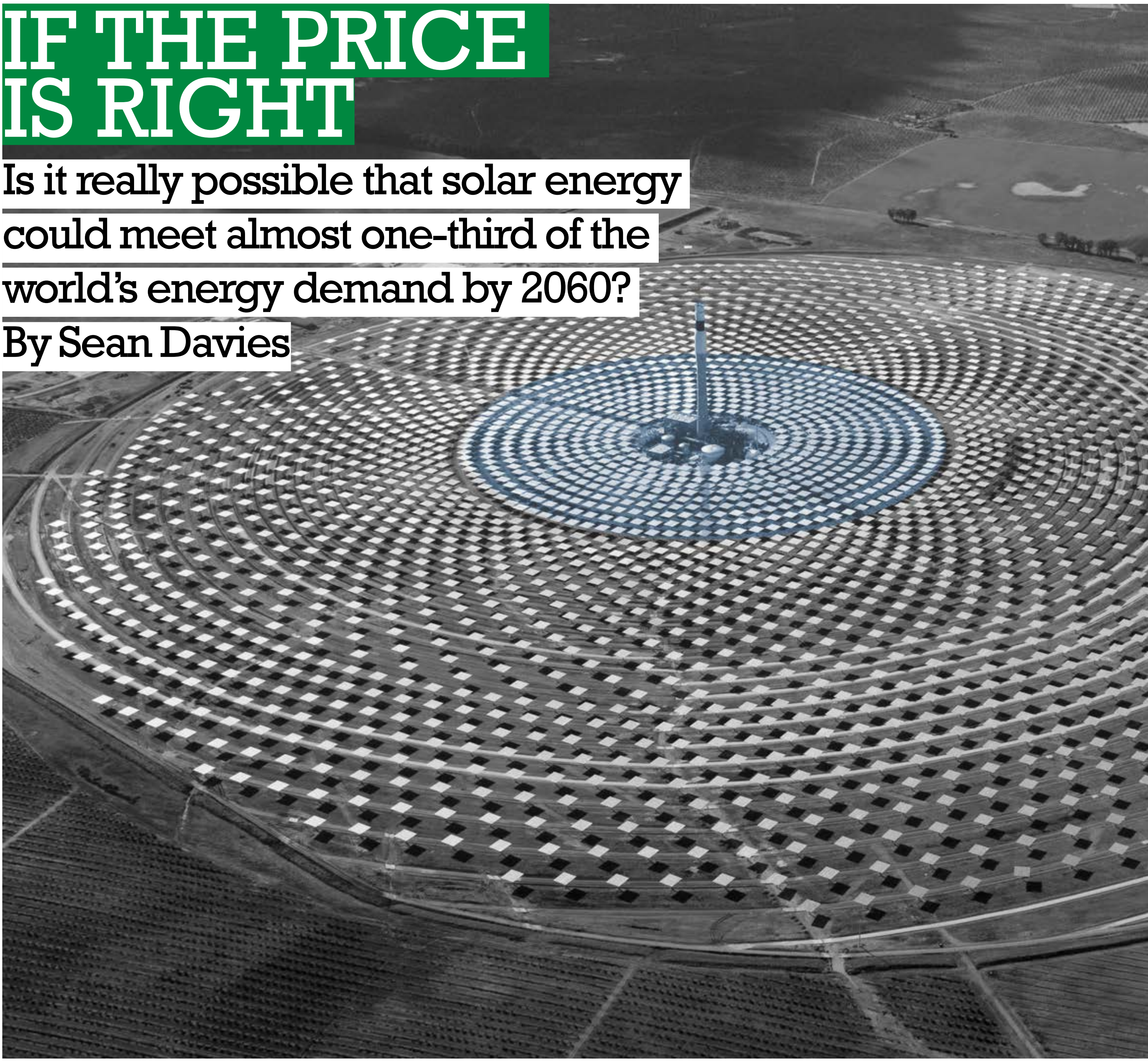
IF THE PRICE IS RIGHT

Is it really possible that solar energy could meet almost one-third of the world's energy demand by 2060?

By Sean Davies



THERE ARE two main kinds of solar energy – solar photovoltaic (PV) and concentrating solar power (CSP). PV directly converts solar energy into electricity using a PV cell made of a semiconductor material, while CSP devices concentrate energy from the sun's rays to heat a receiver to high temperatures. This heat is transformed first into mechanical energy (by turbines or other engines) and then into electricity – solar thermal electricity (STE).

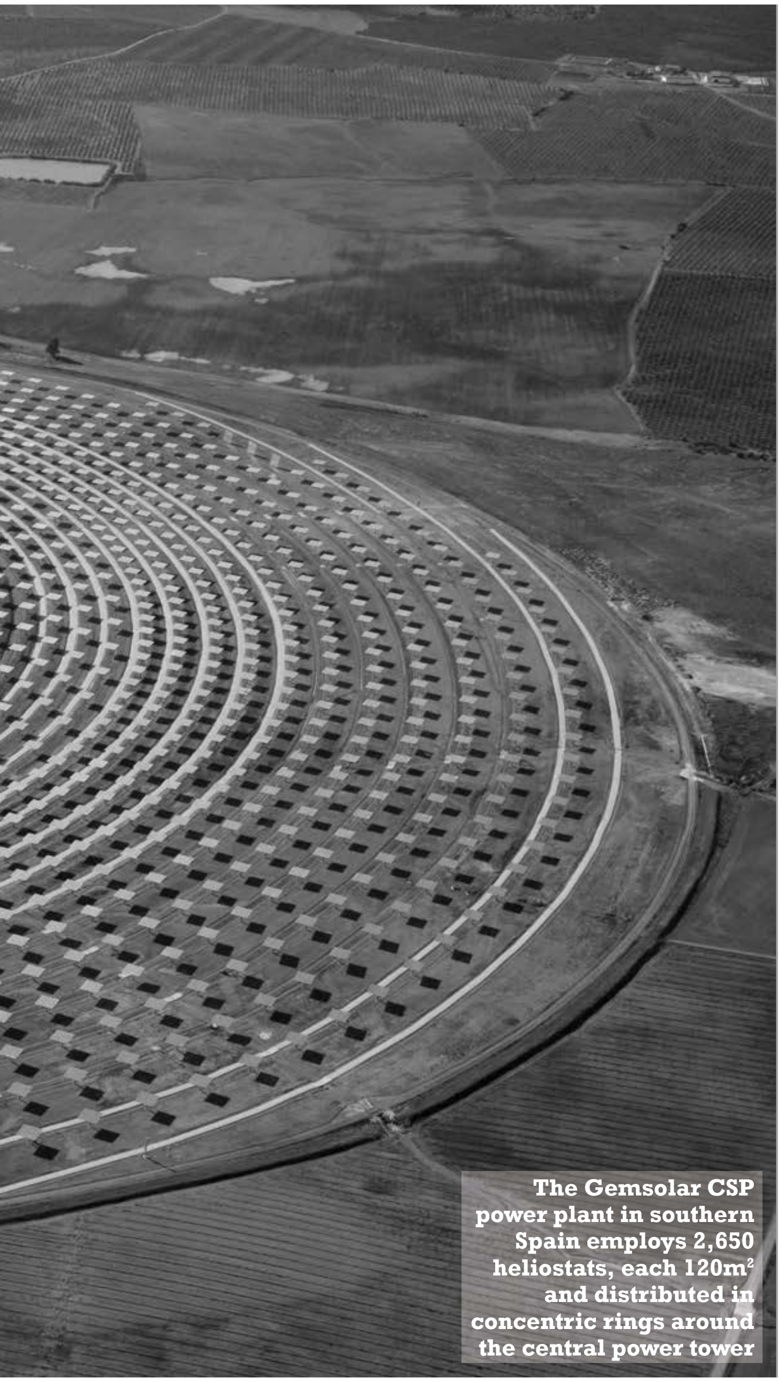
Over the period 2000-11, solar PV was the fastest-growing renewable power technology worldwide. Cumulative installed capacity of solar PV reached roughly 65GW at the end of 2011, up from only 1.5GW in 2000. In 2011, Germany and Italy accounted for over half the global cumulative capacity, followed by Japan, Spain, the United States and China.

In its SunShot strategy the US Department of Energy predicts that when the price of solar electricity reaches about $0.06 per kilowatt-hour over its lifetime, it will be cost-competitive with other non-renewable forms of electricity. This in turn will enable solar-generated power to grow.

The drive to reduce costs encompasses the entire value chain from the efficiency of individual cells to manufacturing costs as well as complementary technologies such as energy storage and effective planning.

Black and dye

One approach is to develop cells that can convert a greater percentage of the



The Gemsolar CSP power plant in southern Spain employs 2,650 heliostats, each $120m^2$ and distributed in concentric rings around the central power tower

sun's spectrum. Around a quarter of the spectrum is made up of infrared radiation, which cannot be converted by standard solar cells. One way to overcome this loss is to use black silicon, a material that absorbs nearly all of the sunlight that hits it, including infrared radiation, and converts it into electricity. Researchers have recently succeeded in doubling their overall efficiency.

"Black silicon is produced by irradiating standard silicon with femtosecond laser pulses under a sulphur-containing atmosphere," says Dr Stefan Kontermann of the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut (HHI). "This structures the surface and integrates sulphur atoms into the silicon lattice, making the treated material appear black." If manufacturers were to equip their solar cells with black silicon, it would significantly boost the cells' efficiency.

By using black silicon, Dr Kontermann and his team at HHI have now managed to double the efficiency of black silicon solar cells. "We achieved that by modifying the shape of the laser pulse we use to irradiate the silicon, enabling us to solve a key problem of black silicon," says Dr Kontermann. In normal silicon, infrared light does not have enough energy to excite the electrons into the conduction band and convert them into electricity, but the sulphur incorporated in black silicon forms a kind of intermediate level.

"You can compare this with climbing a wall," Dr Kontermann adds. "The first time you fail because the wall is too high, but the second time you succeed in two steps by using an intermediate level. However, in sulphur this not only enables electrons to climb the wall, it also works in reverse, enabling electrons from the conduction band to jump back via this intermediate level, which causes electricity to be lost once again.

"By modifying the laser pulse that drives the sulphur atoms into the atomic lattice, researchers can change the positions that these atoms adopt in the lattice and change the height of their levels – in other words, their energy level. We used the laser pulses to alter the embedded sulphur in order to maximise the number of electrons that can climb up while minimising the number that can go back down."

The researchers have already successfully built prototypes of black silicon solar cells and their next step will be to try to merge these cells with commercial technology.

An even more radical approach to delivering solar power would be to dispense with the costly and fragile semiconductor solar panel that uses crystalline silicon. Researchers at the University of Turku believe that they can do this by using flexible, lightweight and inexpensive dyes.

"It is hoped that dye-sensitised solar cells (DSCs) can become a ubiquitous source of energy without the complex and expensive clean-room manufacturing processes associated with current solar panels," Jongyun Moon, researcher at the University of Turku, says.

In a DSC, sunlight hits a layer of the white pigment titanium dioxide, the solar energy absorbed then sucks electrons from dye molecules in a layer beneath this coating, thus generating a flow of electrons and producing a current.

However, Moon suggests that despite the maturity of the silicon technology DSCs could ultimately displace it simply because they are easier and cheaper to manufacture. That said, current DSCs are less efficient than silicon devices and much development work is needed.

Anti-ageing solar

It is not just the high cost of a solar module that is of concern, but also its longevity. Given the high cost of solar power installations it is critical that the modules last as long as possible. Fraunhofer researchers in the US are developing materials to protect solar cells from environmental influences to extend their lives.

Silicone is a promising protective material. It is neither inorganic crystal nor organic polymer, but is related to both. While PV modules have been encapsulated with silicones, until now they were not widely used for laminating solar modules. Lamination is a protective coating that surrounds the fragile silicon wafer. Today, most >

< manufacturers of PV cells use ethylene-vinyl acetate.

To test its properties researchers coated PV cells with liquid silicone. "When the silicone hardens, it encases the cells; the electronic components thus have optimal protection," explains project manager Rafal Mickiewicz.

Prototypes were constructed from the silicone-laminated cells, and tested in a climate chamber at low temperatures and under cyclic loads. Afterwards the module performance was tested with a light flasher.

A comparison of the results with those of conventional solar modules proved that silicone-encased PV modules are more resistant to cyclic loading of the type modules experience in strong winds, in particular at -40°C, giving hope that their useful working life could be extended.

Material concerns

When it comes to utility-scale solar power one of the prime technologies is concentrating solar power. CSP is being widely commercialised and the market has seen about 740MW of generating capacity added between 2007 and the end of 2010.

CSP is expected to grow fast. As of April 2011, another 946MW of capacity was under construction in Spain with total new capacity of 1,789MW expected to be in operation by the end of 2013. A further 1.5GW of parabolic-trough and power-tower plants were under construction in the US, and contracts signed for at least another 6.2GW. Interest is also notable in North Africa and the Middle East, as well as India and China. The global market has been dominated by parabolic-trough plants, which account for 90 per cent of CSP plants.

Unlike some other forms of solar power CSP is largely unrestricted by materials availability. There are, however, some issues that the industry needs to look into soon, like replacing silver in mirrors. In the wake of Chinese export restrictions on rare earth metals, the dependence of some renewable technologies on scarce materials has gained attention. Several players in the PV industry are struggling to get away from excessive use of restricted elements.

A study from Chalmers University of Technology has gone into the details on material issues for CSP, which does indeed seem to be largely unrestricted, viewing the material requirements compared with global reserves. In theory, enough solar plants could be built to cover five times the current global electricity demand.

However, the report also highlights some issues that are likely to pose challenges. Silver, used for reflecting surfaces, will be in short supply in the coming decades even without demand from a booming CSP industry. CSP mirror manufacturers might have to look at other reflective surface materials, such as aluminium, to secure cost competitiveness.

"The prospects for strong growth for CSP over the next few decades seem good, but would cause a stir on the global commodity markets," Dr Erik Pihl of Chalmers University of Technology says.

Solar planning

When it comes to planning a commercial-scale PV plant there are numerous variables to consider including customer specifications, regulations, government subsidy programmes in addition to weather, climate, topography and location. These factors in turn influence the selection and placement of the individual components which include the PV arrays with their solar modules, inverters and wiring, not to mention access roads. Until now, engineers have designed solar-power plants using CAD programs, with every layout separately generated.

Fraunhofer researchers, working with Siemens Energy Photovoltaics, have developed software to aid the process. "Our algorithms provide engineers with several hundred different plant designs in a single operation," ITWM researcher Dr Ingmar Schule explains. "It takes less than a minute of computation time. The only user inputs are parameters such as the topography of the construction site and the module and inverter types that will be used. The user can also change a number of parameters to study the impact on the quality of the planning result."

To evaluate the designed PV power plants, an income calculation is performed that includes a simulation of the weather, the course of the sun throughout the year and the physical module performance including shading effects. With the results of this computation and an estimate of the investment and operating costs, the planning tool can come up with a figure for the LCOE (levelised cost of energy). By comparing the plant with a large number of similar configurations, the planners can investigate the sensitivity of the various parameters to find the right solution.

Solar storage

If solar power is to reach its potential then one piece of the renewable puzzle that needs to be solved is energy storage. With cost-effective storage the fluctuating supply of electricity based on photovoltaics can be stored until the time of consumption. At Karlsruhe Institute of Technology (KIT), several pilot plants of solar cells, small wind-power plants, lithium-ion batteries, and power electronics are under construction to demonstrate how load peaks in the grid can be balanced and what regenerative power supply by an isolated network may look like in the future.

"High-performance batteries on the basis of lithium ions can already be applied reasonably in the grid today," Dr Andreas Gutsch, coordinator of the Competence E project, explains. As stationary storage systems, they can store solar or wind power until it is retrieved by the grid. "When applied correctly, batteries can also balance higher load and production peaks and, hence, make sense from an economic point of view."

Apart from the battery, the key component of the stationary energy storage system is an adapted power-electronics unit that allows the battery to be charged or discharged within two hours. This means that the system can be applied as interim storage for peak load balancing. During times of weak loads, solar energy and wind electricity are fed into the battery. At times of peak load, the energy from the photovoltaics system, wind generator, and battery is fed into the grid.

In spite of the high costs of lithium-ion batteries, this technology may be worthwhile today already, in particular in regions that do not have any stable grids. However, there are projects underway to reduce the cost of the batteries including a joint research project between the University of Southampton and lithium battery technology company REAPsystems.

"Lead acid batteries are used for most photovoltaic systems," MSc Sustainable Energy Technologies student Yue Wu says. "However, as an energy storage device, lithium batteries, especially the LiFePO4 batteries we used, have more favourable characteristics."

Data was collected by connecting a lithium-ion phosphate battery to a photovoltaic system attached to one of the University's buildings, using a specifically designed battery management system.

"The research showed that the lithium battery has an energy efficiency of 95 per cent whereas the lead-acid batteries commonly used today only have around 80 per cent," Wu says. "The weight of the lithium batteries is lower and they have a longer lifespan than >

< the lead-acid batteries, reaching up to 1,600 charge/discharge cycles, meaning they would need to be replaced less frequently."

Although the battery will require further testing before being put into commercial photovoltaic systems the research has shown that the LiFePO4 battery has the potential to improve the efficiency of solar power systems and help to reduce the costs of both their installation and upkeep.

Low-cost production

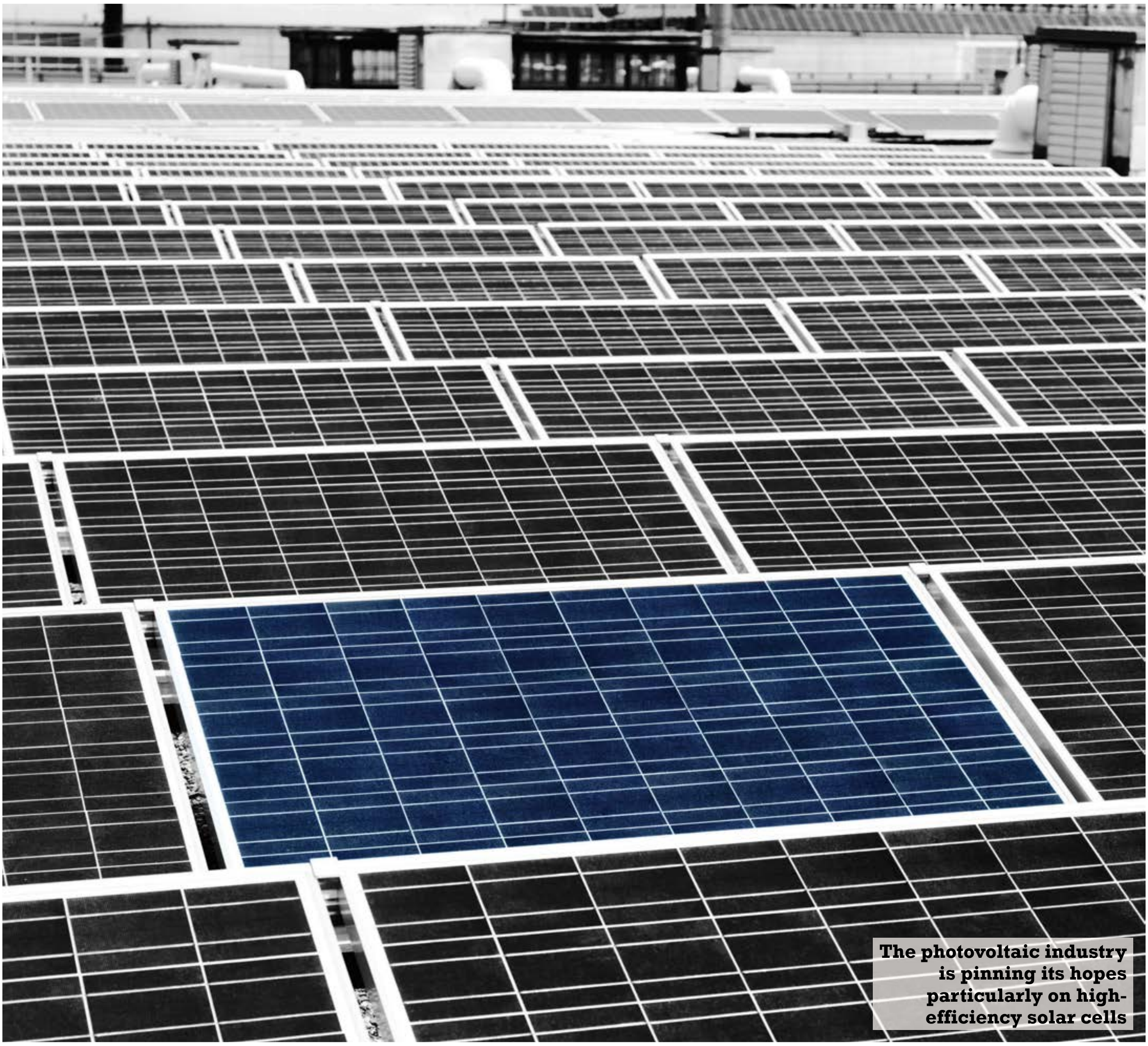
When it comes to economics of solar power it is not just the efficiency of the cells but their manufacturing cost. Asian manufacturers are frequently ahead of the competition in terms of price, which has led to continued research into lowering the manufacturing cost by Western companies.

Researchers at the Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig are designing new coating processes and thin-layer systems that, if used, could help to reduce the price of solar cells significantly.

The photovoltaic industry is pinning its hopes particularly on high-efficiency solar cells. These heterojunction with intrinsic thin-layer cells consisting of a crystalline silicon absorber with additional thin layers of silicon. Until now, manufacturers used the plasma chemical vapour deposition process to apply these layers to the substrate.

In this methodology the reaction chamber is filled with silane, and with the crystalline silicon substrate. Plasma activates the gas, thus breaking apart the silicon-hydrogen bonds. The free silicon atoms and the silicon-hydrogen residues settle on the surface of the substrate. But the plasma only activates 10 to 15 per cent of the expensive silane gas; the remaining 85 to 90 per cent are lost, unused. This involves enormous costs.

The researchers at IST have now replaced this process and activate the gas by hot wires. "This way, we can use almost all of the silane gas, so we recover 85 to 90 per cent of the costly gas," Dr Lothar Schafer, department head at IST, explains. "This reduces the overall manufacturing costs of the layers by over 50 per cent. The price of the wire that we need for this process is negligible when compared to the price of the silane."



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