Skip the hard cell: Flexible solar power is on its way

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ELECTRICITY from sunlight: bright hope for the future, or false dawn? Solar power has its share of detractors who'd go for the latter. Photovoltaic cells are too expensive, they say, requiring huge amounts of material and energy to make. And they are inefficient, too, converting at best about 20 per cent of the incoming solar radiation into usable power.

Solar technology that's ahead of the curve (Image: Darren Stevenson and John Rogers)

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So, the sceptics say, solar cells are only ever likely to be a small, disproportionately expensive part of our future energy mix. In the temperate, oft-cloudy climes of much of Europe and North America, satisfying the population's electricity needs with photovoltaics alone would mean plastering something like 5 to 15 per cent of the land surface with them.

Such criticisms might be tempered by a new generation of solar cells about to flop off the production line. Slim, bendy and versatile, they consume just a fraction of the materials - and costs - of a traditional photovoltaic device. They could be just the fillip solar power needs, opening the way to a host of new applications: solar-charged cellphones and laptops, say, or slimline generators that sit almost invisibly on a building's curved surfaces or even its windows.

Photovoltaic cells have traditionally presented renewable-energy enthusiasts with an unenviable choice. If low cost and flexibility are the watchwords, inefficiency is the price to pay: the best flexible solar cells, made from thin films of amorphous silicon or organic polymers, convert barely 10 per cent of solar radiation into power. That makes them unsuitable for all but low-power gizmos such as solar cells for backpacks. For higher efficiency, you need crystalline silicon, which absorbs light less readily than its amorphous cousin, but does so over a much broader range of wavelengths. Making a solar cell that is 20 per cent efficient takes thick, expensive slabs of the stuff, as seen in today's rooftop solar cells.

Conventional solar cells force an unenviable choice on renewables enthusiasts: flexibility or efficiency

Marrying efficiency with low cost requires thinking outside the box, or at least outside the plane. Traditionally, solar cells consist of a single flat layer of a light-absorbing semiconductor. An alternative currently being explored is to replace this layer with a film of vertically grown nanoscale semiconductor wires (*Nano Research*, vol 2, p 829). Light gets trapped in this forest of nanotrees, bouncing between the individual nanowire trunks (see diagram). "That optimises light absorption," says Ali Javey, who is pioneering these new materials at the University of California, Berkeley.

Absorption alone is not enough: the light must be converted into charge carriers such as electrons, to be extracted from the wires and fed into a power grid. Here, the internal crystal structure of the nanowires is crucial. Any imperfections form "potholes" into which electrons fall, impeding their movement and limiting the cell's overall efficiency. The silicon of normal solar cells is particularly prone to imperfections, so Javey and his colleagues have been experimenting with an alternative semiconductor, cadmium telluride. The resulting cells are economical in their use of material, but, much like amorphous silicon cells, convert only about 6 per cent of the solar radiation into usable power.

That low conversion is partly due to a weak point in the vertical design: the tips of the wires cover only a few per cent of the cell's sun-facing surface, so much of the light hitting the cell passes through unabsorbed. In February this year, Harry Atwater and his colleagues at the California Institute of Technology in Pasadena reported a solution to this problem. They used microscale silicon rods slightly thicker than Javey's nanowires, and poured a polymer containing light-reflecting nanoparticles into the spaces between them. The polymer scatters unabsorbed light back onto the rods and this, combined with a silver reflecting layer at the bottom of the device, allows the cells to absorb up to 85 per cent of incoming light. Still, losses - chiefly from imperfections in the crystal structure of the microrods - drive the overall efficiency below the 20 per cent achieved by the best crystalline silicon cells (*Nature Materials*, vol 9, p 239).

So why the fuss, if these devices are no more efficient than what went before? The key is that although these cells are merely as efficient as conventional devices, they use only about a hundredth of the material. What's more, they are highly flexible: grown on a bed of silicon, Atwater's microrod arrays can simply be peeled off and stuck pretty much wherever you want. "They could even be integrated into buildings, as components that match the shape of roof tiles," says Atwater. He has started up a company, Alta Devices, to do just that, and has recently received research funding from the US Department of Energy.

John Rogers and his colleagues at the University of Illinois at Urbana-Champaign are at a similar stage. They make solar cells by using a rubber stamp to pick up a conventional cell structure etched onto a silicon substrate and imprint it onto a flexible polymer surface (*Nature Materials*, vol 7, p 907). The efficiency of the resulting cells is a respectable 12 per cent, although Rogers thinks they can do markedly better with tweaks such as adding fluorescent molecules to capture the light coming through the sides of the device. His cells also have a unique selling point: by spacing cell features more widely on the polymer substrate, the cells can be made virtually transparent. That makes power-generating windows a distinct possibility.

Rogers, too, has set up a company, Semprius, to commercialise his technology, and has installed about a dozen modules for power-generation companies across the world to test their long-term performance. Another target in the works is vehicle-top cells that generate electricity for music systems, GPS or even air conditioning - lending a whole new meaning to the word "sunroof". The US Department of Defense is also supplying funds for Rogers' work, with a view to equipping special operations troops with lightweight, efficient solar cells.

Other teams are exploiting the bumper light-harvest that comes when solar cells are sprinkled with a little stardust. This takes the form of gold or silver nanoparticles that quiver with electronic resonances known as plasmons when light hits them, focusing it onto the absorbing semiconductor film (*Nature Materials*, vol 9, p 205).

Plasmonic nanostructures can also be designed to bend the incoming light so that it travels along the surface of a device, rather than through it. A slimline layer of silicon 100 nanometres deep can then attain a light-harvesting efficiency usually only achieved with cells several thousand times as thick. "Absorption in 100 nanometres of silicon is negligible, but if you turn the light by 90 degrees then it is a different story altogether," says Albert Polman at the Institute for Atomic and Molecular Physics in Amsterdam, the Netherlands, who designs such cells.

Material wants

Since the first modern photovoltaic cell was demonstrated in 1954, solar-cell efficiency has been increased mainly by slowly improving the purity of the materials used - a strategy with inevitably diminishing returns. Alternative materials often contain scarce elements such as tellurium, indium and selenium, so any technology that reduces the amount of material needed to harvest the sun's power has an obvious appeal. Driving costs down also makes the technology more accessible to developing economies, many of which boast abundant sunlight but limited cash.

It is crunch time for these new technologies as they start to be implemented in real-world applications. Taking small-scale designs up to the realm of square metres is not trivial, and big breakthroughs in solar power have been heralded before. Yet with their winning combination of economy, efficiency and flexibility, this latest generation of solar cells might allow proponents of solar technology to silence its critics at last.

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