BY PETER FAIRLEY

solar on cheap

ONE OF THE CLEANEST ENERGY SOURCES AROUND IS GETTING CHEAPER. THANKS TO NEW MATERIALS, SOLAR CELLS COULD SOON BE UBIQUITOUS.

During his Nobel Lecture at Stockholm University in Sweden, Alan Heeger pulled out a personal digital assistant and held it up so the crowd could marvel at its brilliant display screen. Heeger shared the 2000 Nobel Prize in chemistry for the materials that made this screen possible: electrically conductive plastics. What he didn't hold up, though, was an application of those same new materials that could have a far greater impact. Instead of conducting electricity and emitting light, as they do in flat-panel displays, these same plastics can be made to run the reverse process, absorbing light and producing electricity. If they work, they could fulfill the dream of many energy researchers: inexpensive solar cells.

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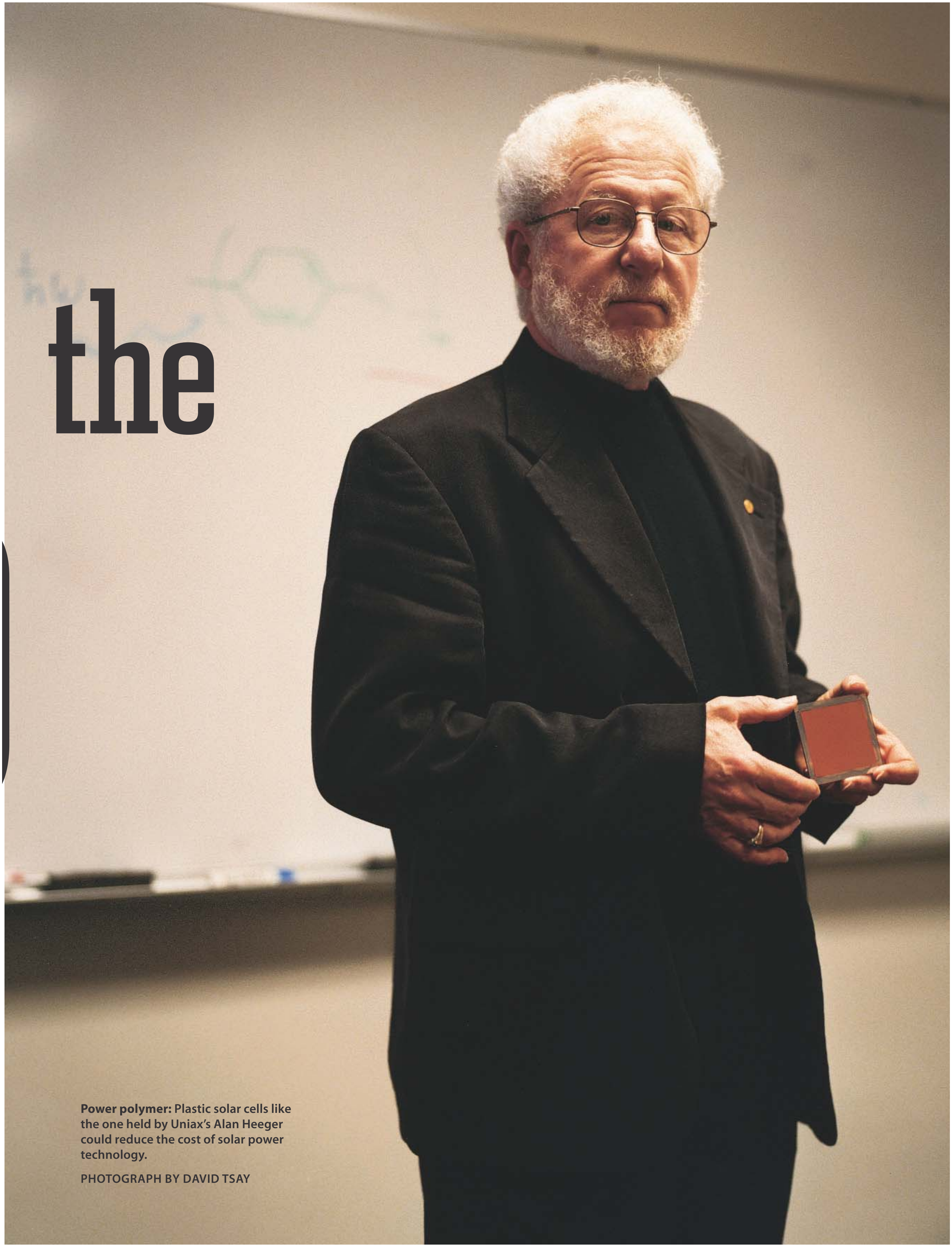

Power polymer: Plastic solar cells like the one held by Uniax's Alan Heeger could reduce the cost of solar power technology.

PHOTOGRAPH BY DAVID TSAY

Rooftop laborers: Cheap thin-film solar panels from Energy Photovoltaics are already generating power in California homes.

PHOTOGRAPH BY ANGELA WYANT

Such materials could change the face of solar power because plastic is cheap, and cheap would be a rather novel and welcome way to describe solar technology. The advantages of solar power are obvious: every minute, the sun pounds the surface of the earth with more energy than the entire world consumes in a year—a potential source of virtually unlimited, clean and free electricity. But until recently the high cost of the materials used in solar cells has relegated the technology to powering satellites, high-tech backwoods cabins and communications towers beyond the reach of power lines. Solar cells made from materials like electrically conductive plastics could finally make solar power affordable for far broader uses. Moreover, says Heeger, the chemistry behind these plastics is rather simple, so they could be fairly easy—and cheap—to manufacture.

Conventional solar cells cost so much because most are made from the same relatively expensive silicon semiconductors used in computer microchips. Recently, manufacturers have found ways of making solar cells using ultrathin films of silicon; consequently, solar power is getting cheaper and consumption is increasing. More than 200,000 homes in the United States now derive at least some of their power from solar cells; the technology is already paying its way in places like California, where energy is expensive and governments are willing to subsidize solar power to make it competitive with fossil fuels.

But switching to thin-film silicon may not bring about the drastic cost reductions solar cells need to effectively compete with coal-, oil- and natural-gas-generated electricity across the globe. Despite nearly quadrupling in sales over the last five years, solar still accounts for only .04 percent of worldwide power generation. What is needed to accelerate the penetration of solar power is even cheaper materials. And an increasing number of companies are looking to electrically conductive plastics and other novel organic materials as the solution.

Researchers developing these new-age materials for solar cells are sensitive to failed promises about solar power and caution that organic solar cells could be a decade or more from the market. At the same time, they are clearly excited about recent advances in the materials which, if sustained, could deliver the performance and affordability that will render solar power ubiquitous. "If the performance of organic solar cells was as good as conventional ones, it would be pretty darn interesting," says Princeton University electronics expert Steven Forrest. "That could be a huge market."

THINK THIN

Solar cells, technically referred to as photovoltaics, take advantage of the same electronic properties that make semiconductors so vital to the computer industry. When sunlight strikes the surface of a semiconductor, the photons transfer their energy to electrons in the material; in a working solar cell that energy is captured and put to use. A sheet of semiconductor material lies sandwiched between two layers of electrode material. A built-in electric field draws the excited electrons to the top electrode, which carries them out of the cell and into a circuit. The bottom electrode gathers electrons from the circuit to fill the "holes" that the excited electrons left behind. The bottom line is that the semiconductors transform sunlight into usable electricity.

But most of the solar panels sold today employ crystals of silicon that are expensive to manufacture. Silicon crystals may justify their cost in microprocessors, but they price solar power out of a market dominated by cheap fossil fuels. "If you want to compare purely on a dollar per watt basis, solar power is three to four times more expensive right now," says Atul Arya, chief operating officer with Linthicum, MD-based BP Solar, a subsidiary of the large oil company and one of the world's top producers of silicon solar cells.

Increasingly, the search for low-cost technology is leading BP Solar and other solar-cell manufacturers to abandon silicon crystals altogether. In its place, these firms and half a dozen startups are developing photovoltaics employing cheap amorphous silicon, and even semiconductor alloys, that can be quickly spread into a thin film just a few thousandths of a millimeter thick—about a hundred times thinner than the silicon crystals used in conventional solar cells. Because these thinner solar cells require less semiconductor material and are amenable to mass production, they are significantly cheaper. And while these types of semiconductors lack the electron-shuttling efficiency of silicon crystals, they compensate by absorbing more photons than silicon crystals.

Ken Zweibel, who leads thin-film development at the Golden, CO-based National Renewable Energy Laboratory complex where many of the technology advances are being made, predicts that thin films will deliver highly efficient solar cells at one-quarter to one-fifth the cost of today's cells. Cheap, thin films of amorphous silicon or alloy that can capture as much as 20 percent of the sun's energy (researchers can now make films in the lab with 18 percent efficiency) could make solar cells practical for homeowners, not just in sunny California, where clogged power lines deliver the country's most expensive electricity, but in Boston, Chattanooga and Tampa Bay.

The low cost and inherent flexibility of these thin solar cells also means they can be easily applied as coatings on a range of materials, including glass and roofing tiles. To demonstrate this aspect of the technology, BP has installed translucent awnings embedded with thin-film photovoltaics at 250 of its gas stations around the world, keeping customers dry while powering the pumps. "It becomes a window pane, or it could be a shading application, or it could be a skylight application. We are doing all of those," says BP's Arya.

Despite such promise, however, it could take decades for thin films to transform solar power from a marginalized technology to a mainstream source of energy. Steady growth at today's impressive rates, doubling the market every three years, will only bring the industry to 10 percent of peak power generation in 2030, according to a U.S. solar-power industry road map issued last year. What is needed to accelerate the penetration of solar power is photovoltaic materials that are really cheap—cheap as plastics.

POWER PICTURES

Carbon-based materials such as Heeger's polymers could steal markets away from conventional semiconductors because they can be applied in even thinner layers and, in theory at least, could lead to simpler and less expensive manufacturing processes. For example, they can be dissolved to produce a photovoltaic ink, which an ink-jet printer could squirt in a thin film on a variety of surfaces.

The underlying technology has been around for years: researchers at Eastman Kodak created the first organic solar cells during the energy crisis of the 1970s. Kodak was already churning out vast quantities of photographic film containing light-absorbing organic dyes and figured it could adapt those dyes to capture energy instead of images. The project fell to Ching Tang, a physicist fresh out of graduate school. Tang struggled for four years and nearly gave up before a breakthrough in 1979, when he borrowed a set of organic pigments developed for other purposes by Kodak's chemists and layered them to mimic the arrangement of electron-shuttling semiconductors in conventional photovoltaics. While these first organic solar cells could convert only one percent of the sun's energy into electricity, they showed promise for improvement.

But Tang kept his success quiet until 1987, because Kodak was close to developing other commercial uses for the proprietary pigments and forbade him from publishing his results. By the time he did, the energy crisis had passed and

Playing the Sun

A sampling of companies developing new thin-film and organic solar cells

COMPANY	LOCATION	TECHNOLOGY	MATERIALS
BP Solar	Linthicum, MD	Thin film	Amorphous silicon, cadmium telluride
Energy Photovoltaics	Princeton, NJ	Thin film	Amorphous silicon, copper indium gallium diselenide
Siemens Solar	Munich, Germany	Thin film	Copper indium diselenide
Cambridge Display Technologies	Cambridge, England	Organic	Pigments and organic liquid crystals
DuPont Displays' Uniax	Santa Barbara, CA	Organic	Polymers
Global Photonic Energy	Ewing, NJ	Organic	Pigments and fullerenes
Quantum Solar Energy Linz	Linz, Austria	Organic	Polymers and fullerenes

Kodak was onto a seemingly more enticing opportunity: using Tang's layered structure to turn similar pigments into organic light-emitting diodes for flat-panel computer displays *(see "A Bright Future for Displays,"* TR *April 2001)*. For over a decade, Kodak and its competitors nurtured this technology, which is now poised to take a piece of the $25 billion-per-year flat-panel market, while organic solar cells were forgotten.

With yet another energy crisis looming, however, organic solar cells are enjoying a renaissance. After two decades stuck at Tang's one percent power output, researchers are succeeding in pushing the boundaries of organic solar cells' performance, and investment in the field is soaring. Recently, research groups produced solar cells that can convert two to 4.5 percent of the energy in sunlight to electricity. They are bullish about matching the power of the low-end thin-film photovoltaics in as little as three years. "We're creeping up on amorphous silicon and there's no reason to believe that we couldn't do as well as crystalline silicon," says Princeton's Forrest.

Uniax, a company cofounded by Alan Heeger and acquired by DuPont two years ago, is taking a somewhat different tack, developing solar cells using polymer blends. And rather than immediately adapting the polymers to make solar cells for powering entire homes, Uniax is first testing the materials as photodetectors in imaging devices like scanners and digital video cameras. Photodetectors consist of arrays of millions of tiny solar cells; the cells reconstruct images by creating electrical currents proportional to the intensity of light shining on them. Each cell represents one pixel of information. Heeger says Uniax has already developed polymer-based photodetectors that rival the sensitivity of commercial photodetectors, which employ standard semiconductors. And unlike conventional devices, plastic photodetectors can be built to larger scales, say for flexible sensors that capture images from sheets of paper without scanning, or still larger detectors for rapid medical imaging.

Manufacturing the plastic solar cells could be relatively quick and easy. Heeger envisions using ink-jet printers to spray a series of films on a surface—the organic semiconductors, electrodes and protective coatings—to fashion a photodetector. And fabricating large devices for power generation could be even simpler, since the light-absorbing films do not need to be divided into pixels. "Making large areas of a thin film from these organic semiconductors in solution is straightforward. That's why it's attractive," says Heeger.

First-generation organic solar cells could begin to enter the market in the next five to 10 years through applications like Heeger's photodetectors, or alternatively through ultra-low-margin products such as solar-powered musical cards and other disposable electronics. Then they could tackle small electronic devices, such as solar-powered calculators and toys.

But to ready organic solar cells for the rooftop, developers must overcome the material's ultimate weakness: its fragility. The light-sensitive organic molecules under development for use in photovoltaics break down when exposed to oxygen. Will they ever be ready to bake under the sun day in, day out for several decades and still generate electricity? Kodak's Tang says the question reminds him of his own early doubts about organic light-emitting diodes. He says he wondered 15 years ago why anyone would bother trying to make a device out of this highly unstable material. Today he marvels at the colorful organic displays entering the market.

What Tang couldn't see 15 years ago was that solar cells could be encapsulated with a polymer similar to Teflon that is all but impervious to the elements and provides a hermetic seal for the fragile organics. Encapsulated organic solar cells could already provide the several thousand hours of working life required of a solar-powered calculator or digital video camera, and the materials' utility could be extended to the hundreds of thousands of working hours required for providing buildings with electrical power.

Kodak is no longer pursuing the idea of organic solar cells, but Tang dreams of returning to research that could help make them a reality. While beautiful displays may be more lucrative in the short term, Tang says the challenge of replacing fossil fuels is more pressing. "People can do without television," says Tang, "but you cannot do without energy." TR

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Basking in the sun: Zoltan Kiss of Energy Photovoltaics showcases his company's latest solar panels made of thin-film silicon solar cells.

PHOTOGRAPH BY KYOKO HAMADA