Solar's Great Leap Forward

Suntech CEO Zhengrong Shi made China a powerhouse in photovoltaic technology—and became a billionaire in the process. His next ambition: to make solar power as cheap as conventional electricity.

By KEVIN BULLIS

MADE IN CHINA
Suntech has become a major supplier of solar panels worldwide, including the ones used at this massive eight-megawatt solar farm in Alamosa, CO.

BRIAN BAILEY

To see the future of solar power, take an hour-long train ride inland from Shanghai and then a horn-blaring cab trek through the smog of Wuxi, a fast-growing Chinese city of five million. After winding through an industrial park, you will arrive at the front door of Suntech Power, a company that in the few years since its founding has become the world's largest maker of crystalline-silicon solar panels.

Solar panels cover the entire front face of the sprawling eight-story headquarters. Nearly 2,600 two-meter-long panels form the largest grid-connected solar façade in the world. Together with an array of 1,800 smaller panels on the roof, it can generate a megawatt of power on a sunny day. It's expected to produce over a million kilowatt-hours of electricity in a year—enough for more than 300 people in China.

In 2001, when Suntech was founded, all the solar-panel factories in China operating at full capacity would have taken six months to build enough panels for such a massive array. Suntech's first factory, which opened in 2002, cut that time to a little more than a month. Today, the company can make that many panels in less than one 12-hour shift. By the end of this year, the workers could be done by lunchtime. Suntech's production capacity has increased from 10 megawatts a year in 2002 to well over 1,000 megawatts today. Chinese solar manufacturing as a whole has increased its capacity from two megawatts in 2001 to over 4,000 megawatts.

That rapid growth, fueled by relentless cost cutting, has allowed Chinese manufacturers to overtake those in the United States, Japan, and Germany in less than a decade to become the biggest source of solar panels in the world. Worldwide, Chinese solar panels accounted for about half of total shipments in 2009. And that share is expected to grow this year. Of the 10 largest solar-panel manufacturers, half are based in China. In 2007, U.S. manufacturers supplied 43 percent of the panels for a solar rebate program in California. The rest came almost exclusively from Japan and Germany; only 2 percent came from China. Now Chinese companies supply 42 percent of the panels, and the U.S. share has dropped to 15 percent.

In 2004, it cost about $3.20 per watt, on average, to make silicon solar panels. By now, according to solar-industry analysts at Photon Consulting in Boston, a Chinese manufacturer can make them for as little as $1.28 per watt, while the lowest-cost Western manufacturer will produce comparable technology for about $2.00 per watt. Not only has this cost advantage made Chinese manufacturers dominant in the industry, but it's also helped redefine the prospects for solar power, pushing it closer to what insiders call "grid parity"—the point where it is just as cheap as electricity on the power grid, most of which is generated with fossil fuels. "In about five years' time, we should be able to reach grid parity in at least 30 to 50 percent of the global market," says Zhengrong Shi, Suntech's founder and CEO, speaking from his spacious office looking out over the back of his company's massive solar façade.

FACE OF SOLAR A huge façade of photovoltaic panels (above) greets visitors at Suntech headquarters in Wuxi, China. Suntech's founder and CEO, Zhengrong Shi (right), poses on a deck outside his office, with the façade in the background.

CHEN GAO

Suntech's strategy so far has been to cut the cost per watt by reducing the expense of manufacturing solar panels. But reaching grid parity will also require increasing the efficiency of the panels so that each one produces more watts. Under the leadership of Shi, who was a solar researcher before he became a businessman, the company has developed a new way to make solar panels; multicrystalline modules made last year broke a 15-year-old record for efficiency in converting sunlight to electricity. A few months later, Suntech increased the efficiency mark yet again. And the company's lab has prototypes that promise even better results. If these advances pan out, it could finally clear the way for Shi's dream of affordable solar power.

RICHES AND RAGS

In many ways, Shi reflects the complexity of contemporary China. Though he was born and grew up less than 100 kilometers from his factories in Wuxi, he began his career in Australia, where he lived for a decade and became a citizen before returning to China in 2000 to take advantage of the country's economic boom. "I have to get a visa to work in China," Shi says with a hint of an Australian accent, laughing. Despite his wealth and executive position, he has the casual but confident air of a researcher, wearing a simple sports coat and open-collar striped shirt. But his relaxed look and easygoing Australian mannerisms belie his ambition and his close connections to his native country. Several copies of magazine covers featuring him as the "Sun King" (*Forbes Asia*) and "China's New King of Solar" (*Fortune*) are arranged carefully around his spacious office, amid citations from national academies and other awards. Greeting visitors in the entryway is a huge version of the Ch'an Chu, the Chinese symbol of prosperity—a stone toad gripping a coin the size of a dinner plate in its mouth.

The figure, which is also a symbol of luck, is appropriate. In 2005, when oil prices were volatile and many countries, particularly in Europe, were pushing to cut carbon dioxide emissions, Shi took Suntech public on the New York Stock Exchange. In 2006 he became the seventh-richest man in China, with a net worth of over $1.4 billion, according to *Forbes*. But the man who made Suntech possible very nearly didn't get into solar at all.

Shi's parents, rural farmers left destitute by famines that plagued China in the early 1960s, were forced to give him up for adoption to a close family friend when he was a small child. He excelled at school, ultimately earning a bachelor's degree in optical science and a master's in laser physics. Shi applied to study abroad, as many talented students did in China in the late 1980s. He was approved—not for studies in the United States, as he'd expected, but in Australia. Knowing little about the country, he relied on a suggestion from one of his colleagues that he meet Martin Green, the director of the Photovoltaics Centre of Excellence at the University of New South Wales, who was famous for inventing an approach to

silicon solar cells that achieved record efficiencies. He applied for a paid research position, but Green "immediately turned me down," Shi recalls. Instead, Green persuaded him to study for a PhD. He completed the degree in only two and half years, and in 1995 he started work at Pacific Solar, a startup spun out of Green's lab that was commercializing a new type of thin-film solar cell.

By 2000, Shi was executive director of the startup, but news about the solar industry's growth in Europe and Japan made him impatient. "I saw the opportunity of solar booming," he says. Meanwhile, Pacific Solar's technology was taking too long to bring to market. "Thin-film at that stage was not quite ready yet," Shi says. He also saw an opportunity in China, where costs were low and no one "really understood the technology and the industry." After 10 years abroad, he returned to China and presented a business plan to politicians in charge of the Wuxi New District, a high-tech industrial park about an hour from where he'd grown up. His plan was to make conventional silicon solar panels and do it cheaply. Government officials turned him down, suggesting that even his conservative approach was "one step early," he recalls. Although venture capitalists and large companies offering joint ventures are common now in China, they were rare at the time. So Shi spent the next 10 months making connections and courting politicians while he, his wife, and their two young children lived off his savings. "The real challenge was convincing local government officials that I could succeed in the solar business and not just in the solar laboratory," he says. Eventually they offered him $6 million, collected from local state-run businesses, to start Suntech.

Shi kept an eye out for every opportunity to cut costs. He bought used equipment. He helped a Japanese company design a new machine in exchange for a discount. And where he could, he found ways to replace machines with cheaper labor.

The manufacturing methods Shi used to get the company off the ground can still be seen in the factory, which is accessible through doors at the back of the headquarters building. Workers, rather than the expensive robots used in solar factories in Japan and the West, transfer eggshell-thin silicon wafers one by one onto racks that can withstand blazing furnaces where temperatures reach 1,000 °C. The operation could be automated, but human labor costs less and can reduce breakage rates. Machines are used where they're worth it: at another station, one tests the power output of finished cells with a flash of light before robotic arms place them into bins according to performance. A human crew sorts those cells further, identifying fine gradations in the deep blue color. (All this sorting is done to ensure the consistency of the cells that go into a panel.) In another building, workers weld solar cells together into strips, then align them by eye on a light box to form the rows and columns of cells that make up a complete solar panel. To finish the panels, pairs of workers glue the frames together by hand and clean them off with a rag.

ON DEMAND

When Shi started Suntech in 2001, his timing couldn't have been better. Solar manufacturing in China was almost nonexistent, so he had little domestic competition. At the same time, the market worldwide was starting to grow. Price incentives for solar power that the German parliament authorized in 2000 were just going into effect *(see "The German Experiment," p. 76)*; after those subsidies were increased in 2004, Germany became the world's largest market for solar panels and Suntech's biggest source of revenue.

As other governments introduced their own incentives for installing renewable sources of energy, demand soared, and build-

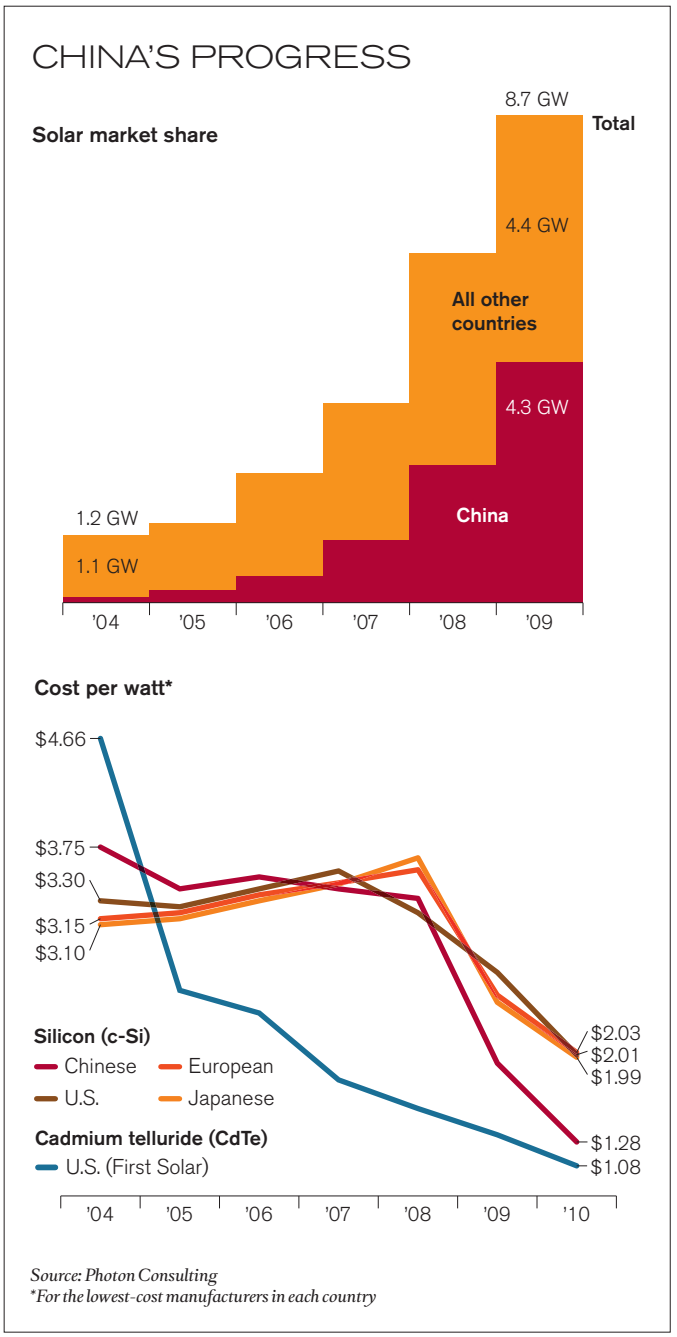
ers began taking a chance on the cheap solar panels coming out of China. "In 2005 and 2006, I couldn't get solar panels," says Barry Cinnamon, CEO of Akeena Solar, a solar installer and one of Suntech's first customers in California. "Demand was way bigger than supply. Any company, anywhere in the world, that could make a piece of glass with wires on it that generated electricity when the sun hit it could sell as many as they wanted." Not only could Suntech meet his demand, but it was willing to accommodate Akeena's requests. "What was interesting about Suntech was they were willing to build a specially designed solar panel for us," he says. "Nobody else would do it."

In the years after Shi founded Suntech, the total number of watts produced by the solar industry doubled roughly every two years. Suntech stayed ahead of the curve, doubling its own production on average every year until 2009, when the recession slowed things down. This year its production is likely to grow by 100 percent yet again; the company will employ 12,000 workers. The government recently made Suntech eligible for $7.3 billion in loans through the Chinese Development Bank to fund even more expansion.

Meanwhile, hundreds of other solar companies have been founded in China, and several have become major suppliers worldwide. Yingli Green Energy, based near Beijing, has an even bigger share of the California market than Suntech, though it produces fewer panels overall. It also has even lower costs. Others, such as JA Solar, Trina Solar, and China Sunergy, are rapidly gaining brand recognition worldwide. Much of the industry can be traced back to Green and his lab in New South Wales; former students of his are key leaders in companies that together produce 60 percent of the solar panels made in China. But if Green supplied much of the technical training, he credits Shi with the business savvy to help create the nation's booming industry. "Former students have had a big impact in China," he says. But, he adds, "I would give all the credit to Zhengrong Shi for blazing the trail the others have followed."

GREEN TRICKS

When he founded Suntech, Shi knew that it was possible to manufacture solar cells nearly twice as powerful as the ones that rolled off the line of his first factory. Green had been making them for years in his lab. If you alter the electronic properties of the very highest-grade silicon wafers in precise patterns and then trace extremely fine electrical contacts on their front and back surfaces to extract electronic current, the resulting cells capture much more of that current than conventional cells do. The only problem is that Green's methods rely on advanced and expensive processing technology borrowed from the semiconductor industry. The cells cost about 100 times as much to make as conventional solar cells like the ones Suntech has been producing so far.



The University of New South Wales had been trying unsuccessfully to commercialize the technology for 20 years, but Shi was determined to find a way. The key was to identify low-cost methods of achieving the same effects with readily available, commercial-grade silicon. Pointing to its 45 patents and 65 pending patents, Suntech claims it has now succeeded, but it's secretive about the details. Only three employees have seen the whole pro-

cess of making its new products. "We know that anyone who has seen the entire line will be targeted very, very enthusiastically by other companies," says Stuart Wenham, Suntech's chief technology officer. Wenham, a colleague of Green's at New South Wales and of Shi's at Pacific Solar, was brought in to Suntech in 2005 to produce the advanced cells. "Dr. Shi was so determined to keep all of this confidential that he bought his own equipment company to make the equipment for this technology," he says.

The process involves replacing a key step in making conventional solar cells: screen printing. To extract electrical current from a cell, manufacturers print lines of silver paste on its front surface. The closer together these electron-conducting lines are, the more efficiently they'll collect charge from the silicon. If too much of the cell's surface is shaded by the lines, however, the cell can't absorb enough light. The thinner the lines are, the closer they can get without causing this problem, but the printing process can't make them thinner than about 120 micrometers.

The Suntech researchers developed a way to chemically treat the silicon wafer in narrow bands. These treated areas attract silver, which forms metal lines just 20 micrometers wide. In addition to resulting in thinner lines, the process makes it possible to save material costs by using wafers of silicon so thin that screen-printing equipment might break them as it stamped the lines on their surface. It also replaces a treatment used in conventional manufacturing that reduces the cells' efficiency by damaging the surface of the silicon. The best modules made with the new technology convert about 18 percent of the energy in light into electricity—as opposed to 13 percent for the company's original solar panels. Next year Suntech intends to roll out a newer version of the technology, which preliminary tests suggest will improve efficiency by another one or two percentage points. The improvement might seem modest, but increased efficiency has a big impact on the cost of the resulting electricity. As a rule of thumb, a percentage-point improvement in efficiency can cut costs by over 6 percent.

Suntech is also funding collaborations with universities, including New South Wales and Swinburne University of Technology in Melbourne, to develop solar cells that get around a fundamental limitation of today's photovoltaics: they can't absorb all the wavelengths in sunlight, and they can't convert all the energy in many of those wavelengths into electronic charge. One key investment is in plasmonics, which makes use of the fact that metal particles deposited on a cell's surface can guide light energy so that it bounces back and forth within the cell instead of being reflected back out. Exploiting this effect could enable researchers to reduce the amount of active semiconductor material in a solar cell by orders of magnitude, or even to make cells out of materials far cheaper than purified, crystalline silicon *(see "Light-Trapping Photovoltaics," May/June 2010 and at technologyreview.com)*. "Those concepts will probably not find their way into commercial products in the next 10 to 20 years," Wenham says. "But they will eventually."

www Listen to the CTO of Suntech explain the company's advanced solar technology: **technologyreview.com/suntech**

ON THE VERGE

In spite of the rapid growth of Suntech and the solar industry worldwide, solar power still contributes a vanishingly small portion of the total electricity produced each year. In the United States, it's slightly above 0.1 percent. "It's a rounding error," says Nathaniel Bullard, an analyst for Bloomberg New Energy Finance.

It's hard to project the course of the still tiny industry. For one thing, all predictions of when solar power might reach grid parity are rife with uncertainties, Bullard says. To take just one example, consider that today the solar panels themselves account for less than half the total cost of the technology. The costs of installation, additional equipment such as inverters, sales and marketing by installers, and, crucially, financing will also need to come down. What's more, when it comes to grid parity, the price that photovoltaics manufacturers charge for their products is actually more significant than the money it costs to make them—and that will depend on the market. If demand for photovoltaics remains high, in part because government incentives in Germany and elsewhere prop it up, then solar panels could remain expensive enough to keep the price of solar energy well above that of electricity from the grid.

It's also not yet clear what technology is best suited for widespread use of solar power. Ten years from now, the solar panels most people buy might not even be made of silicon. Switching would be hard for Suntech. While it has the expertise to change direction, its low manufacturing costs depend on investments in equipment and agreements with silicon suppliers. Meanwhile, rival companies have a head start on the technologies that use other materials. First Solar, based in Tempe, AZ, makes thin-film solar cells made of cadmium and tellurium for even less per watt than the Chinese companies making silicon cells. Admittedly, First Solar's technology converts only about 11 percent of sunlight into electricity; that relatively low efficiency translates into higher installation costs and limits the applications it's good for. Still, thin-film solar is accounting for a steadily greater share of the overall market, from 3 percent in 2003 to more than 15 percent today.

Yet for all this uncertainty, Shi remains convinced that silicon-based solar power is on the verge of becoming competitive without government subsidies. The idea that solar energy will have to wait for a breakthrough to reach grid parity is "crap," he says. He adds: "We're not talking about rocket science. We're talking basic engineering." TR

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