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Bright prospects

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Energy: Solar power is in the ascendant. But despite its rapid growth it will not provide a significant share of the world's electricity for decades

LAST year Microsoft outfitted its campus in Silicon Valley with a solar system from SunPower, a local company that makes high-efficiency (and, some say, the world's best-looking) solar panels. A few months later Microsoft's arch-rival, Google, began building something on an even grander scale—one of the largest corporate solar installations to date. But all of this may yet be topped by Wal-Mart. In December the retail giant solicited bids for placing solar systems on the roofs of many of its supermarkets. Besides producing favourable publicity, the appeal of using solar power is obvious. Unlike fossil fuels, which produce significant amounts of pollution and enormous amounts of greenhouse gases, the sun's energy is clean and its supply virtually limitless. In just one hour the Earth receives more energy from the sun than human beings consume during an entire year. According to America's Department of Energy, solar panels could, if placed on about 0.5% of the country's mainland landmass, provide for all of its current electricity needs.

Yet since they were first invented more than five decades ago, photovoltaic solar cells—devices made of semiconductor materials that convert light into electricity—have generated much publicity but little energy. In 2006 photovoltaic systems produced 0.04% of the world's electricity, according to the International Energy Agency. The thing that has held back the widespread deployment of solar panels is their price. Sunshine is free, but converting it into electricity is not. At present, solar power is at least two to three times as expensive as the typical electricity generated in America for retail customers. (Because homeowners and businesses generally use solar power in place of electricity bought from utilities, the relevant comparison is with the price of retail electricity, not the lower wholesale prices from power plants.)

Even so, many people believe the prospects for solar energy have never looked brighter. Decades of research have improved the efficiency of silicon-based solar cells from 6% to an average of 15% today, whereas improvements in manufacturing have reduced the price of modules from about $200 per watt in the 1950s to $2.70 in 2004. Within three to eight years, many in the industry expect the price of solar power to be cost-competitive with electricity from the grid.

In the meantime, some European countries and parts of America have instituted subsidies to support the adoption of solar power. California's “Million Solar Roofs” initiative, for example, will hand out about $3 billion in rebates and other incentives over a decade to encourage the installation of solar panels. In Europe Germany offers producers of solar power generous feed-in tariffs, which have made it the largest market for photovoltaics in the world. As a result of such incentives, the market for solar power has grown by about 40% a year for the past five years, reaching about $11 billion in 2005. In a matter of a few years, solar power has become a big business.

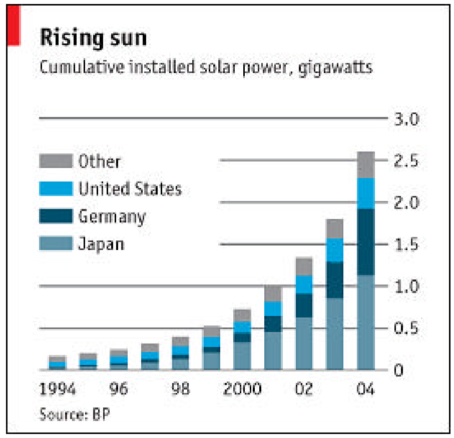
This development has not gone unnoticed by America's venture capitalists, who have embarked on a spending spree. Cleantech Venture Network, an umbrella organisation based in Ann Arbor, Michigan, says VCs invested $2.9 billion in North American clean-technology start-ups in 2006—78% more than in 2005 and 140% up from 2004. Solar power is one of the fastest-growing areas: investments have risen from $59m in 2004 to $308m in 2006, says Nicholas Parker, chairman of the group.

The main beneficiaries of this windfall are start-ups, such as Nanosolar and Miasolé, which are based in Silicon Valley and focus on new technologies. Both firms are betting on "thin film" solar cells, which can be made with vastly less semiconductor material than traditional silicon-based devices. They also intend to employ new, continuous manufacturing processes that promise to reduce the cost of solar panels very quickly in future.

Dawn of a new technology

Humans have always depended on energy from the sun, though it was exploited mostly indirectly for thousands of years. The photoelectric effect was not discovered until 1839, when Alexandre Becquerel, a French physicist, observed that light could generate an electric current between two metal electrodes immersed in a conductive liquid. About 40 years later Charles Fritts, an American inventor, built the first solar cell. Made with selenium and a thin layer of gold, the device was less than 1% efficient.

At the birthplace of the transistor, the now legendary Bell Laboratories, a team of scientists invented the first practical solar cell in 1954. The core of the invention was a semiconductor device made of thin strips of crystalline silicon that boasted a conversion efficiency of 6%. During one of the first public demonstrations of the "Bell Solar Battery" the device powered a small radio transmitter, carrying both speech and music.

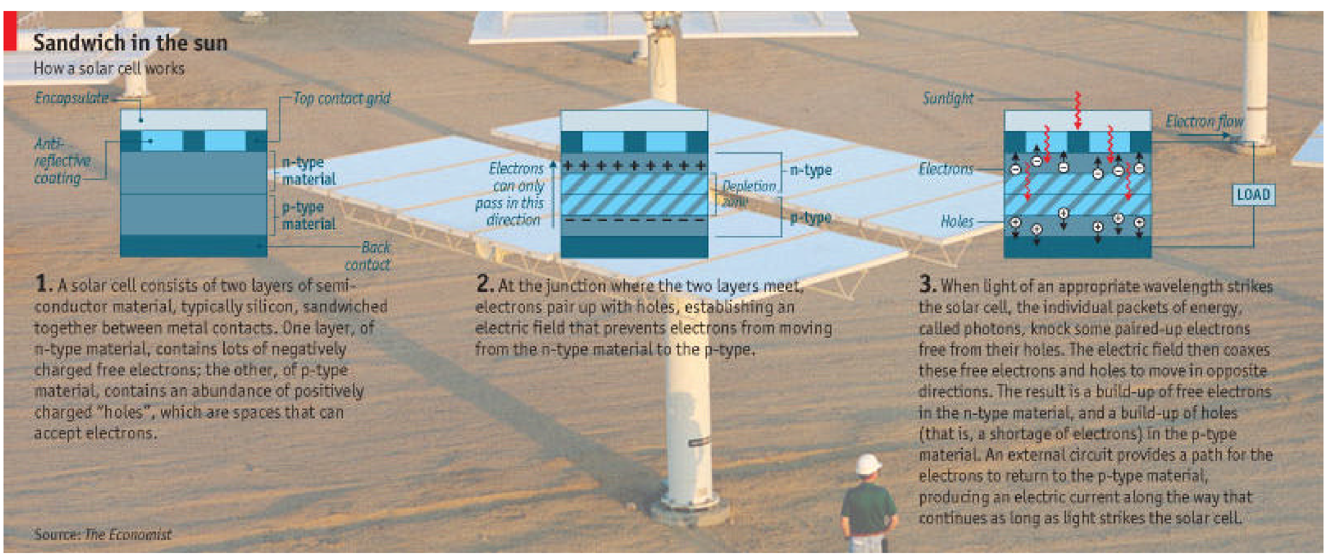


Since then, the basic structure of a solar cell has changed little. It is composed of two layers of semiconductor material, typically silicon, that are sandwiched together between metal contacts. One layer, of n-type material, contains lots of negatively charged free electrons; the other, of p-type material, contains an abundance of positively charged "holes", which are spaces that can accept electrons. At the junction where the two layers meet, electrons pair up with holes, establishing an electric field that prevents electrons from moving from the n-type material to the p-type. When light of an appropriate wavelength strikes the solar cell, the individual packets of energy, called photons, knock some paired-up electrons free from their holes. The electric field then coaxes these free electrons and holes to move in opposite directions. The result is a build-up of free electrons in the n-type material, and a build-up of holes (that is, a shortage of electrons) in the p-type material. An external circuit provides a path for the electrons to return to the p-type material, producing an electric current along the way that continues as long as light strikes the solar cell.

The development of the first efficient photovoltaic cells at Bell Labs made headlines. The *New York Times* hailed the invention as "the beginning of a new era" and *US News & World Report* suggested that solar cells "may provide more power than all the world's coal, oil and uranium." But although the "solar battery" received lots of publicity, the high cost—about $200 per watt—made commercialisation unfeasible.

Fortunately, a few years later both America and the Soviet Union became interested in using solar power in space, where its advantages became apparent very quickly. In 1957 the Soviet Union launched *Sputnik I*, the first artificial satellite. But it stopped transmitting data after only a few weeks because its batteries ran out. In 1958 America fired the first solar-powered satellite into orbit. The batteries of *Vanguard I* also ran out after several weeks, but its solar panels powered the on-board transmitter for years to come.

AFP

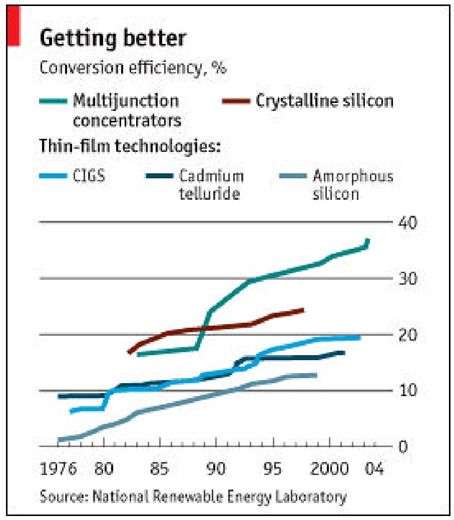


The ensuing competition between America and the Soviet Union funnelled billions of dollars into the development of space technologies, and that included solar cells. Besides efficiency, durability and reliability, the most important requirement for solar cells was how much power they could generate per unit of weight. Cost considerations, at that time, were far less important. Solar cells back then were made much like jewellery, recalls Bill Yerkes, an industry veteran who is now the chief technologist at Solaicx, a start-up dedicated to reducing the price of silicon wafers for the solar industry.

The man who helped bring solar power down to earth was Elliot Berman. He realised that for photovoltaics to succeed in terrestrial applications, reducing their cost was vital. At his company, Solar Power Corporation, he pioneered a number of manufacturing changes. Among other things, he decided to buy cheap silicon wafers that had been cast aside by the semiconductor industry. The wafers he bought were also larger in size, which made it possible to increase the diameter of the individual cells, which in turn reduced the number of cells needed to make a module. As a result he was able to produce far less expensive solar panels, reducing the selling price from $100 per watt in 1970 to $20 per watt in 1973.

The first terrestrial solar cells were used for off-grid applications in remote locations where placing conventional power lines was not possible or economical. Among the earliest buyers of solar panels were gas and oil companies, which began to use solar power in the mid-1970s to protect wellheads and underground pipelines from corrosion and to power navigational aids on offshore oil rigs. In the 1980s America's Coast Guard began using solar panels to supply electricity to buoys. By the early 1990s solar cells powered hundreds of diverse off-grid applications including telecoms equipment, emergency roadside phone boxes, and consumer devices such as calculators and watches.

Although solar cells had now penetrated numerous niche markets, the cost of making them still priced them out of the market for grid-connected electricity. That changed in 1994, when Japan began a subsidy programme. By the time the subsidies were phased out in 2005, the programme had achieved its goal. In Japan, where electricity is expensive, solar power is now fully cost-competitive with power from the grid, says Paul Maycock of PV Energy Systems, a consultancy based in Virginia.



Over the years the solar industry has been able continuously to reduce the cost of silicon-based solar panels. For every doubling in cumulative production volume, the cost of modules has declined by about 20%. That translates to an annual reduction in manufacturing costs of about 5%. A variety of factors has contributed to this, including making the wafers thinner, increasing the efficiency of the cells, and taking advantage of economies of scale by building bigger and more automated factories.

Fifty-three years after their invention, silicon-based solar cells still make up more than 90% of the market. In 2008 the solar industry is even expected to surpass chipmaking in its appetite for silicon feedstock. The extent of the demand has caused a global silicon shortage, limiting sales growth for the solar industry to less than 20% in 2006, says Jesse Pichel, an analyst at Piper Jaffray. As prices for silicon have gone up, so have prices of solar modules. After decades of steady decline, prices increased from a low of $2.70 per watt in 2004 to about $4 per watt in the spring of 2006.

That has increased the opportunity for "thin film" solar cells, which use little or no silicon. Because thin-film cells are very efficient at absorbing photons, they require less than 1% of the semiconductor material needed by their conventional counterparts. At the moment, about 40% of the cost of a conventional module goes on silicon. "If you're making a thin-film module, much of that cost will go away," says John Benner, a group manager at the National Centre for Photovoltaics, a division of America's National Renewable Energy Laboratory. Thin-film technology also offers the potential for faster manufacturing processes and higher levels of automation, which cut costs.

For those reasons, people have wanted to move towards thin-film cells for a long time. But cadmium sulphide, an early thin-film technology that was pursued in the 1960s and 1970s in many research laboratories, did not live up to expectations. In the 1980s most scientists finally abandoned the material, since they were unable to make it stable. Even in newer thin-film technologies, high-volume production has been difficult.

Cells based on amorphous silicon, for example, have been in development for several decades. Unlike the silicon in conventional solar cells, which is arranged using expensive manufacturing processes into a uniform crystalline structure, amorphous silicon is highly disordered and can therefore be made more cheaply. But its efficiency tends to degrade when exposed to sunlight. That problem, however, has now been largely eliminated, says Terence Parker of United Solar Ovonic, one of the firms making amorphous-silicon cells. Its triple-junction solar cells, which can absorb light of different wavelengths, are so popular that the firm has become one of the largest thin-film manufacturers in the world.

Another promising thin-film outfit is First Solar, based in Arizona. Besides completing a successful stockmarket flotation last November, in which it raised $400m, it is the first company to produce large quantities of cadmium telluride-based solar panels. Although the efficiency of the modules is only 9%—far less than the 13% of an average crystalline-silicon module—the manufacturing cost is also much lower, and works out at about $1.40 per watt. That is about a dollar cheaper than conventional silicon-based modules, and has led to strong demand for the company's panels.

But the lower efficiency of thin films means they need more space: more efficient cells can squeeze more electricity out of a given area. “There is an additional cost at the systems level if the module efficiency is lower,” acknowledges First Solar's boss, Michael Ahearn. His company focuses on ground-based and large commercial systems, which are cheaper and easier to install than residential roof-based systems.

A competing thin-film technology is CIGS, which is short for copper indium gallium diselenide. The current efficiency record for this technology is 19.5%, which is why many start-ups, such as Nanosolar and Miasolé, are pursuing it. CIGS promises to combine low cost with efficiencies comparable to silicon, says Mr Benner.

But producing CIGS-based solar modules is not easy. They are composed of four different materials, which must be uniformly deposited on a backing material, or substrate. This is relatively easy when covering a small area, but it is difficult to maintain the uniformity, and thus the efficiency, of the cells over large areas. Nanosolar, which has raised $100m—more funding than any other solar start-up—believes it has found a cheap and effective solution to the problem. It mixes small precursor particles of the different materials to create a “nanoparticle ink” that is continuously coated onto metal foil and then heated so that the particles assemble correctly.

Miasolé, which is backed by Kleiner Perkins, a big Silicon Valley venture-capital firm, is also developing CIGS-based solar cells. Its approach is to deposit the CIGS layer using a sputtering process borrowed from the disk-storage industry. David Pearce, Miasolé's boss, says the firm is also developing flexible encapsulants for its solar cells, which will make it easier to integrate them into roofing materials and produce custom modules of arbitrary sizes. “It could literally be like roll-out carpet,” he says.

Others are taking yet another approach. By using lenses and mirrors to concentrate sunlight onto high-efficiency solar cells, start-ups such as SolFocus, in Palo Alto, are trying to reduce the cost per watt of solar systems. SolFocus's cell technology comes from Spectrolab, a subsidiary of Boeing, which is one of the largest suppliers of solar panels for use in space. David Lillington, Spectrolab's president, says its triple-junction cells have achieved record-breaking efficiencies of over 40% under concentrated sunlight.

These approaches may be very different, but they are all pursuing the same goal—cost-competitiveness with power from the grid. America's Department of Energy aims to get there by 2015. To many in the field this is a conservative target, especially for thin films. With additional gains in cell efficiency and by optimising its manufacturing processes, First Solar hopes to get there in 2010. Nanosolar's boss, Martin Roscheisen, boasts that his company will reach grid parity this year, as soon as its panels hit the market.

Not everyone is convinced. “The introduction of any new technology is going to have all sorts of speed bumps,” says Mr Benner. The bright prospects for thin-film companies could dim in 2008, when more silicon will reach the market and the much-lamented shortage is expected to end. Some experts even foresee a glut of silicon on the horizon, so that prices for modules could fall considerably. Start-ups will have to ramp up production quickly to compete with cheaper silicon modules. “There will definitely be some shakeout, both in terms of companies and technologies,” says Joel Makower, principal of Clean Edge, a research and consulting firm based in San Francisco.

Slow sunrise

The solar industry has in the past profited from the manufacturing improvements of chipmakers, and is now finding ways to benefit from innovations in other high-tech fields. “I think of the silicon solar-cell industry as a marriage between the semiconductor industry, where it gets its base technology, and the CD industry, which is very high volume,” says Richard Swanson, SunPower's president and technology chief. Applied Materials, a leading maker of chipmaking gear, recently decided to apply its expertise in making flat-panel displays to thin-film solar panels.

But despite the growing infusion of capital, innovation and talent, solar power will provide only a tiny fraction of the world's electricity needs for the foreseeable future. Even if the industry continues to grow at the same torrid pace that it has for the past few years, it will not be able to supply more than 1% or so of the world's electricity needs for at least another decade. That may sound like a gloomy forecast, but some regard it as a huge opportunity. It means there is a lot of room for growth, says Mr Roscheisen, Nanosolar's irreverent boss. His company generated an enormous amount of buzz last year when it announced plans to build the world's largest solar factory, in California. But, says Mr Roscheisen, “a couple of years from now this factory is not going to look that big.”