Plastic Power

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Researchers at the Center for Polymers and Organic Solids are finding ways to reduce the cost of solar cells. Their goal: to make photovoltaics at least as cheap as the grid.

Mix sunlight with brainpower and you will get a form of energy that is cheap, inexhaustible, good for America and good for the planet. Such has been the dream, for several decades, of scientists, engineers, entrepreneurs and activists trying to bring photovoltaics — the generation of electric power directly from sunlight — into the economic mainstream. That goal may finally be in sight, and UC Santa Barbara researchers are working to bring it even closer.

Their most recent breakthrough, announced in July 2007 in the journal Science, was the development of tandem organic solar cells that convert more than 6% of the energy from sunlight into electricity. This conversion ratio is well below that of the most efficient silicon cells, which can capture about 25% of light energy. But it’s a big advance for organic cells, whose earlier efficiency topped out at about 5%. More important, the Science paper introduced a new architecture for the multi-layer tandem cell, an advance that will lead to higher conversion efficiencies in the future.
At UC Santa Barbara, the nucleus of the photovoltaic effort is the Center for Polymers and Organic Solids (CPOS), where research groups of Nobel laureate Alan J. Heeger, Kwanghee Lee, Guillermo Bazan and other scientists are developing solar cells that can be painted, printed, mass-produced like photographic film or even woven into clothing. Technically speaking, they are bulk heterojunction cells based on phase-separated blends of polymer semiconductors and globe-shaped carbon structures called fullerenes. In simpler terms, they are power-generating plastic. Heeger says Lee’s work at CPOS “has resulted in the creation of a new architecture for our solar cells that yields the best performance obtained to date—a truly important step forward. This new architecture for the multi-layer tandem cell will lead to higher conversion efficiencies in the future.”

Paintable Photovoltaics

Unlike the familiar rigid silicon cells that provide power for spacecraft and calculators, the plastic cells are thin, flexible films. Heeger says they can be applied like paint and literally printed like ink, using “standard printing tools.” Though they currently lag behind silicon in raw efficiency—the percentage of light converted to electricity—they are potentially much cheaper than silicon to produce and install.

The development of plastic photovoltaics is a “worldwide effort,” says Heeger, a professor of physics and materials who shared the 2000 Nobel Prize in chemistry for discovering polymers that conduct electricity. (He is also chief scientist and co-founder of a company, Konarka Technologies, working to commercialize the new solar-cell technology as “Power Plastic.”) The new tandem solar cells were developed by Lee and Heeger along with Jin Young Kim at Gwangju Institute of Science and Technology in Korea and Nelson Coates, Daniel Moses, Thuc-Quyen Nguyen and Mark Dante of CPOS.

The cells’ leap in efficiency comes from the use of two layers of photovoltaic material that are sensitive to different parts of the spectrum. Together, they absorb light (and energy) from a wider range of wavelengths than a single cell would. They are connected by a transparent layer of titanium oxide that serves as a conductor, collecting the electron flow generated by each of the cells.

In another approach to the problem of squeezing more electricity out of plastic, CPOS scientists
have also seen good results from tweaking the solution that is used to coat films with photovoltaic materials. Recently they found that adding the chemical octanedithiol to the solvent toluene significantly raises the solar cell conversion efficiency. The discovery was due mostly to luck. Bazan, a professor of materials and chemistry and (along with Heeger) co-director of CPOS, says it came about when researchers were trying to incorporate gold nanoparticles into solar cells (as a way of amplifying light) and used the alkyl thiols to keep the gold from clumping. They realized that the process worked well without the gold?though Bazan says they’re not sure why. ?Somehow, if you have [alkane dithiol] in solution, it allows the system to self-organize in a way that gives very good absorption of light, charge generation and charge collection,? he says.

The researchers are now trying to figure out just what makes this additive work, so that the process might be refined and improved further. ?We?ve made the most efficient solar cells in the world,? says Bazan, ?but this has opened up scientific issues.?

Herding Electrons

To get a clearer picture of how scientists are trying to raise the efficiency of plastic photovoltaics to a cost-effective level, it’s helpful to look at just how photovoltaics work.

Solar cells produce electricity by transferring energy from photons to electrons in a semiconductor, such as silicon or (in plastic photovoltaics) a semiconducting organic polymer. In organic cells, the energized, negatively charged electrons jump from the light-absorbing polymer to another material. The polymer is left positively charged or, in physics terminology, ?bearing a hole.? The resulting current is picked up by electrodes.

In conventional silicon solar cells, the current is produced at the junction between two layers of silicon that are ?doped? with chemicals such as boron, arsenic or phosphorus to produce dissimilar charges (hence the term ?heterojunction?). These charges are what pull electrons from one layer to the other. In a plastic solar cell, the polymers that absorb the photon energy and the fullerenes that attract the energized electrons are not separated into smooth layers but are melded together ? it’s a ?bulk? rather than ?bi-layer? heterojunction. (The term ?fullerene? is a tribute to R. Buckminster Fuller, the visionary architect who popularized the geodesic dome. Carbon atoms in fullerenes are arranged in geodesic patterns ? another name for these structures is ?buckyballs.?)

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UCSB's researchers have been able to develop solar cells that absorb photons from more of the sun's wavelength spectrum than did previous cells, creating the most efficient solar cells in the world.

The challenge in plastic photovoltaics, says Bazan, is to get the electrons and holes moving toward the electrodes so that they can produce useful electricity. The structure of organic polymer solar cells makes this more complicated than in common silicon models. The fullerenes and polymers must be packed together to move charges between them, since electron and hole transport are less efficient in these materials than in silicon. At the same time, it's difficult to keep the electrons from breaking ranks and popping into the nearest holes. It is a race to the electrodes before electron and holes recombine and turn the original energy of the photon into heat.

Grid Parity in 2015?
The crucial goal in the development of solar power is to reach grid parity, the point at which price of electricity from solar cells is no more than that of power from the local utility and its conventional sources. The federal government in its Solar America Initiative has set a target of grid parity by 2015. Many factors could affect that timetable, and some (like the price of oil,
coal, natural gas and power generation) are beyond the control of solar-energy scientists. But researchers can improve solar power's chances by continuing to whittle down its per-watt price. Increasing cell efficiency is part of this effort. So is lowering the manufacturing and installation costs of cells, along with cutting replacement cost by making cells more durable.

Efficiency numbers and other details of solar-cell technology are a distant concern to most potential customers, who really just want to know if they can buy this ultimate in renewable energy at a price they can afford. On that score, the mission of researchers is to enable most consumers to get a solar experience now available only to solar aficionados who are willing to pay the higher cost today as an investment in the future.

Heeger has a photovoltaic system installed at his home, and he knows first-hand that today's solar systems work very well. ?Silicon solar cells are wonderful technology,? he says. ?When the sun comes up, my electric meter runs backwards.? But this energy isn?t cheap. Heeger says, ?It will take too long ? eight to 10 years ? to recoup that capital outlay. We really need something that is low-cost and generates over large areas.? Step by step, that vision of mass-market solar power is coming closer to reality as UCSB scientists come up with new designs and new concoctions to boost the power of plastic.