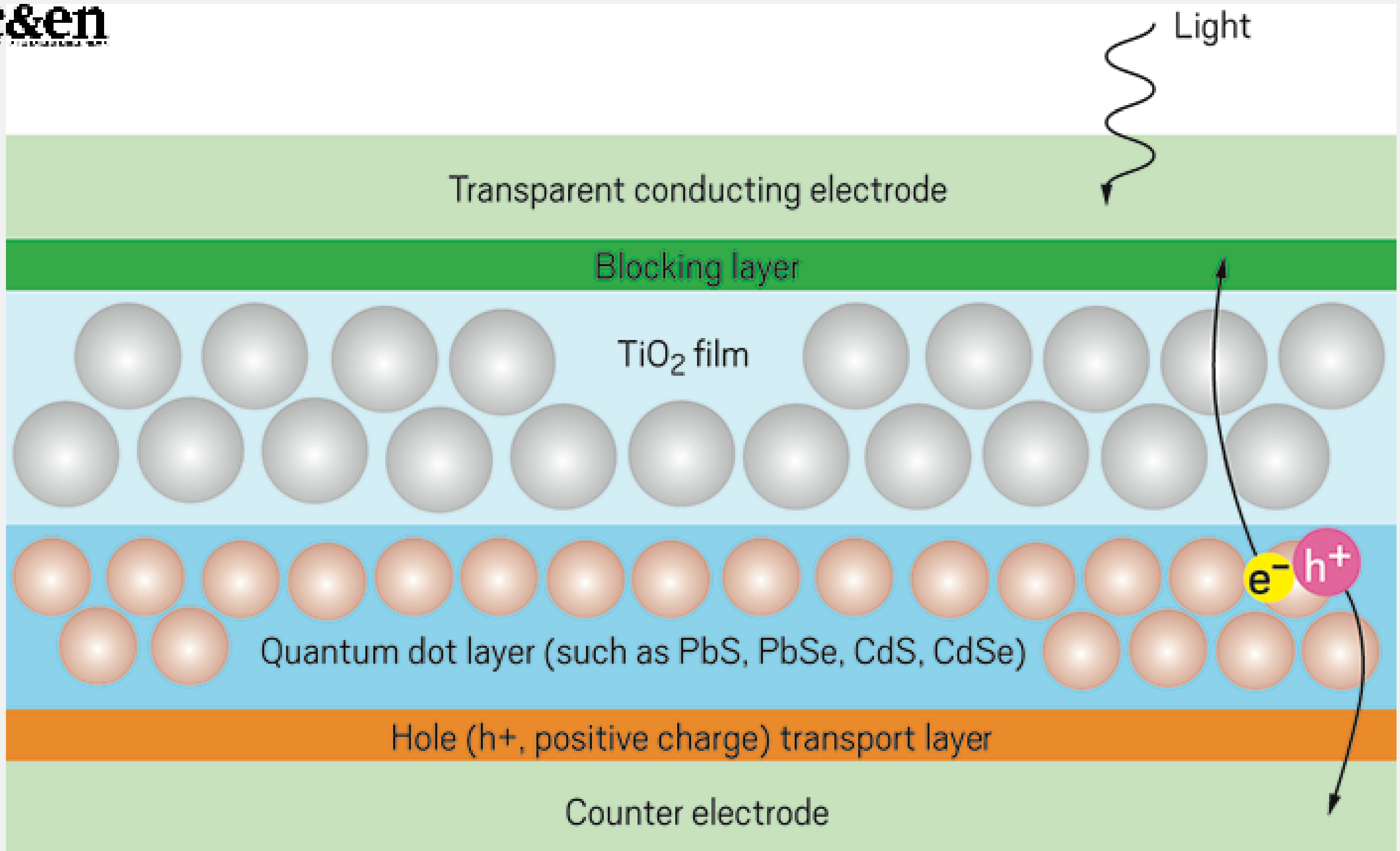
Several companies claim to have devised methods for sealing and protecting their cells and modules, but the procedures are proprietary. Snaith and coworkers tipped their hand slightly in a recent paper. They reported that substituting a fraction of the perovskite compound's formamidinium cations with cesium ions significantly improved stability (*Science* 2016, DOI: 10.1126/science.aad5845).

Scientists must also address the possibility of lead contamination before these cells can be commercialized at large scale. The proprietary sealing methods may help prevent leakage into the environment. Another strategy under development is replacing lead with other metals such as tin. Snaith's group and scientists at Northwestern University are studying that option.

Quantum dot photovoltaics

Maximum certified efficiency: 11.3%

Commercial status: development, no products



Quantum dot solar cells: How they work
Light shining through the transparent electrode of a quantum dot solar cell onto a photosensitive layer of dots leads to the formation of electron-hole pairs (e^-/h^+). The charged particles separate and travel to their respective electrodes, thereby producing electric current.

Credit: Adapted from *J. Phys. Chem. Lett.*

In **quantum dot solar cells <http://cen.acs.org/articles/91/i38/Powerful-Dot-Solar-Energy.html>** , nanocrystals of semiconducting metal chalcogenides—including CdS, CdSe, PbS, and PbSe—and other materials function as the light-absorbing material in the device. As with other emerging photovoltaic technologies, quantum dot cells can be prepared via low-cost solution-phase chemistry methods and are amenable to high-speed printing techniques.

Many academic research groups have shown this technology holds promise. But relatively few companies are betting that they have the combination of unique materials chemistry and manufacturing know-how needed to provide a competitive edge in this area. One exception is Solterra Renewable Technologies, in San Marcos, Texas.

Solterra is a subsidiary of Quantum Materials, a manufacturer of nanocrystals and other nanoscale materials. Solterra's cells are designed to exploit Quantum's low-cost synthesis methods for making four-armed quantum dots. The unique shape of these crystals reduces the probability of electron-hole recombination, which leads to greater charge transport and photovoltaic efficiencies compared with spherical quantum dots of the same material.

According to Vice President David C. Doderer, Solterra aims to produce a prototype quantum dot cell within one year and demonstrate a multicell module within two years. The firm is working to improve its roll-to-roll printing technique and other manufacturing procedures, he says.

In a development that may advance quantum dot photovoltaics, researchers at East China University of Science & Technology just reported that their Zn-Cu-In-Se quantum dot cell yielded an efficiency of 11.6%. That value tops the current U.S. National Renewable Energy Laboratory-certified quantum dot record holder by 0.3% (*J. Am. Chem. Soc.* 2016, DOI: **10.1021/jacs.6b00615 <http://cgi.cen.acs.org/cgi-bin/cen/trustedproxy.cgi?redirect=http://pubs.acs.org/doi/abs/10.1021/jacs.6b00615?source=cen>**).

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Comments

Bill Leigh **(May 2, 2016 9:29 AM)**
What the article doesn't mention and rightly so since it is a science publication is Quantum Materials Corp with their subsidiary Solterra Renewable Technologies,Inc is the only publicly traded company on the OTC under ticker symbol QTMM. Any one with foresight knows solar will be a major energy provider. Why not participate while it's still affordable to the small investor before the Wall Street crowd get interested? Quantum Dots are a game changing technology and solar is only one of many applications. Quantum dots and Perovskite together are already being looked at by other institutions and together they could provide the knock out punch to the oil dominance in energy.
» **Reply**

Jack **(May 24, 2016 3:01 PM)**
Also OPVS is traded OTC has some QD IP, but is focused mainly on ultra cheap thin film flexible GaAs with conversion efficiencies well over 20%, and it has several key patents in the Organic Solar realm as well where it is making good headway as well with an unpublished record and a conversion efficiency goal of 18% (in the lab). I think they are working with Heliatek (or have) - not sure what they are doing since it is all proprietary. They do have a formal JDA with Solaero. They seem to have a communication policy in the 'mum' category. They don't seem to communicate at all except in the form of required filings. They have a good presentation on their website (nanoflexpower).
» **Reply**

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OPV scientist **(May 2, 2016 1:44 PM)**
Regarding organic photovoltaics, you failed to mention all manufacturers of polymer solar cell materials, who are way closer to mass market than Heliatek. Currently, the major players are: Merck KGaA, Darmstadt, Germany (known as EMD in US and Canada); Sumitomo and Mitsubishi. Krebs' startup is notable, but it is one of many OPV module makers (and definitely not the biggest one).
» **Reply**

OPV scientist **(May 2, 2016 1:45 PM)**
Regarding organic photovoltaics, you failed to mention all manufacturers of polymer solar cell materials, who are way closer to mass market than Heliatek. Currently, the major players are: Merck KGaA, Darmstadt, Germany (known as EMD in US and Canada); Sumitomo and Mitsubishi. Krebs' startup is notable, but it is one of many OPV module makers (and definitely not the biggest one).
» **Reply**

OPV Scientist 2 **(May 4, 2016 3:49 AM)**
Dear OPV Scientist
I do not believe that Merck, Sumitomo and Mitsubishi are major players on the OPV market, at least not yet as I have never heard about any OPV product from them. But you might be better informed. On the contrary infinitypv.com (Krebs start-up) is the only company that actually sells OPV products to ordinary people.

» **Reply**

OPV scientist **(May 7, 2016 4:45 AM)**
The three chemical companies I mentioned are the major suppliers of opv materials and owners of key IP, but they don't manufacture solar panels for end users. Infinitypv and other module makers use materials made by (or made under license from) one of these suppliers.
» **Reply**

Pension **(May 11, 2016 5:24 AM)**
I disagree on that, from the website you can see that infinityPV makes and sells its own materials and owns its IPs. This is the company where many Industries and Academics are buying from. Than they also have some solar panels for end users.
» **Reply**

DAK **(May 4, 2016 1:57 PM)**
The real issue with PVs is not the cost of the light-electricity materials but he efficiency. Components like wire, microinverters, clamps, racking, and permits dominate the system for a small investor. The cost of the Si to place a panel on your roof is something like 10% of the total cost. Therefore, if the Si were free, it does not affect much of the total charged. Having a panel of 20% efficiency vs. 15% makes a considerable change in the cost and required real estate, which tends to be limited. Just going from 300W to 400W panels of single crystal silicon would decrease the total cost to something like 10%.

The is not to say that other materials are not better for certain applications like portable power. It is just to reduce energy usage, the consumer needs fixed panels on their roof and that takes efficiency of the converter. Additionally, lifetime is a big deal and silicon has proven that. When you require something to withstand considerable heat-cold and UV light for years puts a great limitation on the materials used - especially organics. Look at car paint for an example.

Comment on if I got this wrong or not. I am open to counter arguments.
» **Reply**

gerald ceasar **(May 5, 2016 12:44 PM)**
Both efficienciency and cost of manaufacturing a large area(square foot) of PV material are important. The PV community uses the metric $/watt to which refers to costs of manufacturing a large area PV module divided by the watts produced which depends on solar conversion efficiency. The long time nirvania of PV technologists has been to get to $1/watt to be competitive with central power plant electricity. This has occurred recently and is reponsible for the growing adoption of PV across the roof tops of America and in in solar farms.

The NIST zero energy house shows that PV can supply most if not a surplus of annual electricity for homes in the northest. See http://phys.org/news/2016-03-nist-net-zero-house-quadruples-energy.html. The NIST experince also shows that PV modules are very reliable and require little maintenance. In fact PV modules are guaranteed by their manufacturers for 25 years with full replacement so lifetime is not an important issue for c-silicon PV.

You are right DAK that stability and reliabilty are important issues for the newer organic and perovskite devices. c-Silicon PV has proven itself reliable in powering satellites in the cold conditions of outer space.
» **Reply**

gerald Ceasar **(May 5, 2016 4:49 PM)**
I didn't run the spell checker on my poor typing version above. Please replace the above comment with this one:

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» **Reply**

OPV scientist **(May 7, 2016 4:09 PM)**

Indeed. That's why OPV does not compete with current rooftop solar, even though installation costs are way lower (due to OPV being lightweight etc.). OPV on the outside of buildings makes most sense on the facade (because of lower dependence of efficiency on incident ray angle it can be mounted vertically) and as a semi-transparent window or window blinds.
» **Reply**

Gerald Ceasar **(May 4, 2016 4:00 PM)**
It should be mentioned that the literature references to the efficiencies quoted in this article for Perovskite and quantum dot solar cells are all at a fraction of 1cm2. Having been involved in PV research since the 1970s, it will take a long time to get to realistic efficiences over square foot module areas.
» **Reply**

Frederik C. Krebs **(May 5, 2016 2:56 AM)**
I was not contacted or solicited prior to the writing of this article which can mean either of two things (poor journalism with a commercial motive and some other hidden motive or good authoritative and informed journalism based on available fact and without input from people interviewed that could distort the views).

In this case I experience the latter. It is a good and honest piece of text that lucidly presents the overhyped field of 3rd generation PV that has been driven by top-scientists at top-universities, it also clearly states where we have failed in progressing the science to a technology and that we perhaps have been too good at marvelling at our own significance while being oblivious to the real world outside that we intend our knowledge to serve in. If read (as I read it) it states that it has been a great academic party and there is hope to move on. But also that we have to move from spending someone else's money to making and spending our own money based on our products that make customers willing to pay for it (for their value and because they add value and not because we fooled someone to pay). A good signature of this is when companies stop publishing scientific articles and competing at scientific conferences and instead start making real products for real money. The large herd of 3rdgenPV scientists will have to either find another scientific topic or transform from being scientists to being technologists. For every paper you write, you loose 1000 customers, 1 year of progress and most importantly you do not improve. Focus on what matters now: get it out there!
» **Reply**

Jagadish **(May 8, 2016 3:38 PM)**
First of all thank you so much for very interesting article and helpful for me, I am confident on perovskite technology to get commercialized in coming future.
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