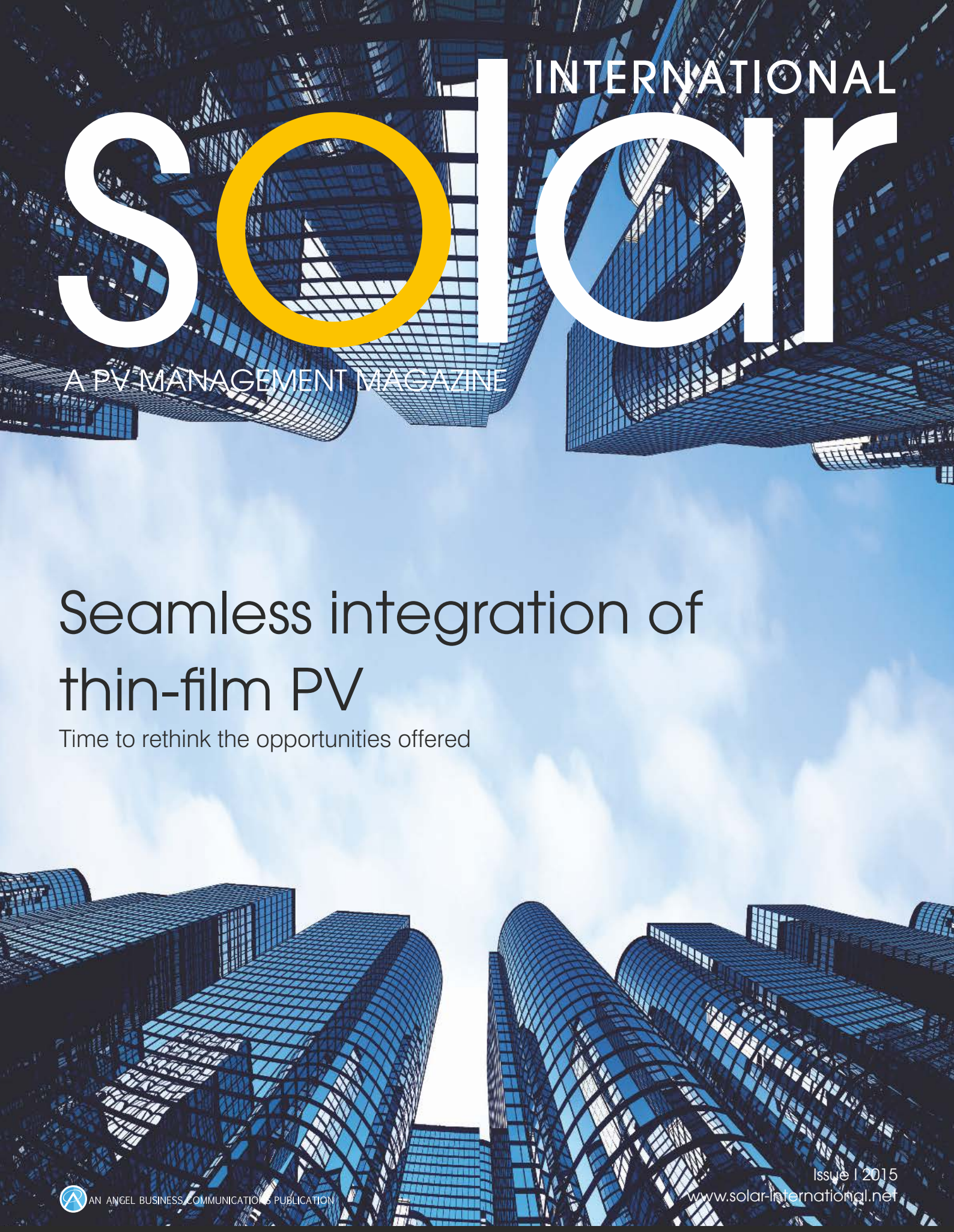

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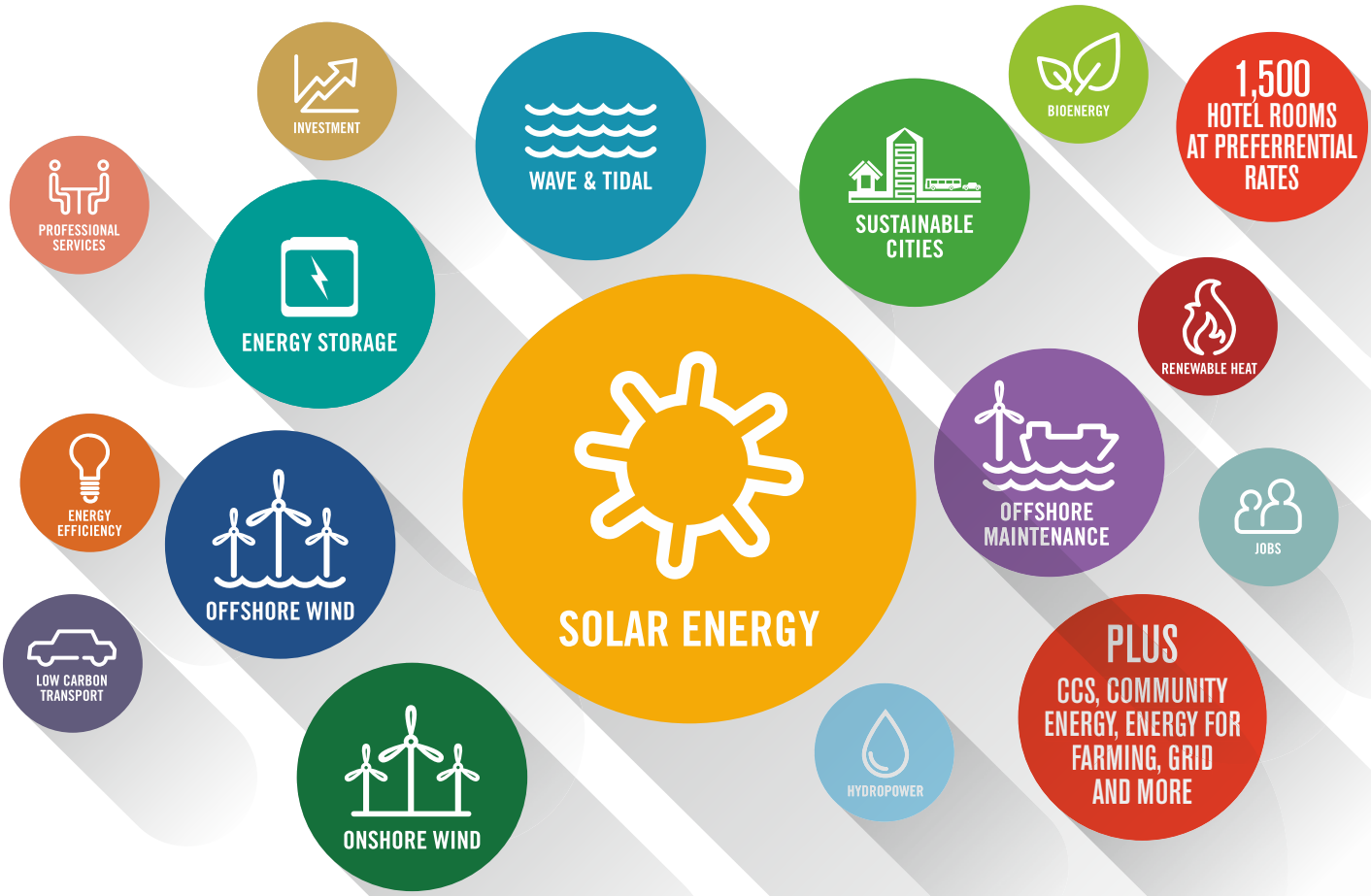

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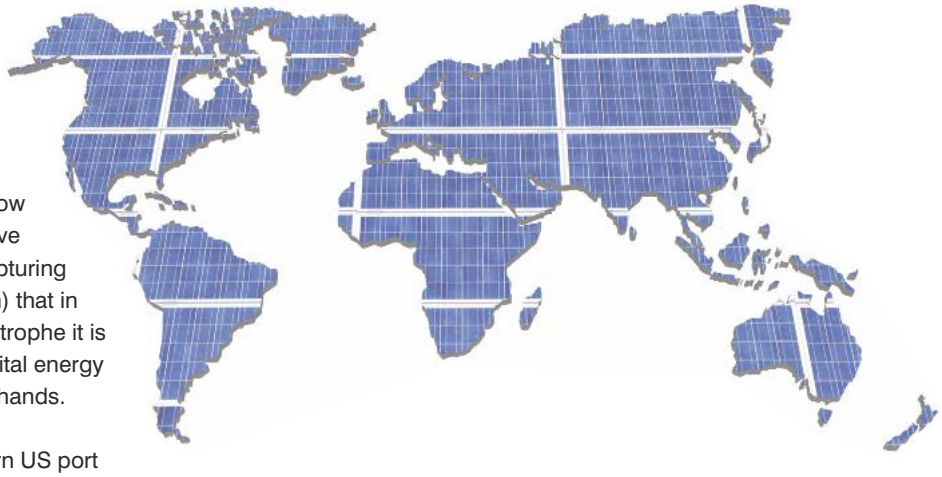
view point

Solar diversity will lead to success in 2015



WITH JUST TWO MONTHS INTO 2015 the year is already looking like a year of extremes.

Extreme weather in the US has seem millions suffering from unprecedented snow and icy conditions. Political extremists have resorted to medieval acts of terrorism, capturing headlines and reminding the world (again) that in addition to being a very real human catastrophe it is perilous economically speaking to have vital energy commodities that could fall into unstable hands.

A long labour slow-down affecting Western US port cities is keeping literally hundreds of container ships off-shore. The EU leadership is wrangling with Greece's new leadership and Europe's Central Bank is again working to maintain unity and avoid a member nation default.

What does it all mean for solar? While technological strides and market conditions have helped foster strong growth, the world is still a complicated place to do business.

What can be said for certain is that solar is likely to see continued strong expansion as its efficiencies and ability to deliver energy independence is further embraced. The technology continues to improve and PERC-based systems are rapidly evolving. This has created opportunities for many companies connected to the supply chain, PV cell manufacturers and consumers who want systems that are more efficient and easier on their wallets. PERC is a many-faceted enhancement, with manufactures and vendors tweaking their formulas as often as a chef seasons her sauce. This one-size-does-not-fit-all approach is worth remembering.

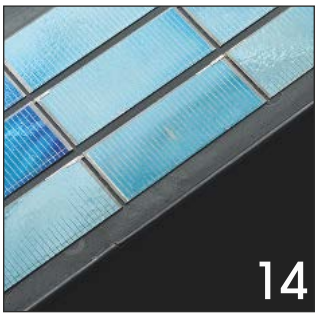
Diversity will lead to success in 2015. Doing 'It' (whether 'It' is designing a PC cell, supplying raw materials or retail sales) is destined to encounter roadblocks as 2015 has shown us. Have trouble getting a product to market? Back-up distribution routes again show their worth. Have PV systems based on a single technology? It's time to accept that the market is embracing both high-performance, premium PV systems as well as lower-cost, entry-level approaches. Is your business built almost totally around installation quotas? Think again—long-term maintenance is factoring into the game. As systems age there will be prosperity for those who service what they sell. If your business depended upon government subsidies to close the deal, have a plan for when subsidies go away; solar has proved its worth; look at more creative means to convince the customer beyond the low interest loan.

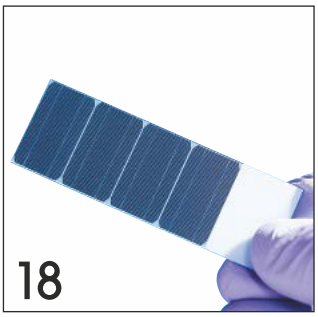
Those who are prepared for the twists and turns of a global market will grow despite the rollercoaster. Success will depend upon long-range planning as much as what competitors are doing.

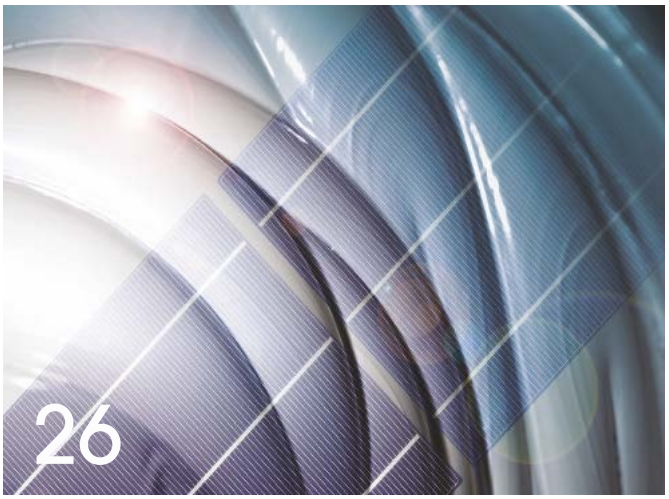
Prospects are bright for the brave in 2015 as solar continues to evolve into a self-sustaining and growing global industry.

Issue I 2015

what's inside







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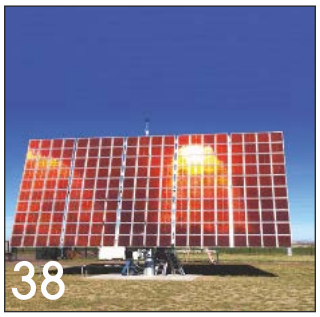


Calyxo to launch new CdTe range

THE DEVELOPMENT TEAM of Calyxo, the German manufacturer of CdTe thin-film solar modules, has announced that it has reached over 14.3 percent efficiency aperture area (97 Wp 0.72 m^2; 13.5 percent full size area), with a new product generation which will be introduced in 2015.

The manufacture of the new product generation has been carried out in the new production line opened a year ago. "It's a great achievement to concurrently both ramp-up a new production line and use it to meet the targeted performance goals for the new product development, " said Michael Bauer, CTO and COO. "We believe that we can achieve over 15 percent efficiency with the new product generation. We are convinced that the unique Calyxo deposition process, in addition to its cost advantages, has the potential for the highest semiconductor layer qualities", he continued.

Calyxo has set new product generation goals for 2015. "The pressure for us to supply higher power classes is clearly evident in the market by competitive crystalline silicon module supplier offerings, " said CEO Florian Holzapfel.

"In the intermediate term, Calyxo's new generation modules will produce more energy per installed area compared to the crystalline competition due to the better temperature coefficient. We also work on other product characteristics, which will reduce the cost of installation on customer side", he added.

At temperatures above 25°C, Calyxo modules produce up to 10 percent more energy than comparable C-Si solar modules due to their lower temperature coefficient. The transition of development concepts into mass production is scheduled for the beginning of 2015 and is being designated under the new module product name CX4.

Transphorm and Fujitsu start mass production of GaN power devices

TRANSPHORM, Transphorm Japan, and Fujitsu Semiconductor have announced that Fujitsu Semiconductor group's CMOS-compatible, 150mm wafer fab in Aizu-Wakamatsu, Fukushima, Japan, has started mass production of GaN power devices for switching applications. The large-scale, automotive-qualified facility, which is providing exclusive GaN foundry services for Transphorm, will allow dramatic expansion of Transphorm's GaN power device business. This stepped up production can satisfy the increasing market demands for GaN devices, thereby enabling the next wave of compact, energy-efficient power conversion systems.

Transphorm has established the industry's first and only qualified 600V GaN device platform, backed by its GaN power IP portfolio. The world's first photovoltaic power conditioner products using the GaN module from Transphorm was launched in January, 2015. Other applications include ultra-small AC adapters, high-density power supplies for PCs, servers and telecom equipment, highly efficient motion control systems, and more.

In 2013, Fujitsu Semiconductor and Transphorm announced the business integration of their GaN power device solutions. Since then, Transphorm's JEDEC-qualified process has been combined with Fujitsu Semiconductor's basic technology and ported to the CMOS-compatible, 150mm fab of Aizu Fujitsu Semiconductor Wafer Solution Limited, with key improvements for high-volume, silicon-compatible device manufacturing.

Understanding that a highly reliable manufacturing production line is one of the essential requirements of any business expansion, the companies have successfully finished the development in Aizu-Wakamatsu and have now started mass production.

"The start of the mass production in a CMOS-compatible fab is a significant step forward toward achieving the widespread use of GaN power devices, as well as a demonstration of the successful integration of both companies' strengths," said Haruki Okada, President of Fujitsu Semiconductor. "We will continue to enhance our high-quality manufacturing technology to support the stable supply of the products and bring the new value of GaN power devices to the world."

"Manufacturing Transphorm's GaN power devices at the Fujitsu Aizu-Wakamatsu facility will assure our customers a scalable, stable supply of products with the stamp of Fujitsu's proven, high-quality standard in mass manufacturing," said Fumihide Esaka, CEO of Transphorm. "We will continue to expand our GaN power device portfolio with continued partnership with Fujitsu Semiconductor."

Dyesol to commercialise perovskite solar cells in Turkey

DYESOL, an Australian clean-tech company, has signed an agreement with Nesli DSC to introduce and commercialise Dyesol's perovskite photovoltaic technology in Turkey.

The agreement envisages three separate stages of development: prototype, staged manufacture and mass manufacture. The first stage, at arm's length, will occur during 2015 with the establishment of a prototype facility in Turkey underpinned by a $1.9 million contract for supply of prototype equipment.

The next stage should begin in 2016 with the establishment of a pilot line facility. This is expected to produce volumes of PV product in excess of 20,000 square metres. With the successful completion of staged manufacture, mass manufacture is planned to commence in 2018 and expected to produce multi-million square metres annually.

Dyesol has received the activation payment to commence work for the first stage contract, undertaken substantially by its Korean subsidiary Dyesol-Timo. Successful completion of this stage will result in the implementation of a commercialisation strategy, which is expected to result in the formation of a 50/50 joint venture between Dyesol and Nesli DSC.

Dyesol will meet with Nesli DSC and the Development Bank of Turkey (TKB) in January 2015 to agree an implementation plan for commercialisation. Key areas for decision will include government assistance, corporate and organisational structure, and business planning. Dyesol director, Gordon Thompson commented:"Dyesol has been working closely with Turkish parties for a number of years and it is gratifying to see our common interests captured in an agreement.

WINAICO ships first modules to Japan

WINAICO, a PV module brand by the semiconductor company, Win Win Precision Technology Co., Ltd., has begun shipping 230W, 48 cell modules to Japanese key customers. The 230W, WST-230M6-H, module combines monocrystalline PERC technology with micro-crack preventing HeatCap technology with SiC (silicon carbide), to protect our customers' solar investments.

In order to become the first module manufacturer to mass produce 230W modules, WINAICO only uses the highest efficiency PERC cells in Taiwan. The PERC cells are coated with WINAICO's patented HeatCap technology with SiC to compensate the structural weakness inherent in PERC cells, and improve micro-crack prevention by 18.12 percent. The result is a 48 cell module with the highest power output density and the best reliability in the field.

"Our key customers in Japan appreciate the combination of high efficiency and reliability in WINAICO's 230 W HeatCap solar modules", said Loftur Thorarinsson, Representative Director of WINAICO Japan K.K. "With the combination of highest energy output and micro-crack preventing SiC technology, our customers can feel safe about the long term reliability of their solar investments."

Magnolia receives US patent on multi-junction solar cells

MAGNOLIA SOLAR has been issued a patent by the United States Patent and Trademark Office that describes an improved multi-junction solar cell structure.

The patent (US Patent No. 8,895,838) describes an advanced multi-junction solar cell design structure employing high-performance III-V absorber materials and nanostructured antireflection coatings that will improve solar cell performance.

"We have been aggressively pursuing more than a dozen US patent applications as a means to protect our IP in the field of flexible photovoltaics, said Ashok K. Sood, president and CEO of Magnolia Solar.

"The 8,895,838 patent pertains to a novel device structure for increasing the efficiency of high-performance multi-junction solar cells. When combined with advanced epitaxial liftoff fabrication processes, this technology can be employed in the construction of ultra-high performance flexible solar photovoltaic modules."

Magnolia Solar's technology portfolio includes nanostructured antireflection coatings, advanced photovoltaic absorber structures to enhance solar cell efficiency, and novel, low-cost manufacturing processes.

In addition, Magnolia Solar has filed a patent application for innovative design of portable power applications. These patents are at various stages of evaluation by the US Patent and Trademark Office.

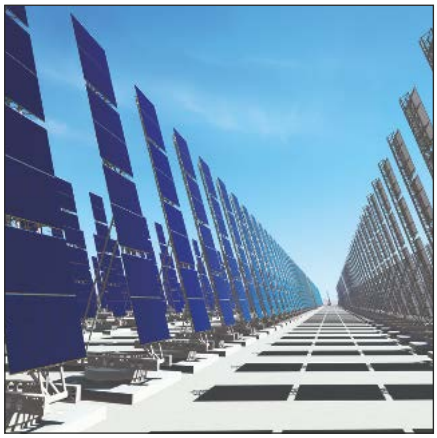
Trina Solar sets new record

TRINA SOLAR LIMITED has announced that its State Key Laboratory of PV Science and Technology has set a new world record for power output from a high efficiency multi-crystalline silicon PV module.

Trina Solar's Honey Plus multi-crystalline silicon PV module reached a new power output record of 324.5Wp, which has been independently certified by TUV Rheinland. This result marks a new world record for a multi-crystalline silicon module composed of 60 high-efficiency Honey Plus multi-crystalline silicon cells (156×156mm^2) produced with advanced technologies including back surface passivation and local back surface field, which were developed by Trina Solar and are currently in pilot production.

This further builds on the Company's recent new world record for its Honey Plus p-type PERC cell which reached an efficiency of 20.76 percent as independently confirmed by Fraunhofer ISE CalLab in Germany. This result was listed in the "Solar Cell Efficiency Table (Version 45)" in the current issue of Progress in Photovoltaics and was also recognized as an R&D highlight at the 6th World Conference on Photovoltaic Energy Conversion (WCPEC-6).

Trina Solar has set four new world records in 2014 for p-type PERC cells and modules. These include new records for large-area (156×156 mm^2) p-type silicon substrates of 21.40 percent for mono-crystalline and 20.76 percent for



multi-crystalline silicon solar cells, as well as new peak power output records for commercial PV modules of 335.2Wp for mono-crystalline and 324.5Wp for multi-crystalline silicon solar cells.

"At the Trina Solar State Key Laboratory of PV Science and Technology (SKL PVST), our focus is on delivering meaningful scientific and technological innovations," said Dr. Zhiqiang Feng, vice president of Trina Solar and director of the SKL PVST.

"We are proud to have set several new world records for PV cells and modules on large-area substrates in 2014 which have delivered improvements to the efficiency, reliability and cost of crystalline silicon photovoltaic devices. Such R&D breakthroughs continue to demonstrate Trina Solar's position as the leader in technological innovations in the solar industry and sets base for future mass production of high efficiency products."

Amtech reaches $30 million in orders for first half of 2015

AMTECH SYSTEMS, INC a global supplier of production and automation systems and related supplies for the manufacture of solar cells, semiconductors, and sapphire and silicon wafers, has announced that total orders for the quarter ended December 31, 2014, were $30 million, including $21 million of solar orders. The orders are expected to ship within the next three to nine months.

Mr. Fokko Pentinga, Chief Executive Officer of Amtech, commented, "We are very pleased to announce this record volume of orders since the last up cycle, which demonstrates our successful participation in selective capacity expansion opportunities in the current solar market. We plan to issue our complete financial results for the first quarter of fiscal 2015 in early February."

Levitech sells systems to Japanese multinational

LEVITECH BV, a supplier of advanced process equipment for the manufacturing of solar cells, has announced that it has sold two Levitrack Atomic Layer Deposition (ALD) systems to Japan, the first multiple system order for ALD equipment in the world. A major multinational, which includes solar cell manufacturing among its many concerns, will use the Levitracks for high-volume production and the development of next-generation, high-efficiency crystalline solar cells.

"The further success of the Levitrack, with two being sold to a prestigious client, is confirmation that our mass production solutions for fast ALD deposition deliver the right product to meet the needs of mass-production manufacturers", stated Jaap Beijersbergen, CEO of Levitech. "The system will be used for PERC cells - with efficiencies exceeding 20 percent - as well as multi-crystalline and n-type products."

Since its introduction in 2010, the Levitrack has consistently demonstrated its advanced passivation capabilities at world-leading manufacturers and institutes in both Europe and Asia. "We know that aluminium oxide film provides excellent cell passivation and increased cell efficiencies, especially when deposited in uniform and dense layers, a particular feature of the ALD technique. In the Levitrack these qualities are combined with an efficient and effective platform for delivery," said Beijersbergen.

Chinese partner with USA on solar microgrids

WHEN PRESIDENT OBAMA and President Xi Jinping of China announced in November 2014 that they will commit to targets for carbon cuts, few thought changes would happen quickly.

Less than two months later, Xiang Yang Institute (XYI) in Hubei, China and Focused Sun of Las Cruces, New Mexico, USA are partnering in the critical area of solar microgrids. Microgrids are small local electric grids for supplying energy to gated communities, shopping malls, eco-resorts and agricultural projects.

XYI Dean Jihong Chen says, "Focused Sun has squeezed the cost out of solar concentrators, the key part of the microgrid system that focuses sunlight. Together with thermal storage and Chinese turbogenerators, we can produce small power plants for microgrids."

Reflected solar energy heats mineral oil to the 300°C temperatures needed by modern turbogenerators. Thermal storage holds the heat for a day or more, generating electricity day or night.

"The solar energy peak is at mid-day, but people need heat and electricity in the evening," says MIT Prof. David Gordon Wilson, an expert on thermal storage and turbomachinery. Wilson believes thermal storage can power generators until the next day.

"For microgrids in the 100 kW to 10 MW range, low cost solar concentrators and thermal storage combined with turbo generators make more sense than photovoltaic collectors and battery storage. Thermal storage is the key missing ingredient," he says.

Four times more solar energy is captured by the concentrators than by conventional photovoltaic panels of the same size. During the day, solar energy is stored thermally. At night or during cloudy periods, the energy is pumped from storage to the turbogenerator where 20 percent of the energy is converted to electricity. The remaining 50 percent of the sun's energy is available as heat for example for warming homes, hotel rooms and greenhouses.

The system produces both electricity and hot water and can pay for itself in as little as two years. The Focused Sun concentrators are made locally bringing local jobs plus cheap, clean energy. For every dollar spent, four times more solar energy is captured.

Dr. Amir Abtahi, Director of the Solar Laboratory at Florida Atlantic University (Boca Raton, FL) has investigated solar microgrids with thermal storage. He says, "The modular approach that Focused Sun uses lets solar energy be customized to various power plant sizes."

DEWA releases standards for PV systems and invites manufacturers to submit applications

DUBAI ELECTRICITY & WATER AUTHORITY (DEWA) has released the standards for installing photovoltaic panels to produce electricity from solar power in buildings in Dubai. The step supports the Smart Dubai initiative launched by HH Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of the UAE and Ruler of Dubai to transform Dubai into the smartest city in the world. The standards help implement DEWA's first initiative, which allows customers to install photovoltaic panels to produce electricity from solar power in Dubai. DEWA has invited manufactures to submit their eligibility applications.

HH Sheikh Hamdan bin Mohammed bin Rashid Al Maktoum, Crown Prince of Dubai and Chairman of the Dubai Executive Council, issued resolution No. (46) for 2014, allowing customers to install photovoltaic (PV) panels for the production of electricity from solar power in buildings, and connect them to DEWA's grid. This makes Dubai the first city in the Middle East to put in place a comprehensive framework at legislative level that allows any interested customer to install PV generation systems. Any surplus of production will be fed into the electricity network. The initiative allows customers to install systems to generate electricity using photovoltaic panels. An offset between exported and imported electricity units is conducted and the customer account is settled based on this offset.

"As part of our efforts to support the Green Economy for Sustainable Development initiative launched by HH Sheikh Mohammed bin Rashid Al Maktoum, and the Smart Dubai initiative to transform Dubai into the smartest city in the world, and to achieve the happiness and satisfaction of our customers about the government services, we call upon all manufacturers of solar power equipment and tools to register their products as eligible for DEWA so that customers have a reference to start installing the solar systems as soon as possible according to the highest design qualification standards," said HE Saeed Mohammed Al Tayer, MD & CEO of DEWA. "DEWA will periodically review the performance of these systems and their compatibility, and improve the process to ensure the solar power technologies are seamlessly integrated with the current power production systems," added Al Tayer.

The eligibility criteria are described in the Standards for Distributed Renewable Resources Generators Connected to the Distribution Network, which set out the requirements for solar photovoltaic modules, inverters, and interface protection systems, among other tools. Contractors and consultants who install photovoltaic panels must use tools and equipment compatible with DEWA's standards before installing or connecting them to the grid.

SunEdison CEO joins US President and India Premier at climate trade talks in Delhi

SUNEDISON, INC., has announced that Ahmad Chatila, Chief Executive Officer of SunEdison joined President Barack Obama and Prime Minister Narendra Modi of India in New Delhi, India, to discuss the ways that renewable energy can drive US-India trade, provide American jobs, and curb India's greenhouse gas emissions.

"It's a great honour to be invited to meet with President Obama and Prime Minister Modi to discuss how renewable energy can benefit the people of both India and America," stated Ahmad Chatila, Chief Executive Officer of SunEdison. "We have recently signed agreements to develop 10 gigawatts of solar energy in India within the next 5 years. Solar is now a cost effective source of energy in India, and as it's supported by the Indian government's strong leadership in energy policy, I anticipate even more rapid growth in the future."

In September 2014, Prime Minister Modi announced that he is seeking to work with the United States to develop 100 gigawatts of solar and wind energy over the next ten years. India has supported this goal by setting aggressive cost and implementation goals and providing regulatory certainty for industry participants, as well as by working to secure land for utility scale projects throughout India. In August 2014, India's energy administration removed all anti-dumping duties on solar panels and pledged to do everything in its power to create a robust ecosystem for renewables in India.

Mr. Chatila added: "By expanding our renewable energy development in countries like India, we are providing jobs back in America. SunEdison runs R&D, engineering, and manufacturing facilities in the US, and all of these functions feed our global projects."

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USITC upholds anti-dumping and countervailing duties

The US International Trade Commission (USITC) has officially voted to uphold the findings that Chinese and Taiwanese PV manufacturers have been dumping their products.

The tariffs against PV imports will follow the Depart of Commerce's (DOC) decision which was released on Dec. 2014: anti-dumping and countervailing duties (AD/CVD) will be imposed on Chinese PV imports and anti-dumping tariffs will be imposed on Taiwanese PV imports. This decision finally closed the latest and most publicized AD/CVD case involving China, America, and Taiwan.

In line with DOC's ruling last December, Chinese PV modules will be severely punished with minimum tariff rates starting at 70% while the rates for Taiwanese PV manufacturers will range from 11.45 percent to 27.55 percent.

However, the first-tier manufacturers in China are able to use the loophole provided by the favorable review and reduction of the 2012 tariff rates earlier this month.

Under the revised rates of 17.5 percent for 2012, the vertically integrated Chinese firms could still sell in the US with a cost advantage.

"Trina Solar, ReneSola, and other major Chinese manufacturers have secured OEMs outside of China and Taiwan during the long investigation period," said Corrine Lin, Analyst for EnergyTrend, a research division of TrendForce, "and BYD, the biggest winner of the 2012 review decision, have already released solar cell orders to second-tier OEMs in China."

Lin further noted that the Chinese manufacturers with the same tariff rate advantage are poised to take over because they have taken account of the former market scenario and are again increasing their export shares to the US market. JA Solar, which is known for its high performance products of excellent quality, did not enjoy the same reduction of the 2012 tariff rates.

However, JA Solar's existing market share in the US is quite small compared with its large gain of market share in Japan. Hence, the trade dispute so far has little impact on its business operations.

The situation for solar cell companies in Taiwan is a lot worse in comparison. Recently, major Chinese manufacturers have been engaging in hard bargaining when it comes to their orders for Taiwan-made cells. Already at zero gross margin, Taiwanese firms will now face another round of price slashing for their products following ITC's vote.

"The Chinese, along with European and American PV manufacturers will still provide solar orders to Taiwanese companies," said Lin, "but the prices of mainstream Taiwanese multi-Si cells will start to fall from US$ 0.31/watt to record lows, pulling down the prices of Taiwanese wafers as well."

Motech is included in this price projection despite having the furthest rate rollback among Taiwanese firms, at 11.45 percent . In response to the situation, Taiwanese manufacturers will opt to relocate their production lines as the quickest and most effective solution instead of devoting their efforts to develop new export markets. It is expected that those firms that have planned for relocation will do so immediately.

Lin also believed that while there is a chance for tariffs returning to zero when the US government reviews the tariff rates for 2016, Taiwanese solar cell makers may not be able to cope with the ruinous change brought by the newest USITC decision. EnergyTrend expects a few firms in the Taiwan's PV industry are going to exit the market as they become uncompetitive. A straightforward wave of mergers is unlikely to happen because acquisitions of smaller second-tier firms do not offer any substantial benefits in the current market.

SolarWorld AG exceeds shipment forecast in 2014

SOLARWORLD boosted groupwide shipments of solar modules and kits in fiscal year 2014 by 55 percent to 849 (2013: 548) MW. Thus, the company considerably exceeded its forecast to raise groupwide shipments by at least 40 percent in 2014.

SolarWorld achieved strong growth in the United States, where the group nearly doubled shipments compared with the previous year. The United States were SolarWorld's biggest market, reaching a share of 41 percent of total shipments of modules and kits. In France, the United Kingdom and Japan, SolarWorld was able to expand its business strongly, too.

The German solar market decreased significantly; against this market trend, SolarWorld managed to increase shipments in its core business, i.e. sales of modules and kits excluding turnkey large-scale projects.Consolidated revenue in fiscal year 2014 increased by 26 percent to € 573 (2013: € 456) million.

Solar-Fabrik AG files for insolvency

SOLAR-FABRIK AG has filed for insolvency proceedings in self administration at the Local Court of Freiburg. A corresponding resolution was adopted by the Managing Board and approved by the Supervisory Board on Jan 29, 2015. The company filed for insolvency, since an insolvency situation due a shortage of liquidity (drohende Zahlungsunfähigkeit) could occur in the course of the 2nd quarter 2015.

The company does not suffer from over-indebtedness and is not insolvent. Solar-Fabrik Wismar GmbH, a subsidiary which is fully owned by Solar-Fabrik AG, has also filed for insolvency proceedings in self administration at the Local Court of Freiburg, today. The remaining subsidiaries of Solar-Fabrik AG have not filed for insolvency proceedings.

Hanergy powers Honda factory at Zengcheng

GUANGZHOU Honda's factory at Zengcheng will be partly powered by solar energy following the official establishment of the 17 MW distributed photovoltaic project jointly launched with Hanergy in January. The 17MW distributed building-integrated PV project, which has already linked to China's national power grid, is the biggest of its type in the country's auto industry.

It covers a total floor space of around 230,000 square meters and is capable of generating 19 million kilowatt hours of electricity each year, or 50,000 to 60,000 kWh per day. The electricity generated by the project will fulfil at least 20 percent of the power demands of the factory, according to Yu Jun, deputy general manager of Guangzhou Honda. He added that the "extra green power" generated on non-production days will be sold to the city's local power grid.

"The 17MW distributed PV project we launched with Hanergy is Guangzhou Honda's response to the country's call for emissions reduction, which we regard as our responsibility to the environment as well as to society," Yu said at the project's launch. Wang Junjuan, vice president of Hanergy Holding Group who oversees the project, said that Hanergy's persistence in developing clean energy has matched Guangzhou Honda's pursuit of value in a green economy. She affirmed that the shared rights and responsibilities of running the PV project will be a model for other clean energy makers seeking diversified profit modes.

Amtech acquires BTU to create growth opportunity

AMTECH SYSTEMS, INC has announced that it has completed its acquisition of BTU International (BTU). J.S. Whang, Executive Chairman of Amtech, said, "The addition of BTU supports our business model of growth through strategic acquisition and continuous innovation. This acquisition further advances our strategy to expand our technology portfolio in adjacent markets and creates an even stronger platform to drive the growth of our solar business."

Fokko Pentinga, President and Chief Executive Officer of Amtech commented, "The combination with BTU further enhances our position as a leading, global supplier of solar and semiconductor production and automation systems. BTU provides Amtech with complementary thermal processing technologies in the semiconductor, electronics and solar sectors, and strengthens our footprint in China and other key geographic markets with attractive growth trends. Our shared focus on service, innovation and quality will further strengthen our highly respected brands and enhance our ability to best serve our customers."

Perovskites provide big boost to silicon solar cells

Stacking perovskites onto a conventional silicon solar cell dramatically improves the overall efficiency of the cell, according to a study led by Stanford University scientists.

THE RESEARCHERS describe their novel perovskite-silicon solar cell in the journal Energy & Environmental Science. "We've been looking for ways to make solar panels that are more efficient and lower cost," said study co-author Michael McGehee, a professor of materials science and engineering at Stanford. "Right now, silicon solar cells dominate the world market, but the power conversion efficiency of silicon photovoltaics has been stuck at 25 percent for 15 years."

One cost-effective way to improve efficiency is to build a tandem device made of silicon and another inexpensive photovoltaic material, he said. "Making low-cost tandems is very desirable," McGehee said.

"You simply put one solar cell on top of the other, and you get more efficiency than either could do by itself. From a commercial standpoint, it makes a lot of sense to use silicon for the bottom cell. Until recently, we didn't have a good material for the top cell, then pervoskites came along."

Perovskite is a crystalline material that is inexpensive and easy to produce in the lab. In 2009, scientists showed that perovskites made of lead, iodide and methylammonium could convert sunlight into electricity with an efficiency of 3.8 percent. Since then, researchers have achieved perovskite efficiencies above 20 percent, rivaling commercially available silicon solar cells and spawning widespread interest among silicon manufacturers.

"Our goal is to leverage the silicon factories that already exist around the world," said Stanford graduate student Colin Bailie, co-lead author of the study. "With tandem solar cells, you don't need a billion-dollar capital expenditure to build a new factory. Instead, you can start with a silicon module and add a layer of perovskite at relatively low cost."

Sunlight to electricity

Solar cells work by converting photons of sunlight into an electric current that moves between two electrodes. Silicon solar cells generate electricity by absorbing photons of visible and infrared light, while perovskite cells harvest only the visible part of the solar spectrum where the photons have more energy.

"Absorbing the high-energy part of the spectrum allows perovskite solar cells to generate more power per photon of visible light than silicon cells," Bailie said. A key roadblock to building an efficient perovskite-silicon tandem has been a lack of transparency.

"Colin had to figure out how to put a transparent electrode on the top so that some photons could penetrate the perovskite layer and be absorbed by the

silicon at the bottom," McGehee said. "No one had ever made a perovskite solar cell with two transparent electrodes." Perovskites are easily damaged by heat and readily dissolve in water. This inherent instability ruled out virtually all of the conventional techniques for applying electrodes onto the perovoskite solar cell, so Bailie did it manually.

"We used a sheet of plastic with silver nanowires on it," he said. "Then we built a tool that uses pressure to transfer the nanowires onto the perovskite cell, kind of like a temporary tattoo. You just need to rub it to transfer the film."

For the experiment, the Stanford team stacked a perovskite solar cell with an efficiency of a 12.7 percent on top of a low-quality silicon cell with an efficiency of just 11.4 percent.

"By combining two cells with approximately the same efficiency, you can get a very large efficiency boost," Bailie said. The results were impressive. "We improved the 11.4 percent silicon cell to 17 percent as a tandem, a remarkable relative efficiency increase of nearly 50 percent," McGehee said. "Such a drastic improvement in efficiency has the potential to redefine the commercial viability of low-quality silicon."

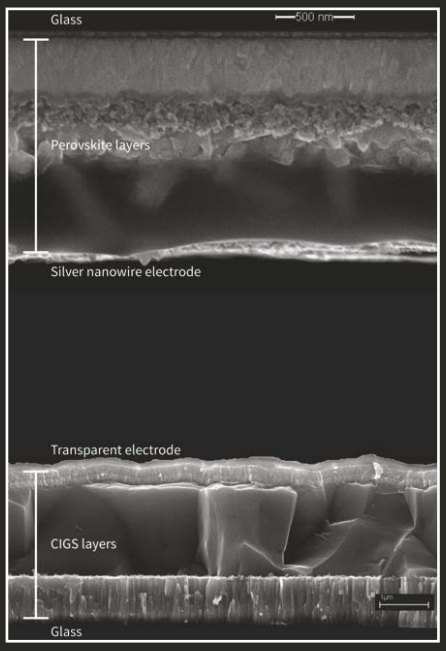
In another experiment, the research team replaced the silicon solar cell with a cell made of copper indium gallium diselenide (CIGS). The researchers stacked a 12.7 percent efficiency perovskite cell onto a CIGS cell with a 17 percent efficiency.

The resulting tandem achieved an overall conversion efficiency of 18.6 percent. "Since most, if not all, of the layers in a perovskite cell can be deposited from solution, it might be possible to upgrade conventional solar cells into higher-performing tandems with little increase in cost," the authors wrote. A big unanswered question is the long-term stability of perovskites, McGehee added.

"Silicon is a rock," he said. "You can heat it to about 600 degrees Fahrenheit shine light on it for 25 years and nothing will happen. But if you expose perovskite to water or light it likely will degrade. We have a ways to go to show that perovskite solar cells are stable enough to last 25 years. My vision is that one day we'll be able to get low-cost tandems that are 25 percent efficient. That's what companies are excited about. In five to 10 years, we could even reach 30 percent efficiency."

Journal Reference:

1.Colin D. Bailie, M. Greyson Christoforo, Jonathan P. Mailoa, Andrea R. Bowring, Eva L. Unger, William H. Nguyen, Julian Burschka, Norman Pellet, Jungwoo Z. Lee, Michael Grätzel, Rommel Noufi, Tonio Buonassisi, Alberto Salleo, Michael D. McGehee. Semi-transparent perovskite solar cells for tandems with silicon and CIGS. Energy Environ. Sci., 2014; DOI: 10.1039/C4EE03322A



This is a microscopic cross-section of a tandem solar cell made with two photovoltaic materials, perovskite and copper indium gallium diselenide, or CIGS. Credit: Colin Bailie, Stanford University

Journal Reference

1.Colin D. Bailie, M. Greyson Christoforo, Jonathan P. Mailoa, Andrea R. Bowring, Eva L. Unger, William H. Nguyen, Julian Burschka, Norman Pellet, Jungwoo Z. Lee, Michael Grätzel, Rommel Noufi, Tonio Buonassisi, Alberto Salleo, Michael D. McGehee. Semi-transparent perovskite solar cells for tandems with silicon and CIGS. Energy Environ. Sci., 2014; DOI: 10.1039/C4EE03322A

Defects in solar cells made of silicon identified

A researcher has focused on defects found on silicon and their impact on the efficiency of solar cells

SINCE HE WAS A TEENAGER, engineer Sergio Castellanos had the desire to study abroad to prepare and do research in the best laboratories, particularly on solar energy. With six years of stay in the United States, first at the University of Arizona and now at the Massachusetts Institute of Technology (MIT) in Boston, his dream has come true: "Working on defects found on silicon and their impact on the efficiency of solar cells made with this material." This research is carried out to obtain his doctorate from MIT.

"Dislocation is a defect that occurs at high temperatures, of 500 ° C onwards. In my research I analyse these defects and their impact on the efficiency of solar cells made from silicon, since this material is used in over 90 percent of solar panels worldwide. The Mexican researcher in Boston explains that the harmful part of the dislocation is interacting with other defects such as metallic impurities within the material of solar cells; they tend to reduce efficiency by -for example- interacting with electrons.

"When having a dislocation is very easy for impurities to settle into a defect in the material. Therefore, in my research I analyse at an early scale what kind of dislocations will be more harmful to the cells, meaning, which ones will interact more with impurities because not all do likewise, hence not all dislocations are equally harmful."

The proposal of Sergio Castellanos at the MIT is to apply a method in wafers of polycrystalline silicon before being processed into solar cells. This method involves using a chemical treatment in order to view the dislocations and analyse the geometric variation on the surface. After making crystallographic

analysis as well as X-rays for determining the distribution and concentration of metal impurities, a correlation is made with the geometric appearance of the surface and then, just by looking at the surface, one can deduce what the electrical behaviour within material will be.

"The goal is to identify which areas of the material will be more likely for electrons to recombine before being extracted by contacts, becoming less efficient cells."

A little bit of history

When the native of Hermosillo, Sonora (northern state of Mexico), was in high school, he applied for the Massachusetts Institute of Technology (MIT) and was not admitted. He told himself he would not be discouraged because surely the opportunity would could come later. He decided to study mechanical engineering at the Technological Institute of Hermosillo and two years in his parents supported him to finish his degree abroad. He was transferred to the University of Arizona where he finished his degree. At the university, he became involved in several projects on the subject of energy, as was the case with hydrogen cells, a solar car and installing solar panels.

The Mexican says he enjoyed doing research and started looking for projects and teachers who worked in that area. He spotted four scientists, but wanted to go to MIT because "for any engineer to be in this school is a dream. I had practice in energy research during my bachelor's and for my doctorate I looked for subjects in this area. I applied at several universities and at last I was admitted at MIT in Boston."

His research in solar cells is in the last stage, and once completed in the next year he will make it available to other researchers. This work was presented at various conferences and has received good reviews in terms of utility. To "finish the tale" on solar cells, the Mexican will complete his studies in six to eight months, and is more than satisfied with the subject that has developed during his research.

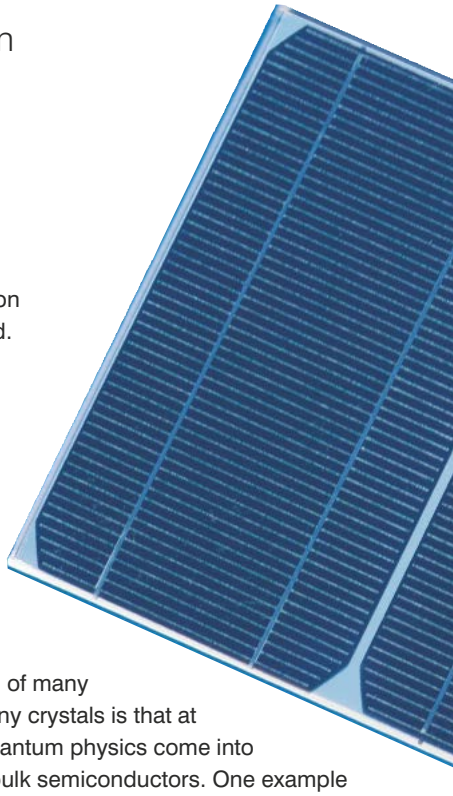
Sergio Castellanos wants continue researching, work in an industry and does not rule out to eventually move to another country. Credit: Image courtesy of Investigación y Desarrollo

Sergio Castellanos wants continue researching, work in an industry and does not rule out to eventually move to another country. In the remaining months he will define his next step.

Demystifying

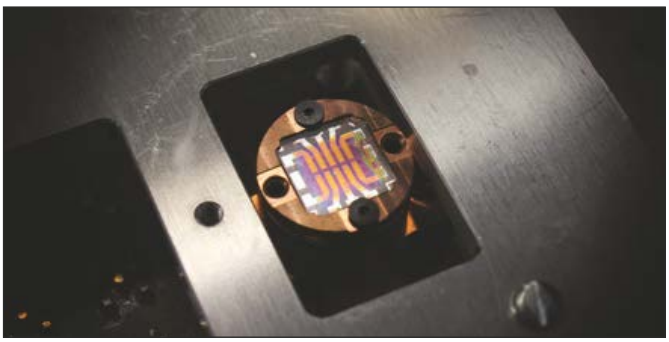
nanocrystal solar cells

ETH researchers have developed a comprehensive model to explain how electrons flow inside new types of solar cells made of tiny crystals. The model allows for a better understanding of such cells and may help to increase their efficiency.



SCIENTISTS ARE FOCUSING on nanometre-sized crystals for the next generation of solar cells. These nanocrystals have excellent optical properties. Compared with silicon in today's solar cells, nanocrystals can be designed to absorb a larger fraction of the solar light spectrum. However, the development of nanocrystal-based solar cells is challenging: "These solar cells contain layers of many individual nano-sized crystals, bound together by a molecular glue. Within this nanocrystal composite, the electrons do not flow as well as needed for commercial applications," explains Vanessa Wood, Professor of Materials and Device Engineering at ETH Zurich. Until now, the physics of electron transport in this complex material system was not understood so it was impossible to systematically engineer better nanocrystal-composites.

Wood and her colleagues conducted an extensive study of nanocrystal solar cells, which they fabricated and characterized in their laboratories at ETH Zurich. They were able to describe the electron transport in these types of cells via a generally applicable physical model for the first time. "Our model is able to explain the impact of changing nanocrystal size, nanocrystal material, or binder molecules on electron transport," says Wood. The model will give scientists in the research field a better understanding of the physical processes inside nanocrystal solar cells and enable them to improve solar cell efficiency.



A solar cell chip based on nanocrystals fabricated by the ETH researchers. (Photo: Deniz Bozyigit / ETH Zurich)

Promising outlook thanks to quantum effects

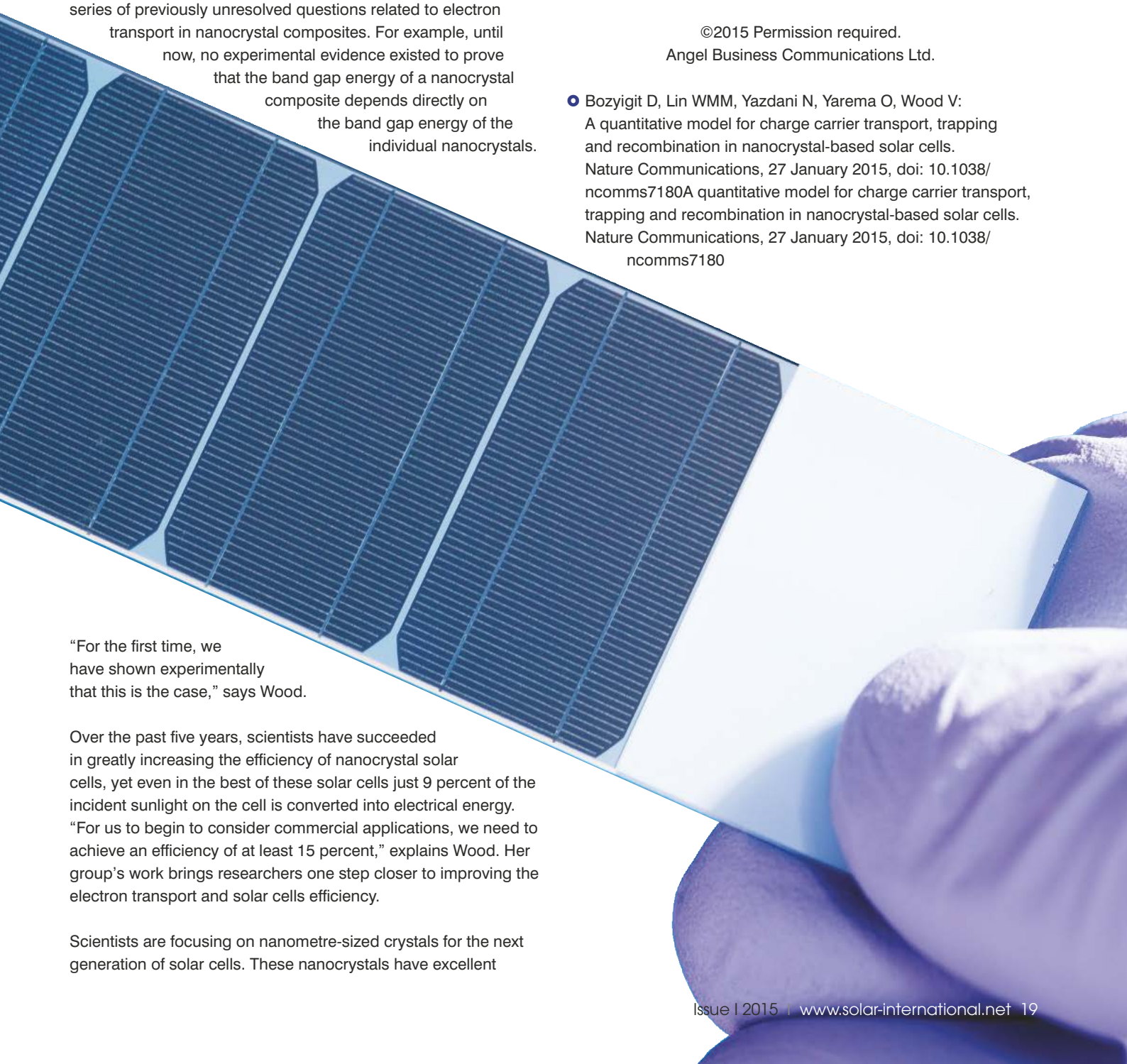
The reason for the enthusiasm of many solar cell researchers for the tiny crystals is that at small dimensions effects of quantum physics come into play that are not observed in bulk semiconductors. One example is that the physical properties of the nanocrystals depend on their size. And because scientists can easily control nanocrystal size in the fabrication process, they are also able to influence the properties of nanocrystal semiconductors and optimize them for solar cells.

One such property that can be influenced by changing nanocrystal size is the amount of sun's spectrum that can be absorbed by the nanocrystals and converted to electricity by the solar cell. Semiconductors do not absorb the entire sunlight spectrum, but rather only radiation below a certain wavelength, or – in other words – with an energy greater than the so-called band gap energy of the semiconductor. In most semiconductors, this threshold can only be changed by changing the material. However, for nanocrystal composites, the threshold can be changed simply by changing the size of the individual crystals. Thus scientists can select the size of nanocrystals in such a way that they absorb the maximum amount of light from a broad range of the sunlight spectrum.

An additional advantage of nanocrystal semiconductors is that they absorb much more sunlight than traditional semiconductors. For example, the absorption coefficient of lead sulfide nanocrystals, used by the ETH researchers in their experimental work, is several orders of magnitude greater than that of silicon semiconductors, used traditionally as solar cells. Thus, a relatively small amount of material is sufficient for the production of nanocrystal solar cells, making it possible to make very thin, flexible solar cells.

Need for greater efficiency

The new model put forth by the ETH researchers answers a series of previously unresolved questions related to electron transport in nanocrystal composites. For example, until now, no experimental evidence existed to prove that the band gap energy of a nanocrystal composite depends directly on the band gap energy of the individual nanocrystals.



"For the first time, we have shown experimentally that this is the case," says Wood.

Over the past five years, scientists have succeeded in greatly increasing the efficiency of nanocrystal solar cells, yet even in the best of these solar cells just 9 percent of the incident sunlight on the cell is converted into electrical energy. "For us to begin to consider commercial applications, we need to achieve an efficiency of at least 15 percent," explains Wood. Her group's work brings researchers one step closer to improving the electron transport and solar cells efficiency.

Scientists are focusing on nanometre-sized crystals for the next generation of solar cells. These nanocrystals have excellent optical properties. Compared with silicon in today's solar cells, nanocrystals can be designed to absorb a larger fraction of the solar light spectrum. However, the development of nanocrystal-based solar cells is challenging: "These solar cells contain layers of many individual nano-sized crystals, bound together by a molecular glue. Within this nanocrystal composite, the electrons do not flow as well as needed for commercial applications," explains Vanessa Wood, Professor of Materials and Device Engineering at ETH Zurich. Until now, the physics of electron transport in this complex material system was not understood so it was impossible to systematically engineer better nanocrystal-composites.

Bozyigit D, Lin WMM, Yazdani N, Yarema O, Wood V: A quantitative model for charge carrier transport, trapping and recombination in nanocrystal-based solar cells. Nature Communications, 27 January 2015, doi: 10.1038/ncomms7180A quantitative model for charge carrier transport, trapping and recombination in nanocrystal-based solar cells. Nature Communications, 27 January 2015, doi: 10.1038/ncomms7180

Pinholes are pitfalls

for high performance solar cells

The most popular next-generation solar cells under development may have a problem – the top layer is full of tiny pinholes, researchers have found.

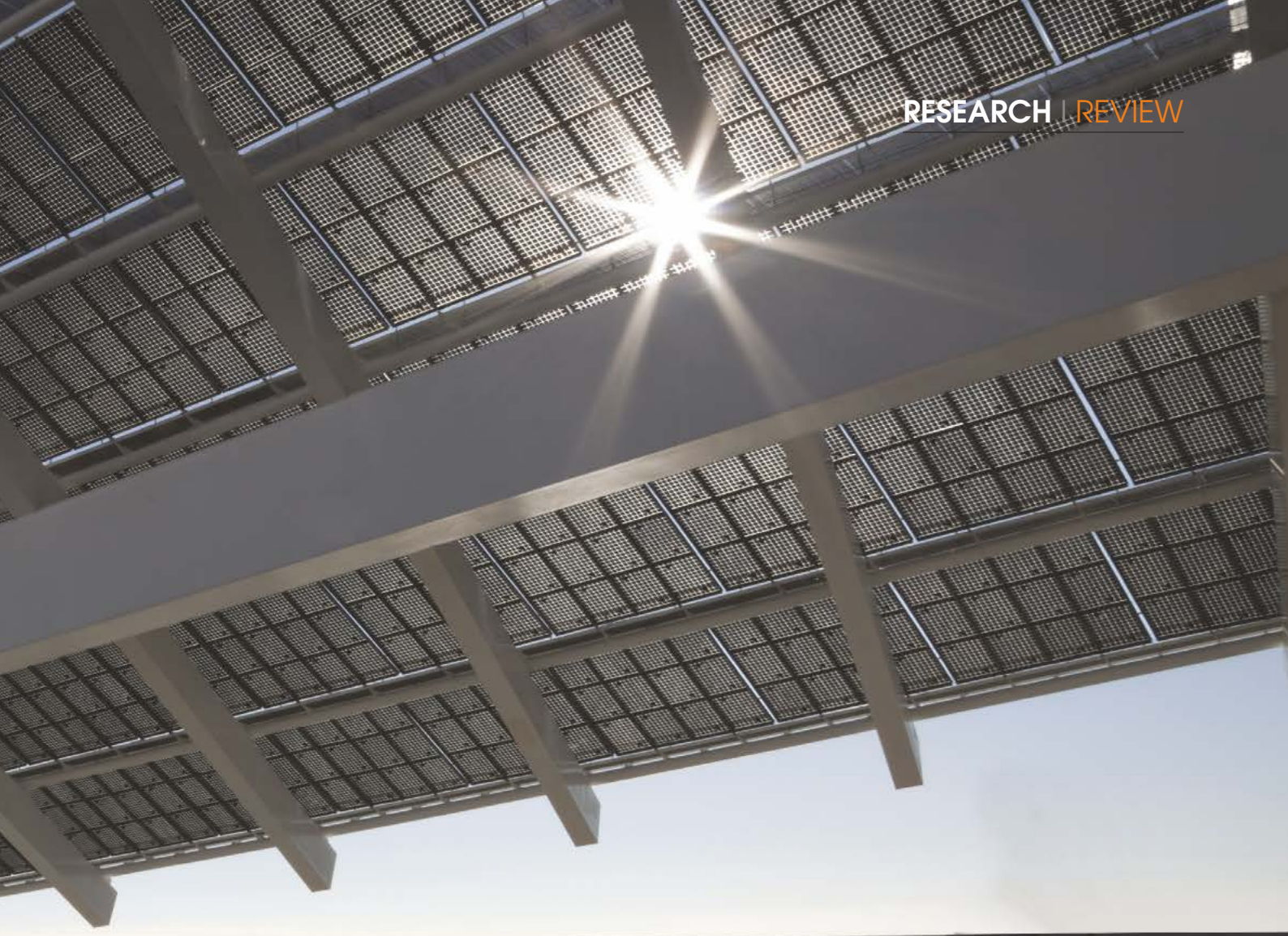
THE MOST POPULAR next-generation solar cells under development may have a problem -- the top layer is full of tiny pinholes, researchers at the Okinawa Institute of Science and Technology Graduate University in Japan have found. The majority of high-performance solar cells under development use a combination of materials including perovskite and spiro-MeOTAD.

These cells are far cheaper than traditional silicon-based solar cells, and their efficiency has been increasing significantly in the past few years. But perovskite, which is the layer that converts sunlight to electricity, degrades quickly.

OIST researchers believe they have identified a key culprit for this problem. Miniscule pinholes in the spiro-MeOTAD layer -- so small they cannot be seen even with a light microscope -- may be creating easy pathways for water and other gas molecules in air to diffuse through the thin film and degrade the perovskite.

"These pinholes may play a major role in the degradation of the lifetime of the solar cells," said Zafer Hawash, a PhD student at OIST who discovered the pinholes. His findings were recently published in the journal Chemistry of Materials.

Hawash noticed the pinholes while analyzing how independent components of air, like water, oxygen and nitrogen, interact with spiro-MeOTAD. At first he didn't think they were important, but when he started looking into it, he found no



mention of them in the scientific literature. "No one has really mentioned this," said Hawash, who works in OIST'sEnergy Materials and Surface Sciences Unit.

"I started realizing it was something important to report, to let people know these pinholes exist and that we should get rid of them to get better lifetime."

The pinholes appear to be related to how the spiro-MeOTAD layer is usually made -- a solution is spin-coated onto a base layer to create a thin film a fraction of the thickness of a human hair.

Another preparation method, vacuum evaporation, does not produce the pinholes, but is less convenient to use, explained Dr. Luis Ono, an Energy Materials and Surface Sciences Unit group leader and paper co-author.

The OIST team is looking into how they can eliminate the pinholes while still keeping the cost low, perhaps by tweaking preparation process or adding other ingredients.

"Currently we are making efforts in finding a way to fix the problem of the pinholes," said Professor Yabing Qi, who heads the Energy Materials and Surface Sciences Unit. This latest finding builds on the Qi's lab ongoing work to overcome the instabilities in perovskite solar cells and develop low-cost solar power.

Journal Reference

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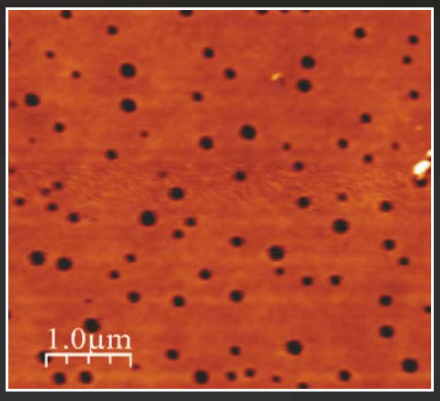


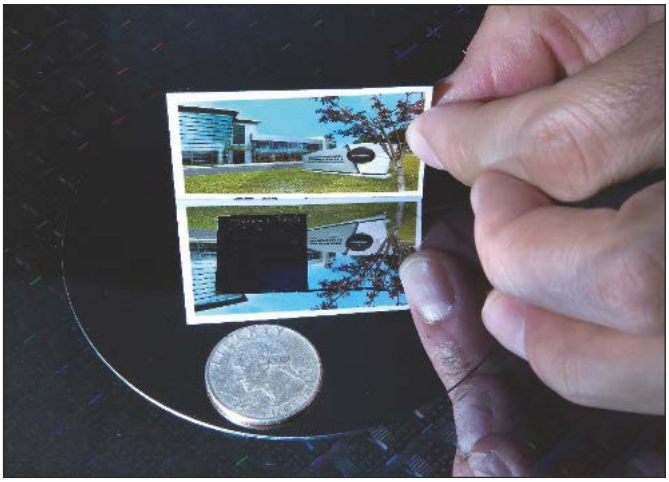
ATOMIC FORCE MICROSCOPY (AFM) images show pinholes in the spiro-MeOTAD when it is first prepared (top) and after air exposure for 24 hours (bottom). The average diameter of the pinholes is about 135 nanometers, with some as large as two microns. Credit: Image courtesy of Okinawa Institute of Science and Technology – OIST

Self-assembled nanotextures create antireflective surface on solar cells

Nanostructured surface textures—with shapes inspired by the structure of moths' eyes—prevent the reflection of light off silicon, improving conversion of sunlight to electricity

Reducing the amount of sunlight that bounces off the surface of solar cells helps maximize the conversion of the sun's rays to electricity, so manufacturers use coatings to cut down on reflections. Now scientists at the U.S. Department of Energy's Brookhaven National Laboratory show that etching a nanoscale texture onto the silicon material itself creates an antireflective surface that works as well as state-of-the-art thin-film multilayer coatings.

Their method, described in the journal Nature Communications and submitted for patent protection, has potential for streamlining silicon solar cell production and reducing manufacturing costs. The approach may find additional applications in reducing glare from windows, providing radar camouflage for military equipment, and increasing the brightness of light-emitting diodes. "For antireflection applications, the idea is to prevent light or radio waves from bouncing at interfaces between materials," said physicist Charles Black, who led the research at Brookhaven Lab's Center for Functional Nanomaterials (CFN), a DOE Office of Science User Facility. Preventing reflections requires controlling an abrupt change in "refractive index," a property that affects how waves such as light propagate through a material. This occurs at the interface where two materials with very different refractive indices meet, for example at the interface between air and silicon. Adding a coating with an intermediate refractive index at the interface eases the transition between materials and reduces the reflection, Black explained.



A closeup shows how the nanotextured square of silicon completely blocks reflection compared with the surrounding silicon wafer.

"The issue with using such coatings for solar cells," he said, "is that we'd prefer to fully capture every color of the light spectrum within the device, and we'd like to capture the light irrespective of the direction it comes from. But each color of light couples best with a different antireflection coating, and each coating is optimized for light coming from a particular direction. So you deal with these issues by using multiple antireflection layers. We were interested in looking for a better way."

For inspiration, the scientists turned to a well-known example of an antireflective surface in nature, the eyes of common moths. The surfaces of their compound eyes have textured patterns made of many tiny "posts," each smaller than the wavelengths of light. This textured surface improves moths' nighttime vision, and also prevents the "deer in the headlights" reflecting glow that might allow predators to detect them. "We set out to recreate moth eye patterns in silicon at even smaller sizes using methods of nanotechnology," said Atikur Rahman, a postdoctoral fellow working with Black at the CFN and first author of the study.

The scientists started by coating the top surface of a silicon solar cell with a polymer material called a "block copolymer," which can be made to self-organize into an ordered surface pattern with dimensions measuring only tens of nanometers. The self-assembled pattern served as a template for forming posts in the solar cell like those in the moth eye using a plasma of reactive gases—a technique commonly used in the manufacture of semiconductor electronic circuits. The resulting surface nanotexture served to gradually change the refractive index to drastically cut down on reflection of many wavelengths of light simultaneously, regardless of the direction of light impinging on the solar cell. "Adding these nanotextures turned the normally shiny

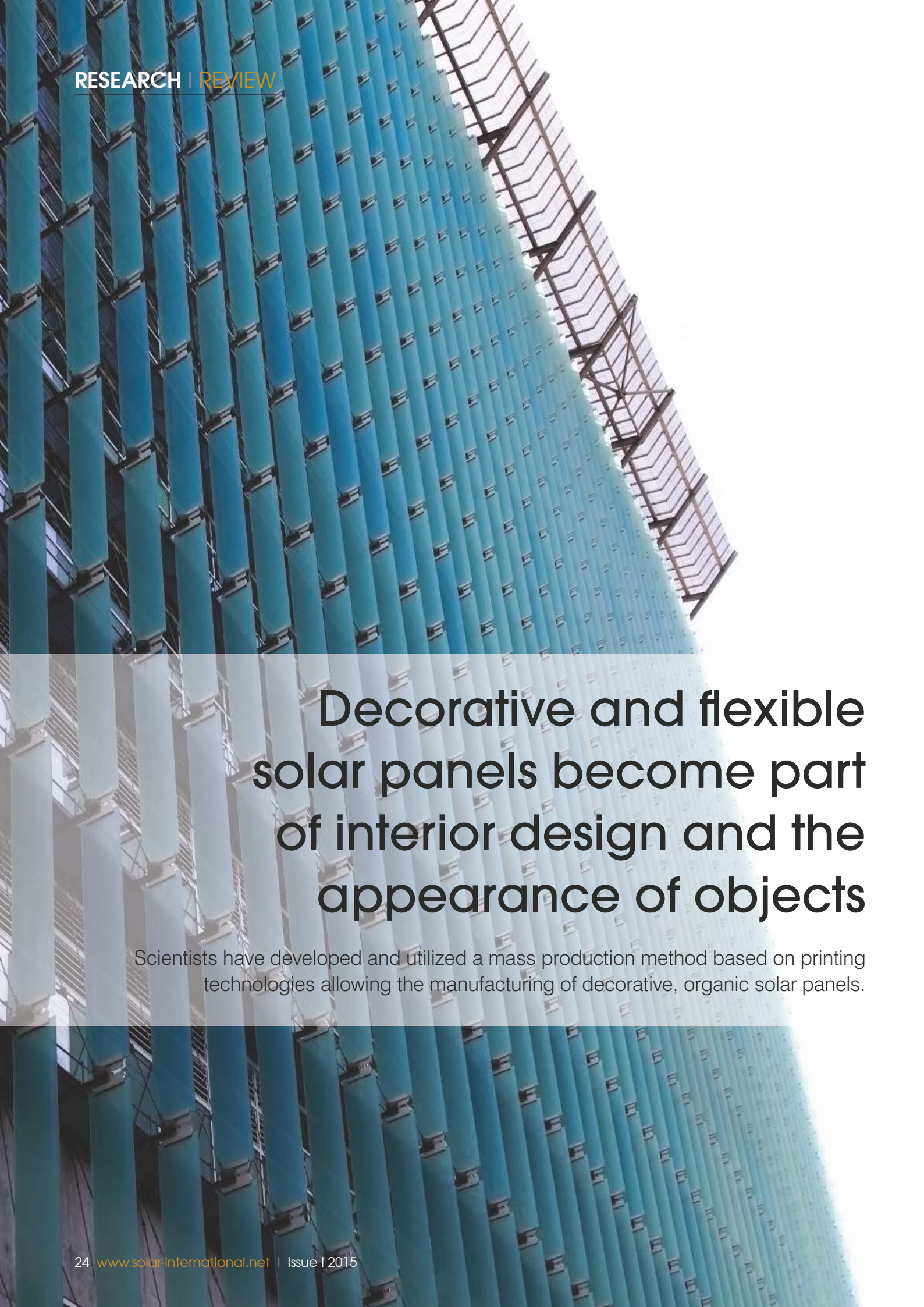
Chuck Black of the Centre for Functional Nanomaterials displays a nanotextured square of silicon on top of an ordinary silicon wafer. The nanotextured surface is completely antireflective and could boost the production of solar energy from silicon solar cells.

silicon surface absolutely black," Rahman said. Solar cells textured in this way outperform those coated with a single antireflective film by about 20 percent, and bring light into the device as well as the best multi-layer-coatings used in the industry.

"We are working to understand whether there are economic advantages to assembling silicon solar cells using our method, compared to other, established processes in the industry," Black said. One intriguing aspect of the study was that the scientists achieved the antireflective performance by creating nanoposts only half as tall as the required height predicted by a mathematical model describing the effect. So they called upon the expertise of colleagues at the CFN and other Brookhaven scientists to help sort out the mystery.

"This is a powerful advantage of doing research at the CFN—both for us and for academic and industrial researchers coming to use our facilities," Black said. "We have all these experts around who can help you solve your problems."
Using a combination of computational modelling, electron microscopy, and surface science, the team deduced that a thin layer of silicon oxide similar to what typically forms when silicon is exposed to air seemed to be having an outsized effect.
"On a flat surface, this layer is so thin that its effect is minimal," explained Matt Eisaman of Brookhaven's Sustainable Energy Technologies Department and a professor at Stony Brook University. "But on the nanopatterned surface, with the thin oxide layer surrounding all sides of the nanotexture, the oxide can have a larger effect because it makes up a significant portion of the nanotextured material."

Said Black, "This 'hidden' layer was the key to the extra boost in performance." The scientists are now interested in developing their self-assembly based method of nanotexture patterning for other materials, including glass and plastic, for antiglare windows and coatings for solar panels. This research was supported by the DOE Office of Science.



Decorative and flexible solar panels become part of interior design and the appearance of objects

Scientists have developed and utilized a mass production method based on printing technologies allowing the manufacturing of decorative, organic solar panels.

DESIGN FREEDOM improves the range of applications of the panels on the surfaces of interior and exterior building spaces. Researchers are also studying the feasibility of printing technology in the mass production of solar panels made from inorganic perovskite materials. The new mass production method enables to create interior design elements from organic solar panels (OPV, organic photovoltaics) harvesting energy from interior lighting or sunlight for various small devices and sensors that gather information from the environment. The panels can, for example, be placed on windows and walls and on machines, devices and advertisement billboards.

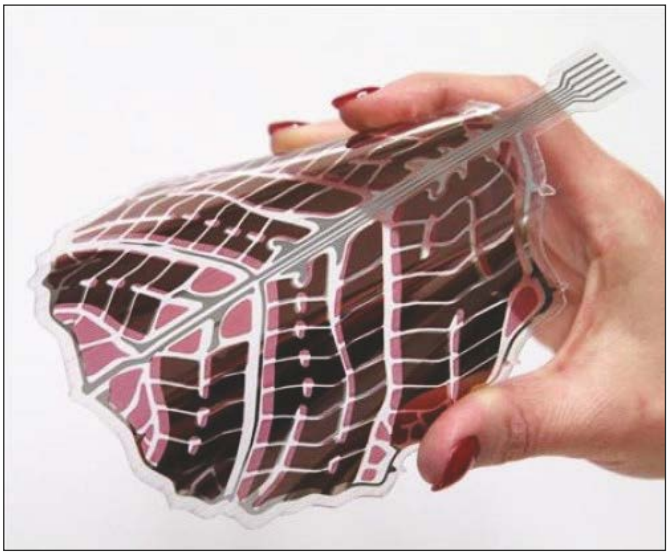
TT Technical Centre of Finland has developed and utilized a mass production method based on printing technologies allowing the manufacturing of decorative, organic solar panels. Design freedom improves the range of applications of the panels on the surfaces of interior and exterior building spaces. VTT is also studying the feasibility of printing technology in the mass production of solar panels made from inorganic perovskite materials.

The new mass production method enables to create interior design elements from organic solar panels (OPV, organic photovoltaics) harvesting energy from interior lighting or sunlight for various small devices and sensors that gather information from the environment. The panels can, for example, be placed on windows and walls and on machines, devices and advertisement billboards. Until now, it has only been possible to pattern OPV panels into a form of stripes.

The solar panel manufactured with VTT's gravure and screen printing technologies is only around 0.2 mm thick, and includes the electrodes and polymer layers where the light is collected. Furthermore, graphics can be printed to improve its visual appearance. VTT has proven the feasibility of the method in its own pilot manufacturing unit, using commercially available materials. VTT is commercialising this manufacturing technology with different operators, and is actively seeking new final-stage appliers of the technology.

The research scientists have tested the feasibility of the method by printing leaf-shaped photovoltaic cells. Active surface of a one leaf is 0.0144 m2 and includes connections and a decorative part. Two hundred OPV leaves make one square metre of active solar panel surface that generates 3.2 amperes of electricity with 10.4 watts of power at Mediterranean latitudes.

Organic solar panels are flexible and light, but their efficiency is lower compared to conventional, rigid silicon-based solar panels. The solar panels are manufactured with printing machines based on conventional printing methods using the roll-to-roll method, which enables the rapid mass production of the products: the printing machine can produce up to 100 metres of layered film per minute. The manufacturing of the OPV cells is affordable; the material consumption is low, and after use, the OPV panels can be recycled. The market for organic photovoltaic cells is developing, with a market breakthrough expected within three years. The operating life of panel is few years which is enough for many applications.



VTT has developed a mass production method allowing the manufacturing of decorative, organic solar panels. Active surface of a one leaf is 0..0144 m2 and includes connections and a decorative part. Graphics can be printed to improve the visual appearance. Credit: Antti Veijola

VTT is developing roll-to-roll manufacturing methods for inorganic perovskite solar panels

VTT is also currently examining how well the roll-to-roll printing methods are suited to the manufacturing of inorganic solar panels made from perovskite materials. The first perovskite solar cells manufactured in the laboratory using solution-based processes have been promising. The performance of this solar cell is roughly five times better than that of an organic photovoltaic cell, and the material costs can be even ten times lower.

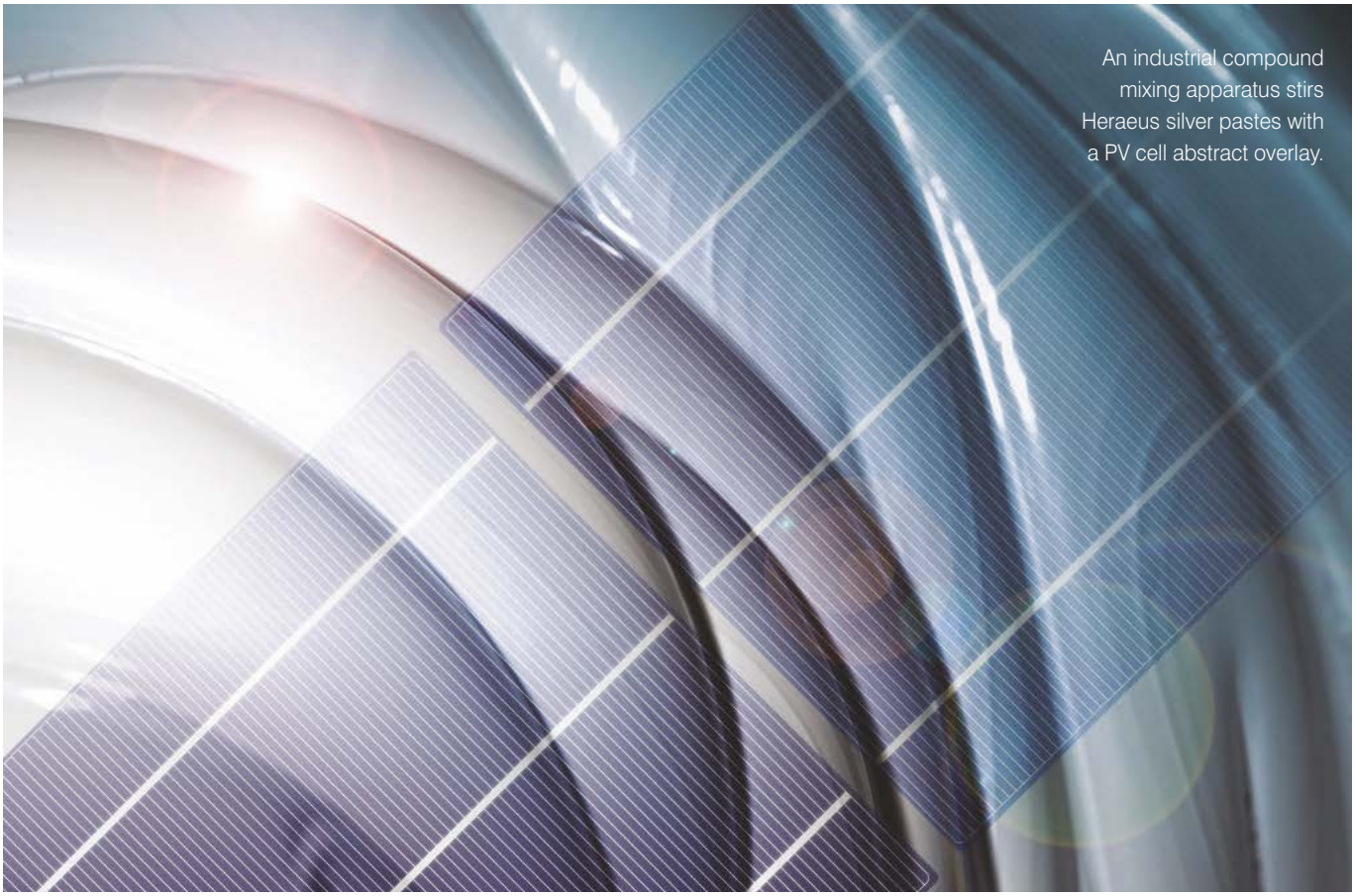
Freely designed decorative organic solar panels are applicable also in indoor use to harvest energy from indoor light. Production methods are cost-effective and materials can be recycled after the use. New materials such as perovskite can be printed with same methods and increase efficiency in future.

Using energy of light in data transfer

VTT is also developing a method to utilize light in wireless data transfer by using solar cells as data receivers.

This will open new application possibilities to utilize printable solar cells e.g. in IoT (Internet of Things) type applications, in which the devices can also harvest energy from the ambient light. The first results have been very promising.

Story Source: Technical Research Centre of Finland (VTT). "Decorative and flexible solar panels become part of interior design and the appearance of objects."



An industrial compound mixing apparatus stirs Heraeus silver pastes with a PV cell abstract overlay.

Heraeus fighting to set new PERC performance record

The Heraeus Photovoltaics Global Business Unit has released a new series of silver pastes that its tests have shown to boost efficiency in Passivated Emitter Rear Cell (PERC) technology. Part of the new SOL9620x series, the new products succeed the SOL9610 series that helped set a 21.2 percent cell conversion efficiency record in 2014 PERC testing by the Institute for Solar Energy Research Hamelin (ISFH).

HERAEUS' testing of their new SOL9620x series has shown 0.5 percent absolute efficiency gains on 90 Ω/sq. mono PERC wafers compared to the SOL9610. The SOL9620x achieves this in part due to lower recombination below the metallized contacts, resulting in an increase of the Voc of as much as 5 mV. The SOL962x series also has a 50 percent reduction in contact resistance compared to the SOL9610 series at a lower doping surface concentration. Improved performance of finger lines of SOL9620x together with non-firing through SOL325 busbar benefits overall PERC cell design performance, Andreas Liebheit, Head of Heraeus Photovoltaics, based in Shanghai, said recently that efficiency gains by the SOL9620x series should be attributed to continuing investment in R&D and partnerships with manufacturers as well as his company's abilities to continually customize and refine products for specific applications. This process is critical to PERC performance improvements.

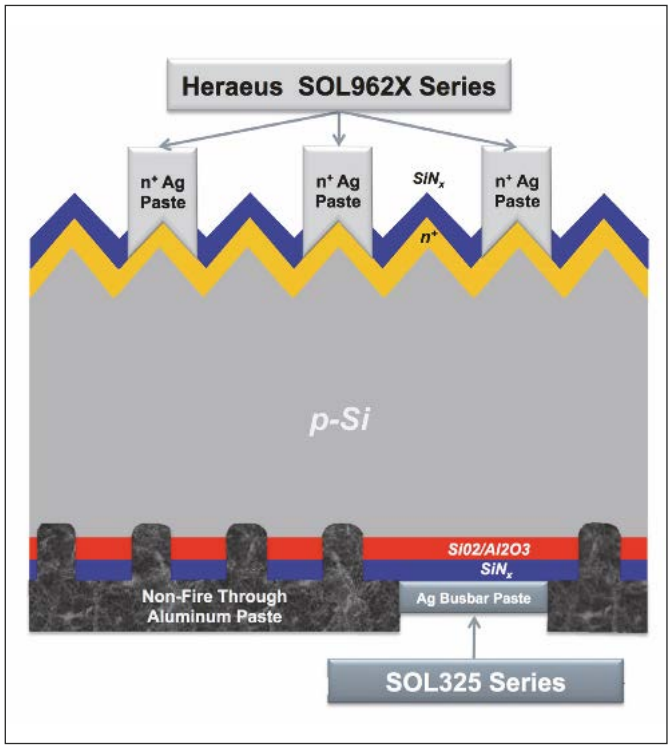
"With the new products added to our successful SOL9620x Series of front-side pastes, combined with our SOL325 Series for busbars, we believe that our partners and customers will have the ability to produce PERC cells with an even higher efficiency than with previous generations of pastes," Liebheit noted.

Are gains in efficiency enough to drive an interconnected global solar electricity generation market? While no one element can be singled out, industry watchers agree that efficiency is a key factor among conditions lining-up to make 2015 a banner year.

Solar industry forecasters see continued growth in PV installations for 2015. Success for solar depends as much on cell efficiency, unit cost reductions and improved manufacturing techniques as it depended in the past upon government subsidies, utility-grade investments and green-minded consumers.

The United States is on pace to complete its one millionth solar system installation in 2015 according to the Solar Energy Industries Association and GTM Research. While highly significant, the US doesn't by itself make or break the global market since 50 percent of solar capacity in 2015 will be found in China and Japan, according to Bloomberg Energy Finance. Growth across Europe and new Sub Saharan Africa markets is expected to be significant despite the fact some EU nations are reducing subsidies that fueled past solar technology gains.

Greater efficiency remains a key to solar's long-term success. Most economists and industry analysts agree that solar can only grow beyond a certain point if it is cost-competitive with other forms of electricity generation. PERC technology is inherently more efficient than traditional p type c-Si solar, usually by 1 percent absolute, yet the battle for 'efficiency supremacy' is fought across many fronts.



Pastes play a key role in photovoltaic cell manufacturing whether in the lattice 'fingers' or in the busbars that channel the electron flow into busways and then to inverters or DC storage.

Call it 'Quicksilver' for PERC manufacturing, the Heraeus SOL9620x series is helping achieve greater efficiency in the industry's latest PV designs.

Heraeus has formulated successive generations of silver paste that boost efficiency. As Liebheit explained, Heraeus sees its value when customers can use their products to increase the value of their cells and modules relative to next-best alternatives.

An efficiency gain impacts the entire value chain; it reduces the number of modules required for a given energy demand, thereby reducing the amount of poly-silicon, wafers, cells and the real-estate requirements for PV installations, not to mention the overall installation BOM.

PERC manufacturers are already working with the latest generation of SOL9620x to create products that are now entering the retail market. Dr. Weiming Zhang of Heraeus Photovoltaics, said that while Heraeus believes their new product is enabling greater efficiency, outside facilities are testing to quantify that belief; results are expected to show gains that outpace those of competing products.

"PERC is a key solar cell technology for improving conversion efficiency as a means to reduce the cost of solar energy. Heraeus employees were proud that our pastes contributed to ISFH's record cell performance in 2014 using our SOL325 and SOL9610 Series. Though that record has been surpassed, this only increases our motivation to use technology and our know-how to create better solutions that solve our customers' greatest challenges," remarked Liebheit.

The battle for efficiency supremacy continues. While Heraeus and its competitors each hope they'll win, the fact there are such competitions shows that consumers and global markets are the real arbiters of success and the ultimate winners.

Stellar solar 2014 sets stage for ambitious 2015

Industry observers agree that while 2014 set growth records across the globe, 2015 brings potentially greater opportunities up and down the solar value chain. By Mark Andrews, Solar International Editorial Consultant.

AS A TECHNOLOGY-DRIVEN ecosystem we can't consider 2014 without delving into how institutional R&D and manufacturers' initiatives have pushed cell efficiency to new highs. Enhancements to existing processes and new innovations show that solar is a dynamic industry with long-term viability and with profit growth potential.

Speaking of money and solar industry investment prospects, 2014 saw the cost of capital become less of a factor driving (or inhibiting) investors. As Mercantus noted in its 2014 North American Solar Trend Report, across 2,500 projects making up 60 percent of the US commercial and utility-grade solar market over two years, the cost of capital has fallen dramatically. Or to put it more plainly, each one percent drop in capital costs translates into a 20-30 percent reduction in cents-per-watt project costs.

On the technological side, component suppliers and PV manufacturers both large and small brought new products with potential to the table in 2014; get ready for a parade of new tech innovation throughout 2015.

PERC comes into its own

While many technology approaches can enhance efficiency and cut unit costs, it was clear in 2014 that Passivated Emitter Rear Contact (PERC) c-Si technology demonstrated it could be a manufacturing fit with existing infrastructure while also setting efficiency records. In a sizeable way, PERC is bringing to market performance benefits that wholesalers, retailers and end-use customers could readily embrace. High performance often means higher costs, so there naturally remains a market for lower-cost tech that meets needs with smaller upfront investment. But according to an NPD Solarbuzz (now IHS) report in August 2014, PERC capacity reached 2.5GW with manufacturers who were building advanced concept c-Si cells nearly

doubling output by third quarter of 2014 with continued growth expected into and through 2015.

The PERC backstory

Although well-regarded for years, PERC's efficiency and compatibility with existing plant infrastructure took-off in 2014 thanks to most major manufacturers having previously rung-out as many benefits as they could from eroding polysilicon prices and 'front side' tech advances like dual printing. As in any industry, manufacturers don't change underlying technologies unless there are gains to be had.
Dual printing technology had boosted efficiency for years and become widely utilised. Under pressure to continually improve performance and lower costs, technologies like PERC seemed logical 'next-steps' and the number of manufacturers working with it in 2014 increased dramatically. Perhaps more importantly this appears not as a 'spike' in the charts, but growth most analysts consider sustainable through 2015 and beyond.

That having been said, it is in a way simplistic to only see the shift to improved rear-side processing (a PERC hallmark) as a natural successor to front-side process optimisation. We should recall that end-market price drops occurred not just because polysilicon materials were cheaper; over-capacity also contributed.

Facing an abundance of high-performing cells and few choices to reduce costs further without costly plant investment, it becomes clearer why manufacturers re-examined enhancement technologies not already in production. PERC was already in many company's road maps, but formally moving in that direction grew out of a complicated mix of material cost reductions, markets transitioning through difficult years, followed by more robust growth. Yet opportunities were tempered by the fact that consumers had grown accustomed to declining prices. PERC offered clear advantages now that other economic forces had done their work; it could increase module power ratings, cut costs per watt and deliver more usable power.

It's worth noting at this point that while most c-Si cells use some type of rear metallization, there are inherent limitations to efficiency due to high surface recombination velocities that can inhibit superior efficiency. An added step is necessary to solve the problem; some type of passivation layer (such as the one enabled by PERC designs) became a strong ingredient in tech upgrades.

While manufacturers face challenges with PERC due to its unique attributes, 2014 saw these being overcome with strong drives among Asian c-Si manufacturers and in other regions. PERC is also interesting because unlike dual printing technology that could be purchased and implemented, PERC evolved through in-house expertise growing alongside proprietary solutions from vendors marketing key components. It wasn't and isn't a 'buy-this-new-widget-to-win' approach. But as the Institute for Solar Energy Research Hamelin (ISFH) showed in 2014, high performance including a record 21.2 percent cell conversion efficiency record set using commercial PERC products was achievable. Since then, other PERC manufacturers have announced even greater achievements.

The race is on

Findings from NPD Solarbuzz (now IHS) in both September and October 2014 point to two key PERC technology trends: there has been a sizeable shift to high-efficiency p-type, multi c-Si module production over the past two years. Secondly, mono-based technologies are still much in the game but growth is not as robust. Within the high performance categories, PERC is the leading rear side passivation technology, growing to 2.5GW in ramped annual capacity. PERC-based designs are of course still a minority within the overall market, but the trend is clear. While benefits from dual-printing/front-side technologies may take three to five more years to cycle through, PERC is at the start of its stride that should continue as markets further divide between premium

high performance systems and less costly alternatives that deliver less efficiency, but provide acceptable performance at a compelling cost differential.

New milestones

New efficiency records were set by PV technologies in 2014 that will be tested and no doubt foster innovative manufacturing initiatives for years to come. The most notable efficiency boost came from University of New South Wales (UNSW) researchers in Sydney, Australia who demonstrated the highest performance of a PV system late in fourth quarter 2014.

The UNSW team achieved 40.1 percent efficiency using a 'power cube' approach with conventional cells arranged together with UNSW's performance-enhancing additions with focused sunlight to replicate grid-level commercial systems that employ solar cell towers and fields of tracking mirror arrays. National Renewable Energy Laboratory (NREL) scientists in Colorado achieved 40.4 percent efficiency when working to replicate the UNSW work in November.

While researchers at the UNSW essentially doubled their photovoltaic efficiency performance compared to records they set in 1989, the 21.2 percent cell conversion efficiency record set with commercial PERC cell tests by the ISFH shows the disparity between high-as-we-can-go experiments and real-world performance. ISFH researchers were testing conventional state-of-the-art manufactured cells that could already be in a panel sitting on your rooftop. UNSW researchers demonstrated what is possible in highly-advanced PV cell technology, yet it will take a while for milestones like 40 percent efficiency to translate into purchasable products. But setting milestones paves the way for innovations, demonstrating once again that solar power technology in 2014 rides on a wave of innovation into 2015 driven by market forces that are gaining momentum.

Boosting green manufacturing practices

While solar-based electricity generation is undeniably greener that fossil fuel-based power plants, it's also clear that processes used to manufacture key components can consume a great deal of energy while involving chemistries and processes that are not themselves environmentally friendly. One such factor was addressed in work by UK-based researchers at the University of Liverpool made public in mid-2014. Looking for a way to find non-toxic salts to replace cadmium chloride that enhances and 'activates' conversion of photons into electrons –a critical step for PV cells to operate, researchers discovered that magnesium chloride (commonly extracted from sea water and found in everything from bath salts to tofu,) could lessen or outright eliminate the need for toxic cadmium chloride.

The U of L work doesn't eliminate all cadmium from the equation. But by switching to magnesium chloride researchers found they could activate cadmium telluride quite well; it was simple to apply using materials purchased from a local hobbyist centre; no exotic new processes were involved. Existing manufacturing with cadmium chloride works very well, which likely explains why industry has not sought alternatives. But the U of L research shows that toxic by-products could be eliminated, and since toxic chemicals not only pose in-plant safety hazards, they come with hefty waste disposal costs. Manufacturers are bound to take note of the work in Liverpool that could save tens of thousands of dollars/euros/pounds each year.

Solar increases world energy market position

Solar's contribution to satisfying the world's hunger for more electricity also grew in 2014. The year had a record-setting first quarter, particularly with gains in Japan, the UK and Germany, which continued throughout the year with minor fluctuations. The researchers at Solarbuzz (now IHS) tallied 9,000 additional MW early in 2014, with projected increases to total 50,000MW by year's end. Meanwhile, the IHS organization projected a gain of 46,000MW for 2014. While those numbers are still being finalised, it's clear records were set, performance that was attributed to many forces including the continued decline in unit cell and PV panel prices compared to earlier generations based upon a watts-per-dollar/euro/yen or RMB basis. It is expected that 2014 will represent the fifth straight year of net gains despite uneven world economic recoveries.

Where were most of the gains in solar capacity made in 2014? Look to the top 10 countries that are deploying PV systems including China, Japan, the United States, the UK and the top trend-setter of Continental Europe, Germany. The actual types of deployments varied greatly between major solar countries, with grid-level systems favoured in China

while more system variations were found in the United States, along with a relatively even distribution in other areas where government and institutional investment in solar systems fostered both residential and grid-level installations.

China is a particularly interesting market to examine given the number of PV manufacturers based there and the government's growing emphasis on solar power taking a more active role in its energy future. At the beginning of 2014, the official forecast for growth in generating capacity saw adding a bit over 11GW of capacity while outside analysts saw growth as little as 7GW and as much as 13GW. According to InterSolar analysts, the Chinese finished 2013 on the high end of forecast, adding about 13GW, making them one of the more aggressively growing markets. While most countries for top solar investment rely heavily on a mix of private and public capitalization, China's preference for top-down planning with its evolving Five Year Plans can do a lot to drive a market.

Germany is a stand-out among solar success stories worth examining because of its declared commitments to independence from non-renewable sources by 2050. This has helped create a somewhat unique public/private partnership. Like many countries across Europe and the world, Germany uses a FIT (Feed-in Tariff) to help finance its move away from non-renewable resources. In Germany this has resulted in a very large commitment to PV-based solar systems. Installations continue to outpace government targets and they set a record in 2014 during the first quarter, generating 27 percent of the country's electricity due to favorable weather and a record number of installations. They also achieved cost parity with other forms of electricity generation. It's notable that what Germany achieved (27 percent) is double that of what the US generated, approximately 13 percent from all renewable sources.

To be fair this is not completely 'apples to apples' due to timing of the research (the US was measured in late 2013 and Germany's achievement was in first quarter 2014,) but it does show how the 'solar-rich' countries in Europe, despite arguably more challenging weather conditions, are outpacing the US in terms of commitment to renewable resources. Big Oil take note: you still have a great friend in Uncle Sam. But one should remember that the United States is by itself significantly larger than most countries and has emerged as the world's largest producer of domestic natural gas thanks to its pioneering hydraulic fracturing technology. Whether you are a fan of this process or consider it a ticking time bomb of engineering recklessness, its capabilities in areas rich with oil shale have left the US somewhat less incented to foster renewables growth right now compared to areas of the world where energy resources are typically not of domestic origin.

Looking ahead to 2015, major solar growth areas should continue to be in Asia, with China and Japan making up

50 percent of expected added capacity in 2015, followed by the United States and Europe, according to the US-based Energy Information Agency (EIA) and researcher GTM. Government-backed incentives across the board will continue to drive investment in solar energy throughout 2015. While incentives are trailing-off in some countries, researchers expect that they will have positive market impacts as manufacturers strive for efficiencies and cost of power generation using solar technologies move much closer to parity with fossil fuel-generated electricity.

In the United States, its Income Tax Credit (ITC) program is slated to drop from 30 percent to 10 percent starting in 2016, but most experts agree that even if this sizeable reduction continues unchanged by the US Congress, the present level of ITC will incent even the most cost sensitive fence sitters to make a move in 2015. Many US legislators and President Barack Obama favour a more gradual, phased reduction in incentives, but it remains to be seen if this will be adopted.

The United States is on track to set new records for solar installations in 2015. 2014 was a record-setter, with installed capacity reaching more than 17.5GW. Nearly 600,000 US homes have solar systems and nearly 150,000 persons have jobs tied directly to the industry. In 2015 the US should see its one millionth solar installation. As seen in every country with significant solar adoption, increasingly efficient PV cells, reductions in system costs, diversifying purchase options and government incentives of one type or another are all benefitting the industry.

It's interesting to note that while pending development of nuclear, gas-fired and coal-fueled power plants remains largely stalled in the US, solar is the one generating technology that continues to grow. Widespread backing in 'solar hotspots' such as California, Arizona, the US Northeast and North Carolina lead in the amount of overall solar capacity they have and are expected to add.

Tax incentives aside, communities and individuals are backing solar compared to other alternatives. Proof continues to roll in, not the least of which was an announcement by First Solar on 11th February that Apple Computers is committing up to $848 million to back First Solar's clean energy development in Monterey California. It is expected to meet 100 percent of the company's projected energy requirements when it comes online at the end of 2016. The contract is for 25 years.

Storage finds new momentum

Whether for electric vehicle (EV) battery packs or serving as the link that lets consumers cut ties to local utilities, efficient and cost-effective storage remains a critical piece of the puzzle in renewable energy. 2014 saw this 'puzzle' become markedly more solvable thanks to ongoing technological advancements, new projects and long-term commitments by brand-name market players. 2014 was the year that saw storage take centre stage thanks to major projects in California, Hawaii, Nevada, Illinois, North Carolina and other locations around the globe. First on the list of headline grabbers is the news that Tesla Motors is moving ahead with the 'Giga' factory in southern Nevada. The mile-long program is grandiose on the scale of the pyramids. Elon Musk's plan to flood the world with high quality lithium batteries is on track to satisfy the company's long range goal of producing 500,000 EVs by 2020 while supporting solar power needs in the bargain.

Tesla forecasts up to 50GWh in annual battery production by 2020. Plant start-up is forecast between 2016 and 2017. Along either timeline the Giga-Factory could be a real game-changer, enabling new generations of EVs at lower prices that the company promotes as being more family-friendly (i.e. cheaper) compared to today's top-shelf roadsters and the popular Model S that can be had for a 'mere' $75,000.

Sticker shock keeps some buyers away from premium-shelf EVs, but the issue in China seems to be more marketing fall-off than price for the country's top tier car buyers. EV sales have not been living up to expectations and its believed that Tesla will 'reenergise' the market with a stronger sales initiative including staff shake-ups to regain momentum and get closer to its ambitious goals, according to market watcher and researcher Doug Young based in Shanghai.

On the other side of storage are the so-called 'Jake and Elwood' twin 19.8MW lithium phosphate energy storage systems outside Chicago, Illinois, announced by Renewable Energy Systems Americas in 2014. Southern Cal Edison announcement that it was procuring 261MW of storage instead of the 2014 mandate of 50MW for its local

> "Looking ahead to 2015, major solar growth areas should continue to be in Asia, with China and Japan making up 50 percent of expected added capacity in 2015, followed by the United States and Europe, according to the US-based Energy Information Agency (EIA) and researcher GTM"

customer base, supporting load leveling and related power management needs. New battery technologies entered the fray as well, with start-up Alevo announcing that it was moving forward with a lithium ferrophosphate battery technology that it has been developing for 10 years. The new home of this technology is a 4 million square foot former cigarette plant in North Carolina. That plant is the size of nearly 40 Walmart retail centers. The irony of a clean energy super-plant being built inside a former cigarette factory has not been lost of even the most pro-carbon pundits.

Just as lithium battery-based growth was making headlines last year, makers of alternative chemistry/alternative technology storage systems were making their own noise. A large number of redox flow battery companies in various stages of funding sought the public eye. Redox flow solutions utilize tanks of electrolytes that can be scaled up or down to meet grid requirements – these are emerging from laboratory testing to trial project status of various sizes in the field.

Companies including Ambri and Aquion are entering the market with promises of solutions for utility companies to manage peak demand periods with leveling approaches that, when paired with innovative generating tech including solar, wind and other renewables, could deliver long-term solutions far removed from non-renewable generation options that don't include any way to 'warehouse' power. Often overlooked in many solar and energy-related headlines is the continuing growth of hybrid meters. Companies like Stem and GreenCharge Networks are deploying behind the meter at scale with financing coming online.

Add this to the reality that as grid-level solar becomes more affordable, and thanks in part to investments that made these utility-grade developments possible in the first place, we are starting to see some solar panel and battery companies morph into utilities, albeit at smaller scales than the long-entrenched public utilities that electrified the world starting in the late 19th century. As examples, SolarCity announced it will include batteries in default offerings, giving customers a 'no-brainer' option for largely cutting the cord to local power monopolies. SunEdison bought FirstWind, and SunPower acquired the micro inverter company SolarBridge.

In Europe, E.On, Germany's largest utility, sold-off poorly performing generation assets while exploring ways to rebuild itself into a customer focused distribution utility. At the same time public utilities in Florida and a few other US states have fought off state-funded incentive programs over fears that in sunshine rich areas like Florida, it is becoming increasingly easy for consumers to flip the switch on solar and pocket traditional monthly expenditures for power while insulating themselves from arbitrary future utility rate hikes.

Several traditional utilities put off or cancelled solar-based projects in Florida or elsewhere, with industry watchers crediting the move to either hopes that natural gas prices in the US will remain low, or, that utilities were motivated to stay out of the solar arena given the technology's long-term impact on their business models that are heavily dependent on fossil fueled systems.

The future is bright

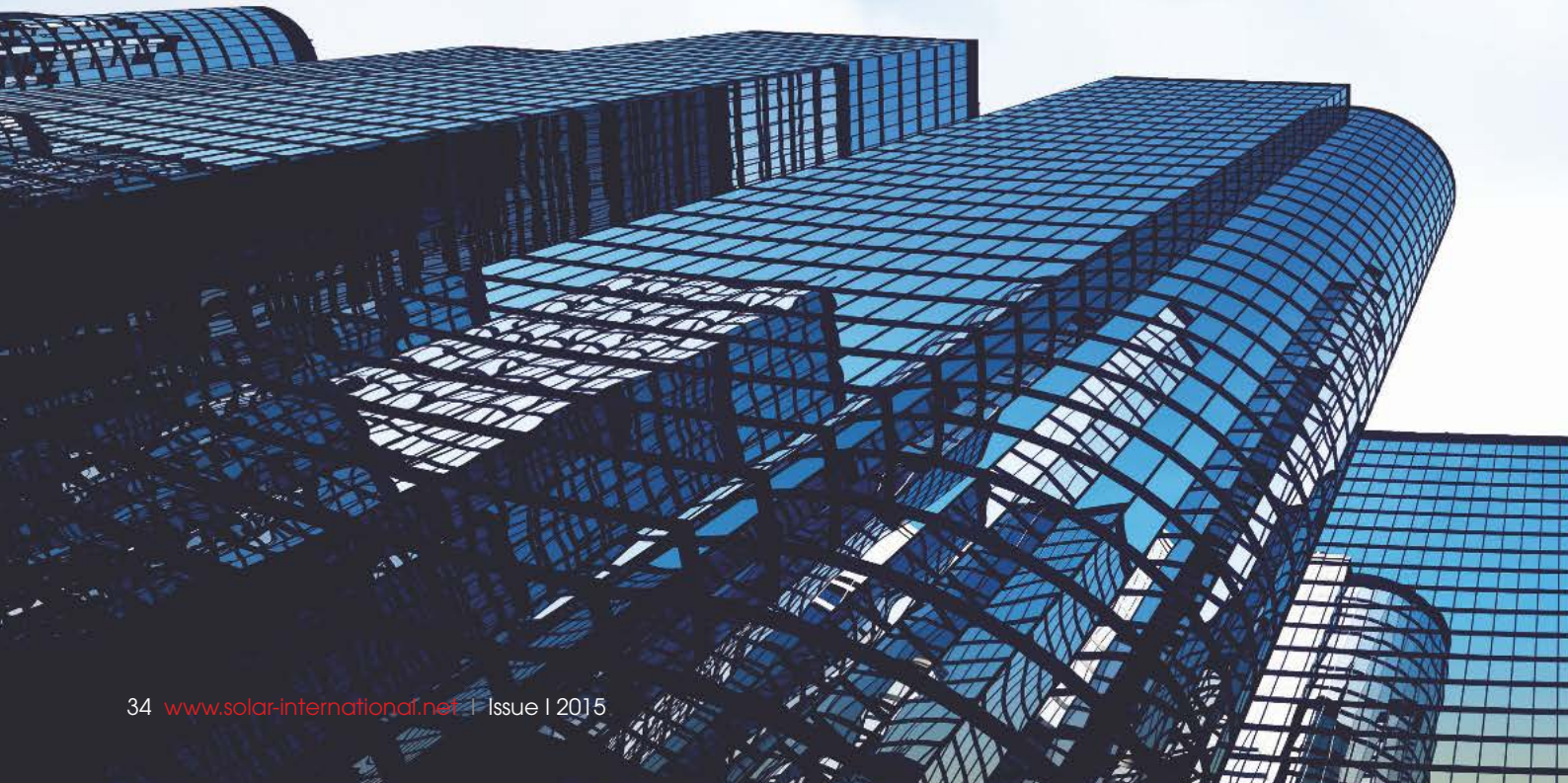
By any measure, 2014 was a stellar year for solar innovation both in technology and business growth. Investors are seeing real opportunities that underscore the short- and long-term viability of the renewable energy market. While installed systems begin to age, solar companies up and down the value chain have to start reckoning the cost of long-term maintenance into their game plans. While this may add some cost implications, it may also create opportunities for companies that do not now derive the bulk of their profits from maintaining previously installed systems.

Success by solar to innovate and grow its market share is evident to the point that even the most skeptical critics have to admit that dollars, euros and pounds invested in solar are making sense like never before. While government-backed subsidies are ending or slowing in some locations, these reductions are due in large part to the industry's own success at proving its viability without sizeable government intervention. The numbers show where the industry is headed; solar is starting to thrive and should continue to do so well into the future.

- Note: Look for explorations of technology advancements, economic impacts and the implications of long-term growth in future editions of 'Solar International.'

SEAMLESS INTEGRATION
OF THIN-FILM PV

Over the last decade, the industry has witnessed the growth of crystalline Si based photovoltaics at the expense of thin-film technologies. This has led many to rethink the opportunities offered by thin-film photovoltaics and the technological needs to serve specific markets like building-integrated photovoltaics where thin-film photovoltaics would offer unique opportunities. Tom Aernouts - group leader organic photovoltaics at imec and Jef Poortmans - scientific director photovoltaics, professor at K.U.Leuven discuss.



ENERGY EFFICIENCY is a keyword in many strategic documents about the evolution towards a sustainable energy system (IEA, EU Commission, …). Given the fact that the energy used in buildings accounts for a significant part of the energy consumed (20-40 percent), it is clear that improving energy efficiency in buildings will be a crucial factor towards the goal of a more sustainable energy system. This is the rationale behind European directives (see e.g. EU directive 2010/31 on energy performance of buildings and its translation in national legislation).

In these directives it is stated that Member States shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings. This has to be achieved by measures at or near the building.

It is obvious that the integration in buildings represents a unique opportunity for PV-modules at the condition they are integrated in an aesthetically attractive way in the building and can serve multiple purposes besides generating electricity like protection against external moisture, partial shading to reduce cooling requirements in the building, ventilation, … Especially the aspect of aesthetics is not be underestimated. In this context building-integrated photovoltaics (BIPV) is to be discriminated from building-added photovoltaics (BAPV).

In the latter the PV-modules are just added on an existing building, whereas in the former the integration of the PV-module in the building envelope of the new or to be renovated building is part of the design process from the beginning which results in aesthetically much more appealing solutions.

It is also becoming more and more clear that in order to reach this improved aesthetics, architects and project developers would like to go beyond the use of standard PV-modules in terms

of dimensions, shape, outlook, colours and transparency as to leave them a maximum of free design space. These aesthetical aspects combined with the multi-functionality of the PV-module – it is to be considered as a building component rather than a pure electricity generating device – are also an attractive opportunity for the PV-industry as it opens up the possibility of broadening product competition scope beyond the level of pure costs on the level of Euro/Wp. The knowledge about the local rules and norms for buildings and the close interaction with building component companies is a necessity to be successful in this emerging market. This represents obviously an excellent opportunity for a value chain in which European-based companies can build up a sustainable business model.

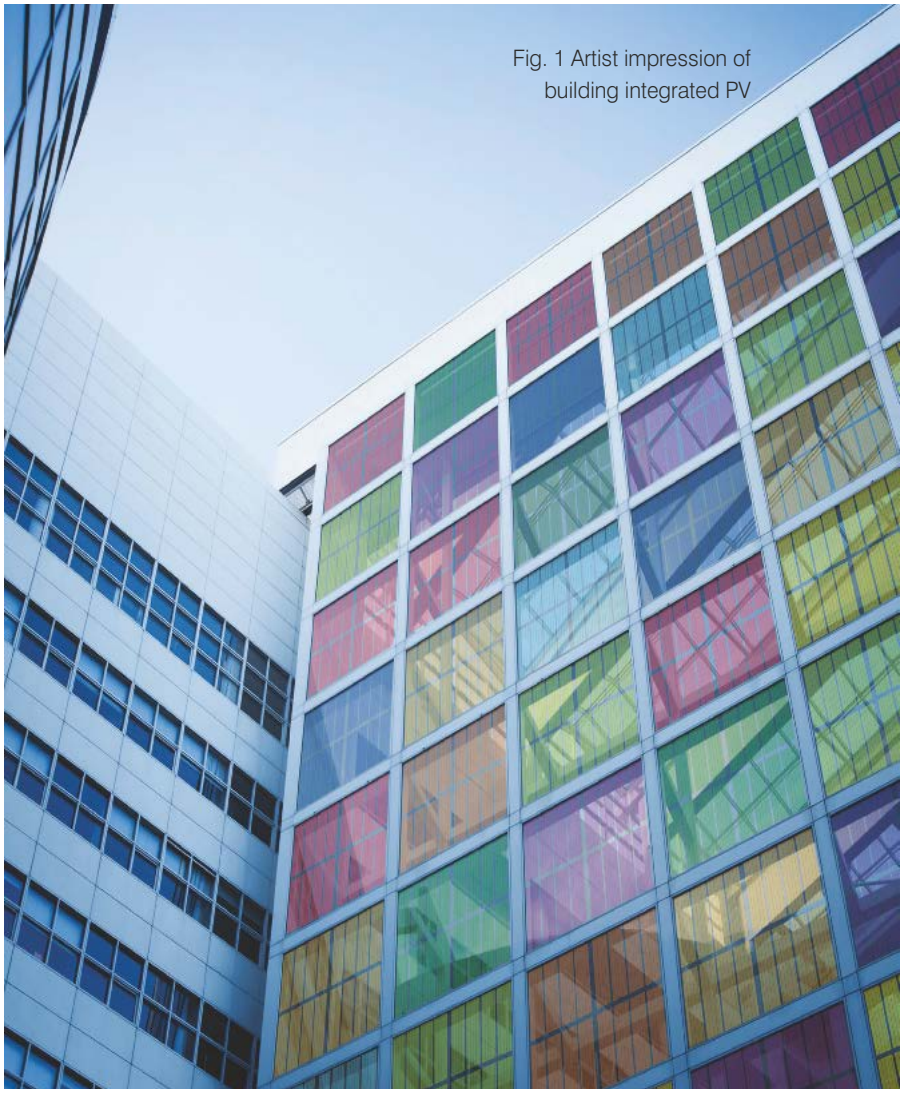


Fig. 1 Artist impression of building integrated PV

Building-integrated photovoltaics and thin-film photovoltaics

Thin-film photovoltaics has a number of assets which make it particularly attractive to reach the improved aesthetics and design freedom requirements outlined above. The rather naïve idea over the last decades that thin-film PV would replace crystalline Si based PV purely based on cost advantages has to make way for a more realistic view that thin-film PV will in first instance make it in applications where some of its unique properties can be exploited to the full extent. BIPV is definitely such an area. The possibility to integrate thin-film PV on a broad variety of carriers, either flexible or rigid, its homogeneous outlook extending to the possibility of reaching for homogeneous semitransparency, its response under indirect light and its reduced T-coefficient are all important assets which are less easily achieved by crystalline Si. These assets have been proven in a number of attractive demonstration projects.

Maximum design freedom with thin-film PV freeform module technology

Beyond these favourable features of thin-film PV for BIPV, the design freedom for the architects, project developers and the design of the electrical system of the building can be further enlarged by developing a thin-film PV module technology which deviates considerably from the industrial practice nowadays. The present practice for thin-film PV module technology is still mostly based on the traditional sequence of layer deposition followed by a scribe to define the separate cells and realize the interconnection between the cells. This procedure has been optimized for different thin-film PV technologies in terms of reduced dead area etc. but leaves relatively room for varying dimensions and also reduces the freedom on parameters like output voltage of the module (the voltage is essentially determined by the number of cells in series which is fixed).

To cope with these limitations came the idea to disruptive module technology development where first all the layers are being deposited on a substrate and only afterwards the scribes are made and the interconnections are being realized by printing. This leads to an interesting restructuring of the value chain in the sense that the front-end of the process (deposition of all the layers, e.g. by a glass manufacturer which would like to increase the value of its end product) is now separated from the back-end part of the process (the scribing and printing) which can now be executed by the building component manufacturer or a company working closely together with the latter. Such a freeform module technology development will be specific for different active absorber materials as it relies on depth selectivity of the different scribes and the realization of contacts with low contact resistance and stable contact interfaces.

Freeform module technology development in imec and Solliance

Within the Solliance consortium, in collaboration with Smit Ovens, novel equipment has already been developed, addressing this back-end technology. It

allows for inline laser scribing of thin-film PV modules whereby the interconnects are finalised with an additional inkjet printed line of Ag-based conductive ink. The Solliance consortium has the ambition to demonstrate this newly developed process flow on two main thin-film PV technologies, being the more established CIGS technology, and the newly emerging Perovskite based thin-film PV technology.

In the current thin-film PV market, mainly three different technologies are commercially available. Where over 10 years ago amorphous-Si was by far the largest market for thin-film PV (above 10 percent of the total PV market), nowadays it has been shrinking to below 1 percent of the total PV market. Nonetheless, the excellent progress in performance, both in efficiency and reliability, that has been achieved in the last few years for thin-film PV technologies like CdTe and CI(G)S, in combination with cost-competitive production has ensured that thin-film PV was able to maintain its market share in an overall growing PV market still at the level of 7-9 percent. Noticeable there is also that CIGS is substantially growing its share, reaching a 1.5GW production in 2014, whereas CdTe is stagnating and a-Si even declining. It is believed that CIGS will indeed continue this growth and so becoming the lead TF-PV technology for the coming years.

The emergence of organic-inorganic Perovskite materials in the field of photovoltaics occurred actually by introducing these compounds as potential dye material in dye-sensitized solar cells. Rapidly it turned out that the Perovskite material has also very good charge transporting properties making first the use of an electrolyte and later even the mesoporous TiOx-structure obsolete. This resulted in a device architecture whereby a single, planar layer of Perovskite material of ~300nm, sandwiched in between selective contact layers, acts as an efficient absorber, charge generation and charge transporting medium.

This development took less than 5 years to raise the efficiency from the level of a few percent to a current state-of-the-art 20.1 percent. Since this performance has not yet been demonstrated neither for pure organic nor for dye-sensitized solar cells, perovskite-based photovoltaics has raised a lot of attention and is considered nowadays as the highest potential next generation thin-film PV technology. Nonetheless, two major concerns are to be taken into account, next to developing scale-up of this technology, before perovskite PV can be actually brought into market applications. The first one is the issue with stability, whereas current understanding is that control of humidity is crucial to enable device operation lifespans of many years. Secondly, the current perovskite compounds used for PV contain a central lead atom. For health, safety and environmental reasons alternatives have to be found to replace this component.

The Solliance consortium has a strong track record in CIGS device and process developments and will complement that further with demonstration of this new back-end process still this year. The developments in the field of perovskite modules are based on the strong background that Solliance has built up in the field of organic photovoltaics.

Conclusion

Thin-film PV modules have unique characteristics (can be integrated on a broad variety of substrates, can be made semitransparent with a homogeneous outlook, have a good response under indirect light, ...) that make them the ideal candidates for realizing multifunctional electricity-generating building components. But for architects and project developers to be able to use these building components, more flexibility needs to be introduced. A thin-film technology is required that allows to adjust dimensions, shape, outlook, color, transparency and even output voltage of the PV module.

Within the framework of the Solliance consortium, a new thin-film PV module technology is being developed that fulfills this need. It is a freeform module technology in which first all layers are deposited on a substrate and afterwards the scribes are made and interconnections are printed.

This new technology makes it possible to restructure the value chain: the building material supplier (e.g. glass manufacturer) deposits all the thin-film PV layers on the material and the building component manufacturer uses this material to finalize the product (e.g. a solar window) by scribing and printing the contacts. This latter party can determine dimensions, shape, outlook etc. It is our conviction that such a new technology and business model will enable to accelerate the development and market introduction of building-integrated PV.

Authors

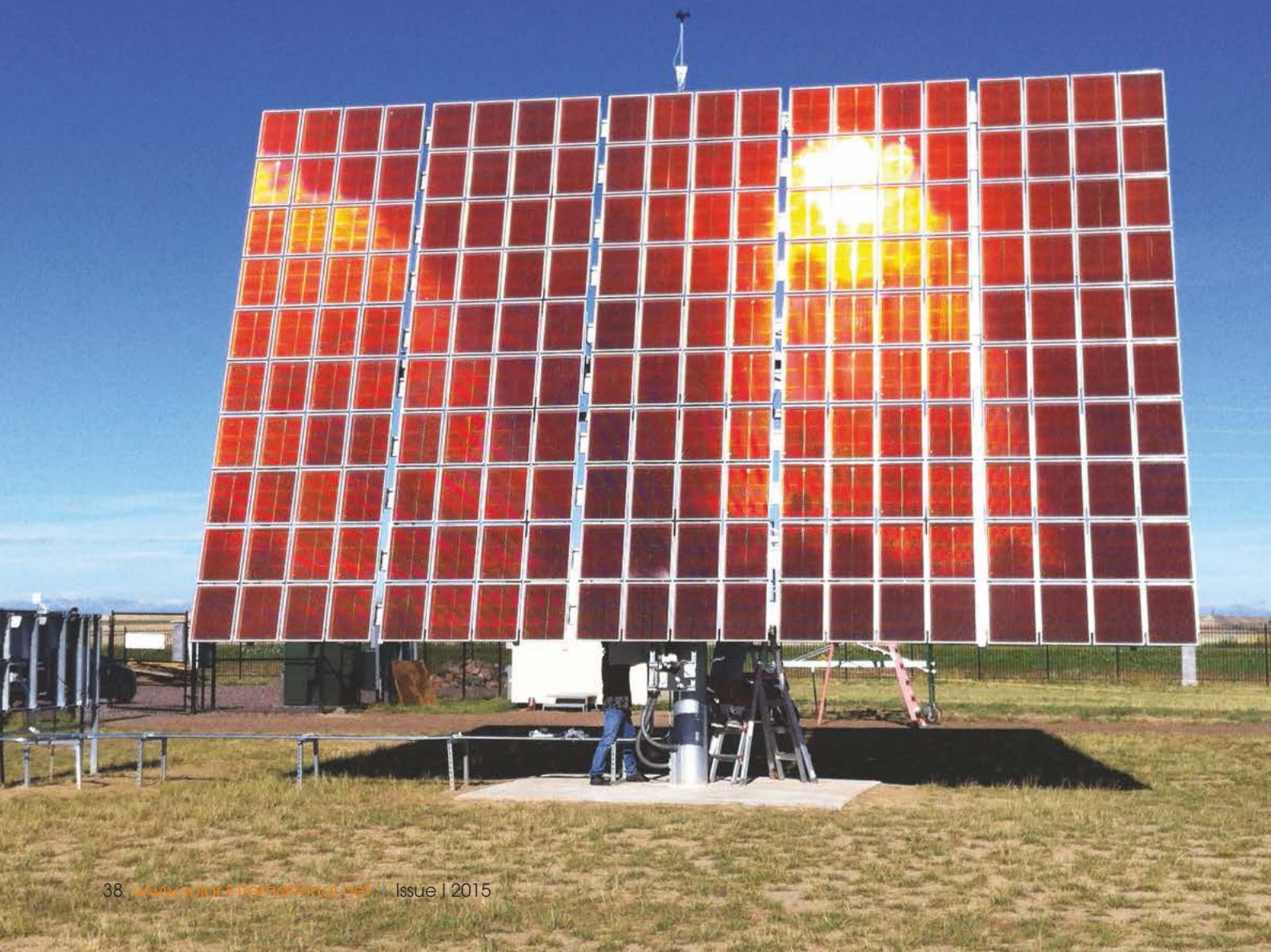
Tom Aernouts - Group leader organic photovoltaics.
Dr. Tom Aernouts is R&D team leader of the organic photovoltaics team at imec since 2006. This team grew from an initial 4 persons at that time to more than 10 currently. Also the lab environment was drastically improved with setting-up the O-line infrastructure at imec, allowing the processing and characterization of organic solar cells and modules with area up to 15 x 15 cm^2. He earned his Master of Science and PhD degree in Physics at the Catholic University of Leuven, Belgium.

Jef Poortmans - Scientific director photovoltaics, professor at K.U.Leuven. Dr. Jozef Poortmans received his degree in electronic engineering from the Catholic University of Leuven, Belgium, in 1985. He joined the newly built imec in Leuven where he worked on laser recrystallization of polysilicon and a-Si for SOI-applications and thin-film transistors. In 1988 he started his PhD study on strained SiGe-layers. Both the deposition and the use of these SiGe-alloys within the base of a heterojunction bipolar transistor were investigated in the frame of this study. He received his PhD degree in June 1993.

MAGNIFYING MARGINS WITH MICROCELLS

Parallel printing of miniature multi-junction cells offers a low-cost, scalable approach to the production of CPV modules

BY KANCHAN GHOSAL AND MATTHEW MEITL FROM SEMPRIUS



THE CPV INDUSTRY is in the midst of a transition. The days of building first-generation prototype systems are now behind us, and the manufacture of high-performance, reliable systems that can turn a profit are underway. Deployment is rising fast, with installations of 80 MW in 2013 following on the heels of about 40 MW in 2012, and suppliers such as Soitec have shown five-year field results with minimal degradation and an availability in excess of 99 percent.

However, despite all this success, CPV is still dwarfed by the incumbent solar technology, silicon – deployment of this totalled 40 GW in 2013. The plummeting prices of crystalline silicon over the last few years have made it challenging for advanced technologies that are not already at gigawatt levels to make a commercial impact.

One solar technology that can compete is a novel form of CPV developed by our team at Semprius, headquartered in Durham, NC. Our CPV technology is based on the parallel printing of thousands of cells, which are far smaller than those used by other CPV companies. Thanks to this move to greater miniaturization, alongside the selection of cost-effective, high-quality materials and processes, it is possible to address the challenges of scale, cost and reliability that must be overcome to have success in today's highly competitive solar market.

The micro-assembly technology that we employ, which we refer to as micro-transfer printing, has its origins at the University of Illinois. Researchers working there developed a technique that enables the removal of semiconductor devices from the growth substrate and subsequent printing on another platform in a massively parallel manner (see Figure 1). Armed with this technology, it is possible to print thousands of devices simultaneously, each with a $\pm 2\,\mu$m placement accuracy. This capability allows us to work with devices that are too small, numerous, fragile, or otherwise difficult to handle by conventional methods. Using our printing technique, we transfer sub-millimetre solar cells from their native growth substrates onto low-cost interposers (see Figure 2) to form surface-mountable sub-receivers that serve as the engines of our modules. To make a module, hundreds of sub-receivers are mounted onto a backplane, each with a spherical secondary optic (see Figure 3). The backplane is then mounted inside a steel enclosure upon which a primary optic is attached.

The steel enclosure protects the receivers from the environment and maintains the focal distance between the primary optic and the cell. The primary optic consists of a silicone lens array on a tempered front glass sheet, each lenslet perfectly aligned to a cell. The primary optic concentrates sunlight by a factor of 1,111 onto the micro-cells.
This module architecture is compatible with the most advanced III-V cell materials, which operate at the highest efficiencies and increase the competitiveness of CPV technology. Traditionally, cells used at high concentrations have been based on up to

Left: Semprius 64 m2 system at Solar Technology Acceleration Center, Denver, Colorado, USA.

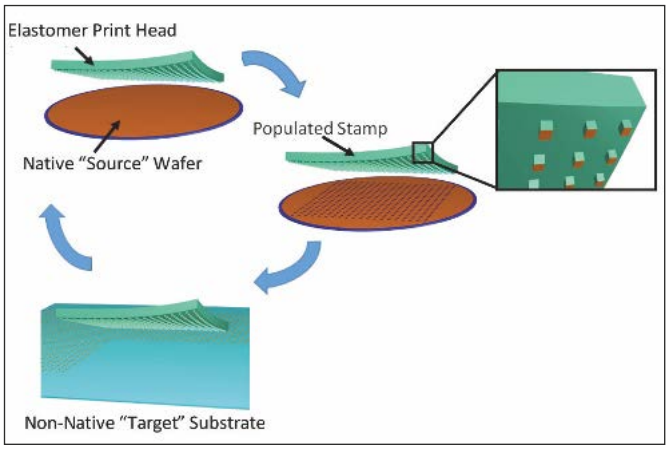


Figure 1. Micro-transfer printing using a rubber stamp enables the parallel transfer of many chips

three junctions, but we, like several other CPV companies, are now progressing to devices based on four or more junctions that could lead to cell conversion efficiencies in excess of 50 percent.

These include those produced mechanically by combining sub-cells from different kinds of growth substrates. Recent work by us, in collaboration with colleagues at the University of Illinois and Solar Junction, has demonstrated how micro-assembly can facilitate this kind of mechanical stacking, using a micro-scale, heterogeneous integration approach.

Small cells

Our team at Semprius have made significant strides with our printed micro-cell technology since we started work in this area in 2008. Our initial proof of concept module consisted of printed single-junction GaAs cells, measuring 0.1 to 0.3 mm on a side, which were designed for a concentration of a few hundred suns. After significant development and optimisation, we have progressed to 0.6 mm multi-junction cells that operate optimally at more than a thousand suns and are built from state-of-the-art epitaxial materials from partners such as Solar Junction.
Cell size optimization is a complex process that maximises the performance-to-cost ratio. Cost is influenced by the part count, yield and wafer utilization. Performance considerations include passive thermal dissipation, current density and optical efficiency. A small cell size delivers many benefits, which are discussed below, including a reduced optical path, better thermal management, superior optics, and a lower series resistance for the cells.

Reducing the optical path unlocks the door to thinner modules. A thin module design has multiple benefits, including lower weight, a reduction of the material required to construct the modules, reduced wind loading, and greater packing density. This means lower cost modules, lower cost trackers and lower cost shipping.

Thermal management is a big issue for CPV, because focusing sunlight by factors of more than a thousand can lead to significant cell heating. Our design is superior in this regard, because the thermal load is distributed over a larger area.

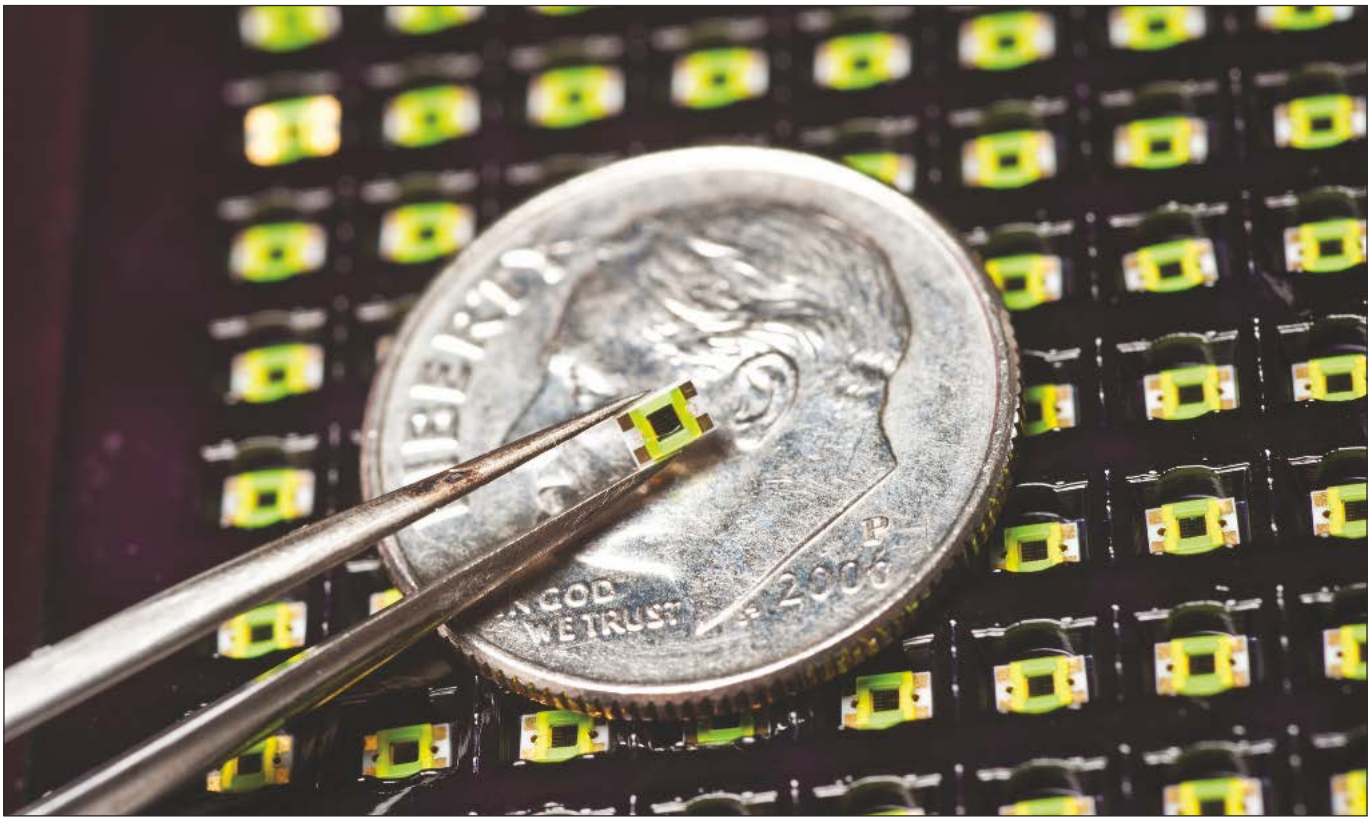


Figure 2. The 600 μm cell on interposer lies at the heart of the Semprius CPV module

For example, each of our cells has to dissipate about 220 mW of heat, compared to about 60 W for a more typically sized cell with an area of 1 cm^2. Thanks to the reduced requirement for heat dissipation, our modules don't require heat sinks, and this leads to significant cost savings. Crucially, we can do this without compromising performance or reliability – even without heat sinks, our cells remain relatively cool during operation. Another strength of our design is that it allows the use of unique, high-performance secondary optics. In our case, the secondary optic is a tiny ball lens placed on top of the cell (see Figure 4). The advantages of this pupil-imaging optic are that it provides a wide acceptance angle, delivers a uniform distribution of light on the cells and produces minimal chromatic aberration. While micro-cells are compatible with this type of optic, it is impractical for larger cells because larger ball lenses require too much glass and are therefore too costly.

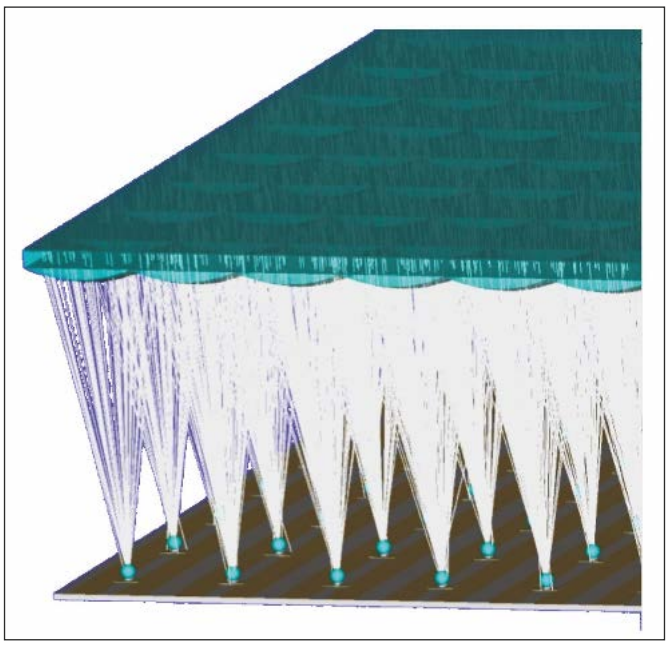


Figure 3. Semprius' optical train enables high levels of concentration on an array of triple-junction cells

In order for the electrons generated in a solar cell to provide useable electricity, they have to traverse the lateral extent of the device. With smaller cells, electrons travel a shorter distance, leading to a lower series resistance and an increase in the power produced by the module. On top of all these benefits, our approach to module production has several other virtues, including substrate re-use, whereby the relatively expensive substrate can be cleaned after the micro-transfer printing process and re-used many times. This significantly reduces the cost of the solar cell.

Another benefit of our approach to module production is that it is similar to a standard microelectronics process. After we use micro-transfer printing to transfer thousands of cells from the source wafer to a ceramic substrate in a massively parallel manner, receivers are then attached to a backplane using standard surface mount technology. By adopting this approach, the only 'assembly' part of the process is the attachment of the lens and the backplane to the enclosure. Alignment, though critical, is easily performed

with adequate precision using existing technologies. As a result, the capital expenditure for setting up a manufacturing plant is among the lowest for PV module technologies and the process is highly scalable.

One major benefit of this manufacturing process is that it allows for a distributed manufacturing strategy. The receivers can be fabricated at a wafer fab, shipped as tiny die in tape and reel, while the modules can be assembled closer to the end markets, reducing transport costs related to materials such as steel and glass and addressing 'local content' requirements, as necessary.

Module evolution

In 2008, we prototyped a module that operated at 1000 suns and was based on 4 single-junction microcells. This design evolved into an engineering prototype module with nominal dimensions of 14 inches by 14 inches, using 384 transfer-printed two-junction cells. Evaluation of this module's performance on-sun for more than 18 months confirmed the feasibility of this design and provided valuable insight for our production module. A small number of engineering prototype modules were integrated into a 1.3 kW research, development and demonstration (RD&D) system in Tucson, Arizona.

Thanks in part to a SunShot Incubator Award for $ 3 million from the US Department of Energy, we have refined our module design, making it better-suited to high-volume manufacturing and improving its performance-to-cost ratio. The latest version, which has now been in the field for more than two years, operates at 1111 suns and has a nominal surface area of 18 inches by 24 inches with a thickness of 2.7 inches. This module, manufactured at a pilot plant in Henderson, NC, features 660 transfer-printed triple-junction cells.

One of our overriding aims from a very early stage has been to develop cost-optimized modules that can be manufactured in high volumes and perform reliably in the field for more than 25 years. To accomplish this goal, we have taken great care to select materials that are already available and cost-effective in high volume, and have been characterized outdoors and in reliability chambers. We have used processes and equipment that are standard in the semiconductor, optoelectronic and automotive industries; the only unique process is the micro-transfer printer.

Reliability is paramount, and to address this in an appropriate manner, we have been running a rigorous outdoor and chamber testing programme for several years. The benefits of this programme includes being able to accurately characterize the impact of our development progress and to gain feedback on the suitability of the design to field conditions. Maturation of the CPV industry has also led to the development of IEC and UL standards that have been agreed to by the industry, vendors and national and commercial test labs. Additional characterization of our modules – both the early engineering prototype and the current design – has been performed at various independent labs, including NREL, Sandia National Labs and the Fraunhofer Institute for Solar Energy, providing valuable feedback to our design and characterization process.

Figure 4. The fabrication of the module backplane with receivers employs processes based on surface mount technology

Efficiency gains

Today's modules, which are produced in our pilot plant, have an efficiency of 34 percent to 36 percent at concentrator standard test conditions (CSTC): 1000 W m^{-2} direct normal irradiance, 25˚C cell temperature and spectrum defined by the standard AM 1.5. Independent testing of one of our higher performing modules by scientists at Fraunhofer ISE revealed an efficiency of 35.5 percent (see Figure 5).

Encouragingly, after more than two years in the field, our latest generation of modules are showing no measurable deterioration in performance, or any other unwanted effects. Testing in this operating environment continues, with our modules currently under scrutiny in 15 pilot systems in eight countries. These systems are providing data from locations on three different continents, and are enabling us to understand the performance of our modules under different geographical and climatic conditions.

The seven systems installed since late 2012 range from 14 kW to 24 kW and are suitable for future commercial deployments. They feature optimized trackers from mature vendors and industry standard inverters. This effort has involved working with tracker partners, who have partnered with us to design a system that optimises the performance-to-cost ratio. To alleviate any concerns relating to tracker reliability, we have only selected tracker partners with field experience spanning years and hundreds of megawatts of deployment. These systems have now been operating for more than a year, and they have a peak AC efficiency exceeding 30 percent.

High efficiency, low equipment cost and reliability are clearly important, but they are not the only issues relating to CPV deployment – there are also more underappreciated aspects, such as equipment transport, field installation, operation and maintenance. For example, it is critical that both the tracker and the modules are optimised for transport in standard ocean containers; otherwise transportation to the project site can add significantly to the costs. Thanks to the low profile of our module

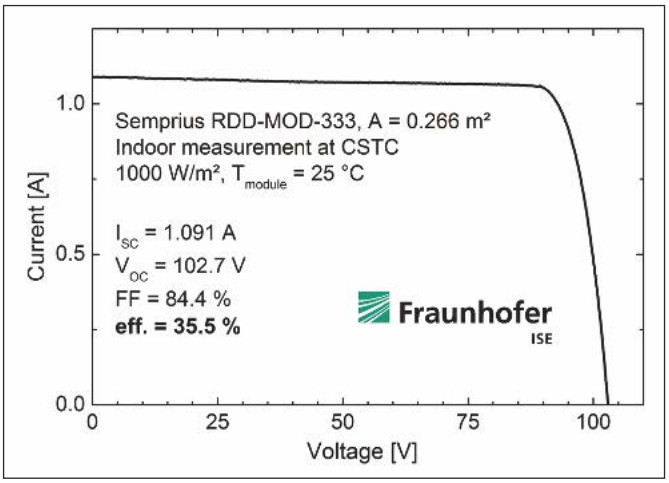


Figure 5. Independent test results from the Fraunhofer Institute for Solar Energy confirming a module efficiency of 35.5 percent

and the configuration of the module arrays, it is possible for us to realise a high packing density that is competitive with flat plate silicon modules and better than CPV modules made by our peers. It is also critical to devise installation methods that are standard in the construction industry, can be executed by construction labour, are safe and can be performed with high velocity and at a low cost.

We have also developed installation, operation and maintenance methodology and documented best practices that have drawn on our and our partners' experiences in civil construction, field assembly and commissioning. The experience gained from these activities will aid our next deployments, and lead to further refinements in the ways we approach fulfilling our customer's orders, as we deploy systems in larger projects.

Goals for the future

We have just completed the design and initial tests relating to our third generation module, and we unveiled the results at the 40th IEEE PVSC, which was held this June in Denver, CO. The overarching goal for this latest design was to cut costs further, while maintaining much of the existing design elements and making no impact on the pilot plant process and toolset. These considerations have led to a design that maintains the dimensions of the existing design, while increasing concentration to 1600 suns.

Indoor and outdoor testing of the new module, which has 30 percent fewer receivers than the existing design and provides a significant reduction in module cost, shows it delivers a similar performance to its predecessor.

Another recent breakthrough that we have made is to demonstrate stacked cells that are fabricated by printing two micro-cells, grown on different substrates, on top of each other. In this project a top InGaP/GaAs/InGaAsNSb cell is grown on a GaAs substrate, released from it by etching a sacrificial AlInP layer and printed on a germanium bottom cell.

A spin-cast, 300 nm-thick film of As_2Se_3 binds together these two cells together while providing a low-loss optical interface that is thermally conductive and electrically insulating. The triple-junction and germanium cells operate independently with separate sets of terminals, thereby avoiding current matching issues. Operating at 1000 suns, these multi-junction and single junction cells have efficiencies of 42.1 percent and 1.8 percent, respectively, and thus combine to deliver an efficiency of 43.9 percent.

This work represents the first demonstration of a four-junction, four terminal cell, and it lowers the barriers towards developing a cell operating at an efficiency greater than 50 percent, and a module operating at an efficiency in excess of 40 percent. Such cells can be fabricated on existing equipment and quickly integrated into our current module design, which will help to accelerate the adoption of CPV systems that are more competitive in sunny climates than those based on silicon.

Semprius has increased the concentration factor of its modules. This version operates at 1100 suns

Other opportunities for micro-transfer printing

MICRO-TRANSFER-PRINTING is a powerful device assembly technology that can serve various compound semiconductor applications. For non-photovoltaic applications, it is being commercialized by X-Celeprint Limited of Cork, Ireland. This micro-assembly technology offers a practical way to combine arrays of micron-scale, diverse, high-performance materials and devices with substrates that have vastly different properties and cost structures compared with traditional packages. It is a technology that opens new levels of component miniaturization, facilitates heterogeneous integration, and readily interfaces with epitaxial lift-off techniques for substrate re-use.

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10 reasons to test installations

There is a drive to always find a financial rationale behind anything done in the industry and although there are fiscal benefits from maintaining a solar array, Jim Wallace of Seaward Solar highlights why electrical testing of solar PV installations is a fundamental requirement of any installation.

SAFETY IS PARAMOUNT in any electrical installation but solar and PV installations come with specific challenges for the installer and longer-term steward of an installation. The future of the solar industry is as dependent on public support as much as finance and ensuring the highest safety levels ensures that PV stays safe in the mind of the consumer.

You would think the safety needs of a solar array would be obvious but there are still examples around the world where safety shortcuts have led to dangerous problems. Here is the ten most important reasons to continually test soalr arrays.

Compliance with IEC 62446

IEC 62446 recommends that periodic verification of an existing installation shall be performed. The standard defines the minimum requirements for system documentation, commissioning tests and inspection for PV systems. As such, this standard not only specifies the minimum electrical testing and inspection requirements but equally importantly how the inspection and test results are documented and supplied to the consumer after installation.

Where appropriate, the results and recommendations of previous periodic verifications shall be taken into account. A periodic verification report shall be provided and include a list of any faults and recommendations for repairs or improvements (such as upgrading a system to meet current standards).

Avoiding fire risks

As the number of rooftop solar installation systems have grown over the years, so have the number of reported incidents of fires. Household fires started by electrical faults in rooftop solar PV systems have been reported in the UK, Australia, the USA and France – among others. The periodic testing of the electrical cabling and components associated with solar PV systems will ensure the safe operation of the system and reduce the potential fire risk associated with any electrical faults.

Effective grounding

As with all electrical equipment, solar panels and their racking systems must be grounded to mitigate potential electric shocks and fire hazards. If the grounding system degrades over time, anyone who comes into contact with a metal piece of the system may receive a shock. While the likelihood of shock is low, should one occur, the chance of substantial injury is great, because of the high voltage arrays, and the added danger of falling from roof mounted systems.

Ground faults

PV systems, in particular large scale systems, have many metres of cabling,

much of which is buried underground. Poor levels of insulation will allow energy generated by the PV system to leak to earth. This can be particularly problematic during damp or wet conditions where the insulation monitoring or residual current monitoring function within an inverter prevents the inverter from starting up which in turn can significantly reduce the operational efficiency of the PV installation.

Environmental degradation

connectors caused by moisture ingress can result in degradation in performance or increased risk of fire. Regular electrical testing will enable system performance to be monitored and any necessary repairs or remedial actions to be taken

Surface contamination and physical damage

PV modules can become dirty or contaminated over time and this can reduce the operational efficiency and system performance. Similarly, exposure to the elements can result in physical damage to the component parts of a PV installation. Objects dropped by birds can result in physical damage to PV modules which may result in reduced output performance. Periodic electrical testing as part of regular maintenance will enable any problems to be identified and diagnosed.

Damage to wiring

The most obvious example of bad wiring is when wires hang below the panels and touch the roof or underlying vegetation. Eventually the wire coating will wear or be damaged by rodent attach and potentially expose the copper wires, presenting a shock hazard. Any deterioration of cable connections and wiring can be identified by applying regular electrical testing to identify potential faults.

Verification of system performance

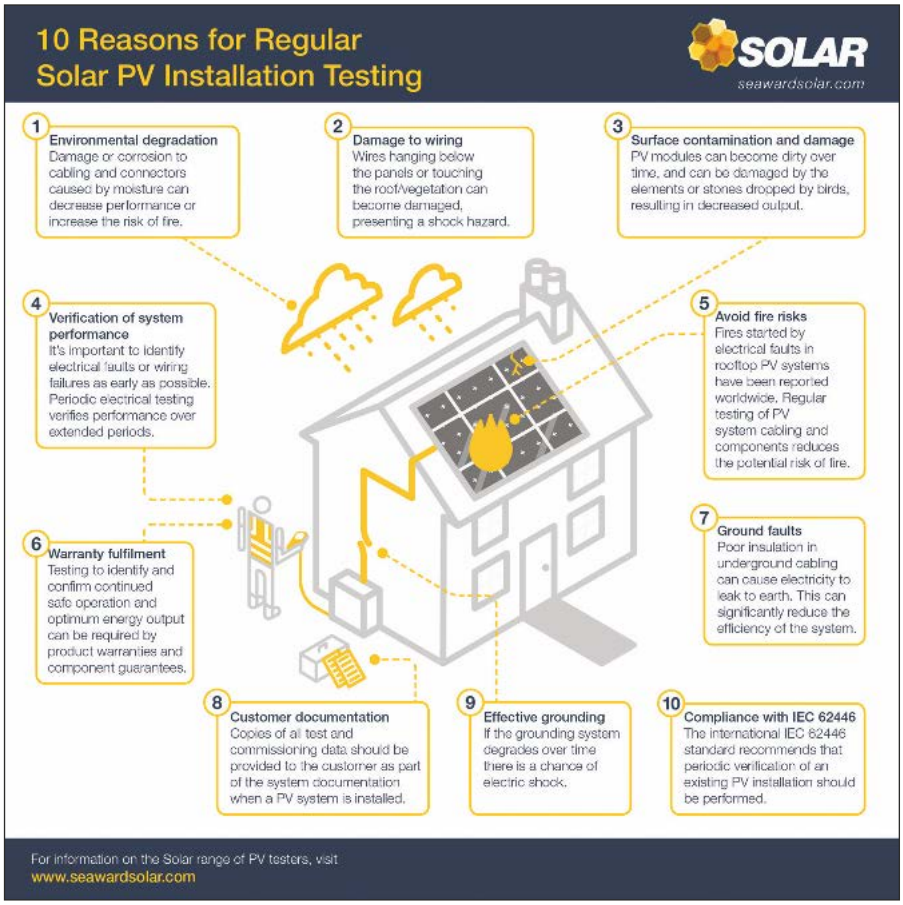
The installation of solar PV systems is only undertaken after careful consideration of the costs involved and the potential return on investment provided by lower energy bills and FIT payments.

As a result, the verification of system performance and energy output from the panels is particularly important. In many cases simple electrical faults or wiring failures can cause a serious inefficiency in the ability of the panel to produce power.

Although proper metering will give an indication of system performance, periodic electrical testing is vital to verify ongoing functional performance over extended periods.

Warranty fulfilment

Periodic electrical testing of solar PV systems to identify and confirm continued safe operation and maximum energy output performance can be required as part of product warranties and PV system component guarantees.



Customer documentation

All solar PV installations require the provision of various documentation and forms to the customer. System documentation usually includes system data, installer details, electrical diagrams, operation and maintenance instructions and other information that may be required by certain standards or regulatory bodies. Copies of all test and commissioning data should also be provided and as a minimum this should include the results from the electrical safety and verification tests undertaken as part of the system installation procedures.

This list can serve as a simple checklist for anyone interested or involved in solar and PV installations.

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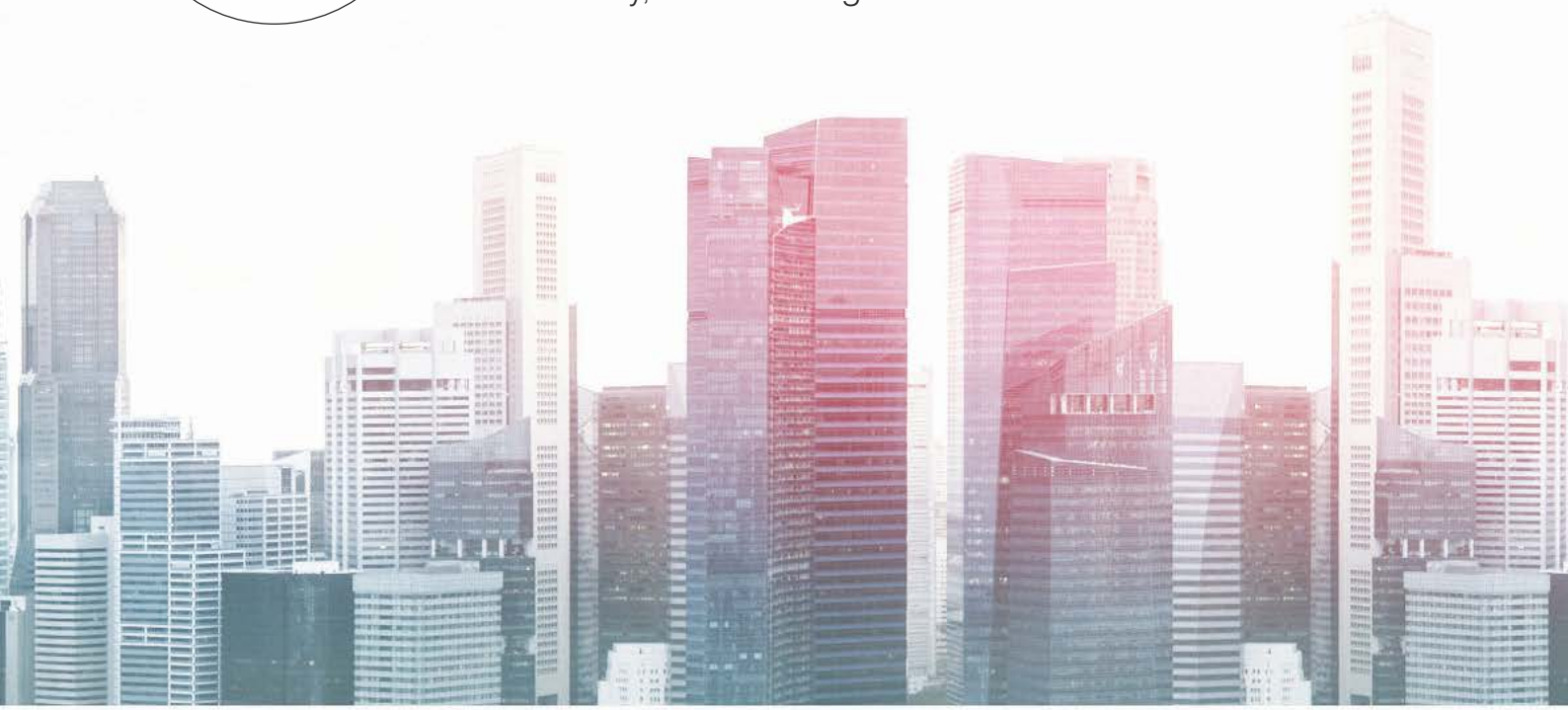
Five solar asset management **predictions for 2015**

Good solar asset management needs a cross-disciplinary team of experts both technical and commercial to work together to ensure that solar technology can produce a return of the investment while meeting quality and industries standards. Solar international asked solar asset management expert Edmee Kelsey, CEO of 3megawatt to look into the future.



SOLAR ASSET MANAGEMENT is an important part on the success of solar energy projects both in the operational and planning stages. Photovoltaic systems require much less maintenance than fossil fuel plants, however they require a rigorous maintenance plan to ensure their correct functioning and prolong their useful life. This is just one of the aspects taken care of by solar asset management which also monitors and supervises the production of energy, day to day operations and even the correct disposal of obsolete or damaged equipment.

Other important goal of solar asset management is to achieve the greater return possible on an investment. Large scale projects such as the ones on solar energy production require optimization of all the resources to prevent losses.

2014 was the year when many owner/operators started to realize the importance of solar asset management. 2015 marks the year where for the first time there is an industry conference dedicated to the topic. The solar installed base is growing, the market is getting more mature and consolidation is starting. These are our five predictions for 2015

1. There will be more solar assets to manage

Market research firm IHS expects that there will be about 55GW of solar installed in 2015. This means an increase of the worldwide installed operational solar asset base to 235 GW by the end of this year - an increase of almost 25 percent.

2. There will be a large influx of new players

New owners and operators will enter the market daily. As the market matures, the investor base will get larger as more investors will get comfortable with the risk profile of solar. New solar asset management operators will emerge from many different backgrounds.

Examples of backgrounds of new operators include:

- O&M operators expanding the scope of their activities to include commercial asset management;
- Developers with asset management activities wanting to leverage their existing organization with 3rd party business;
- Hardware manufacturers wanting to become fully integrated along the value chain
- Technical advisors wanting to lever their technical skills

- Property managers seeing parallels with their own activities
- Solar asset owners starting an in-house activity;
- Start-up teams with various backgrounds perceiving low barriers to entry

3. Global operators will start to emerge

Until today, solar asset management service has been relatively local. Some markets already have their national champions (Germany and Spain) and other markets are still very fragmented (Italy). But as asset owners are chasing higher yielding opportunities in non-local markets, operators with global aspirations will expand internationally to cater to the needs of their client base.

4. The balance of in-house versus outsourcing will shift

In the US most asset management activities have traditionally been performed in-house. In 2015, the percentage of outsourced solar asset management will grow, as third party solar asset management firms are starting to get traction. In Europe, where traditionally most asset management has been outsourced, an increasing number of owner/operators are bringing asset management in-house because they find that it becomes more cost effective as their portfolios grow.

5. Solar asset management will get more complicated

The industry is getting more and more creative to get deals done. This means that project documents will include terms and conditions that have far reaching implications for asset management.

The list is long, but some examples include:

- More complicated invoicing processes stemming from market oriented power purchase agreements: synthetic PPAs (with energy swaps), market discount PPAs (fixed discount to utility pricing), time of day billing, hybrid PPAs, increased performance and capacity guarantees, etc.
- More reporting requirements and regulatory compliance with public financing structures such as YieldCos and green bonds
- Impact of new business models including storage
- Need for frequent forecasting to feed into demand/response systems
- Need for detailed project cash flow forecasting manage liquidity bottle necks as a result of cuts in government incentive rates
- Need to manage a larger number of smaller installations
- Consolidation of existing operating portfolios with incomplete historical documentation.

EDMEE KELSEY - CEO - 3MEGAWATT

Edmée Kelsey brings a wealth of solar asset management expertise to her role as founder and CEO of 3megawatt. 3megawatt provides solar asset management software designed to support asset owners with managing their solar portfolio risks and asset managers with reducing their asset management costs. As former CFO of Main Street Power, she closed project financing for over 100 of distributed solar PV projects and was responsible for the asset management of those solar assets.

As a former VP at the investment bank JP Morgan and managing director of a clean energy corporate finance advisory firm, she gained a deep understanding of the requirements of project finance providers and sponsors, funds and investors. Her background as a founder and CEO of a venture-backed telecom service provider brings utility billing, asset tracking and O&M service ticketing experience.

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Energy revolution takes off for solar across East Africa

With reliable suppliers moving into the market, the often high cost of diesel and increasing political support, it was only a matter of time until East African countries began to capitalise on their plentiful sunshine hours as a source of cheap, low carbon energy. Dr Dan Davies, Director of Solarcentury in East Africa talks about the growth of solar energy in the region and this British company's readiness to deliver solar to Africa.

OIL PRICES may be spiralling down, but soon, they could be spiralling up. Aside from energy costs eating into company profits, it's the unpredictability of fossil fuel prices that is motivating many businesses to seek out more stable energy sources. With the sun shining all year round countries like Kenya can use solar PV to harness the sun's energy to provide a sustainable source of clean green energy. And Kenya has big ambitions for solar: the country is looking to generate over half of its electricity through solar power by 2016.

Also spurring interest in solar is the economics: East African countries are at a stage where the falling cost of solar technology means solar is competive with the cost of fossil fuel. Solar electricity is cheaper than running a diesel generator – a primary source of fuel for many

businesses when the grid isn't working – where costs range widely, from $300/MWh if you have a new machine, low fuel costs and run it very efficiently, up to $1000/MWh if you have an old machine and the cost of fuel is high.

The levelised cost of solar power is much lower: 12-15USc/kWh depending on finance/solar resource and ongoing O&M costs, which works out at $120-150/MWh. While coal is the cheapest, it isn't always available, and anyway, many governments are looking to move away from energy sources that belch out dirty emissions and contribute to smog issues in urban areas. Of course, the energy landscape varies between countries and each faces its own unique set of challenges.

In Kenya, the issue is that the power comes from a mix of hydro, wind, geothermal, heavy fuel oil and diesel. When there is a drought and the hydro dams are low, the amount of diesel in the mix is higher – so national grid power becomes more expensive. As demand grows, the rate at which new generation capacity can be deployed is the limiting factor, and in Kenya, if there is a shortfall then businesses turn to diesel. For a burgeoning increasingly power-hungry economy, this isn't ideal. Aside from the obvious environmental problems of burning diesel, it's also prohibitively expensive for many businesses.

Now a growing number of African enterprises are looking to solar to reduce running costs. Deployed quickly and easily, it's becoming an attractive option for businesses looking to enhance their competitiveness. Last year, Solarcentury installed a 1 megawatt (MWp) solar farm for one of Kenya's largest tea producers at an estate in the Rift Valley, slashing grid reliance for the company by nearly a third and reducing the need for back-up diesel generators. When the national grid is working, the solar power system works in parallel with the grid and reduce the amount of grid electricity imported. When the grid is unavailable, the solar power system will work together with the standby diesel generators, which means significantly less diesel is consumed.

The solar farm is one of only a handful of systems in the world using this hybrid technology. The design enables the solar power system to operate in parallel with a standby generator and provides a stable power supply, negating the need for batteries. This makes solar an economically viable solution for many factories, farms and other businesses in locations where grid power is unstable and standby generators are relied on for power.

Costs

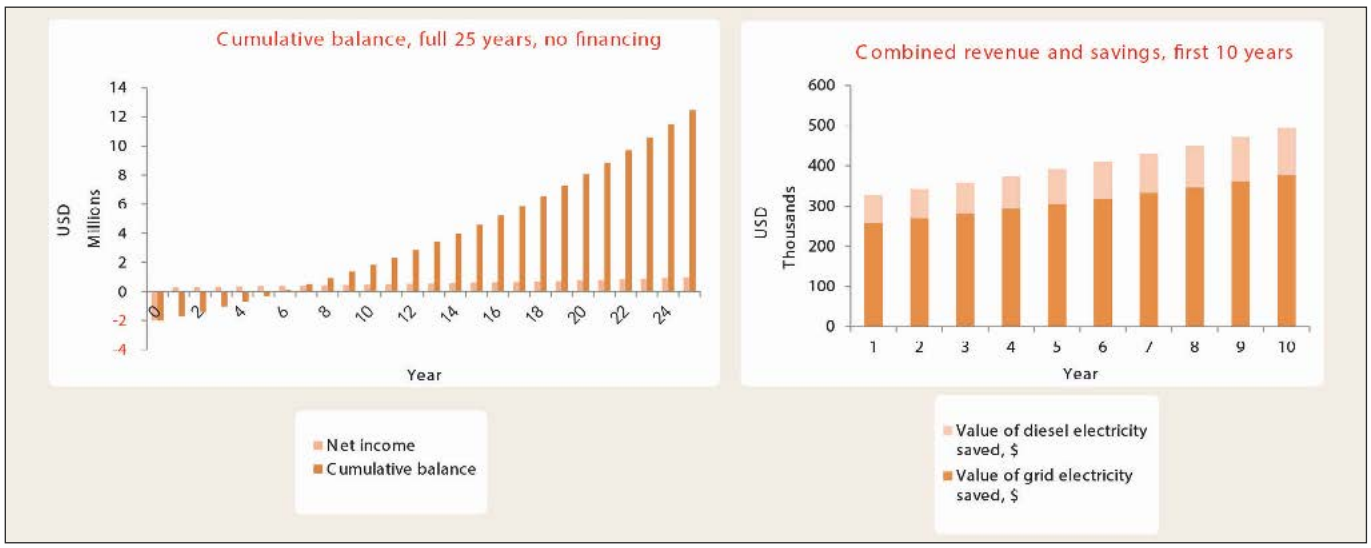
In Kenya, the cost of diesel- produced electricity can exceed $0.30 per kWh. The cost of grid power for businesses is $0.20 per kWh. In comparison, the cost of power from a solar PV system is generally $0.10-0.15/kWh, depending on finance costs and irradiation. Adding a solar PV system to the local network to offset diesel and grid consumption will significantly reduce the overall energy bill. Cost of energy is the most significant business expense, which is typical of many rural businesses, so installing solar is a financially savvy strategy to boost profits and maintain a competitive advantage.

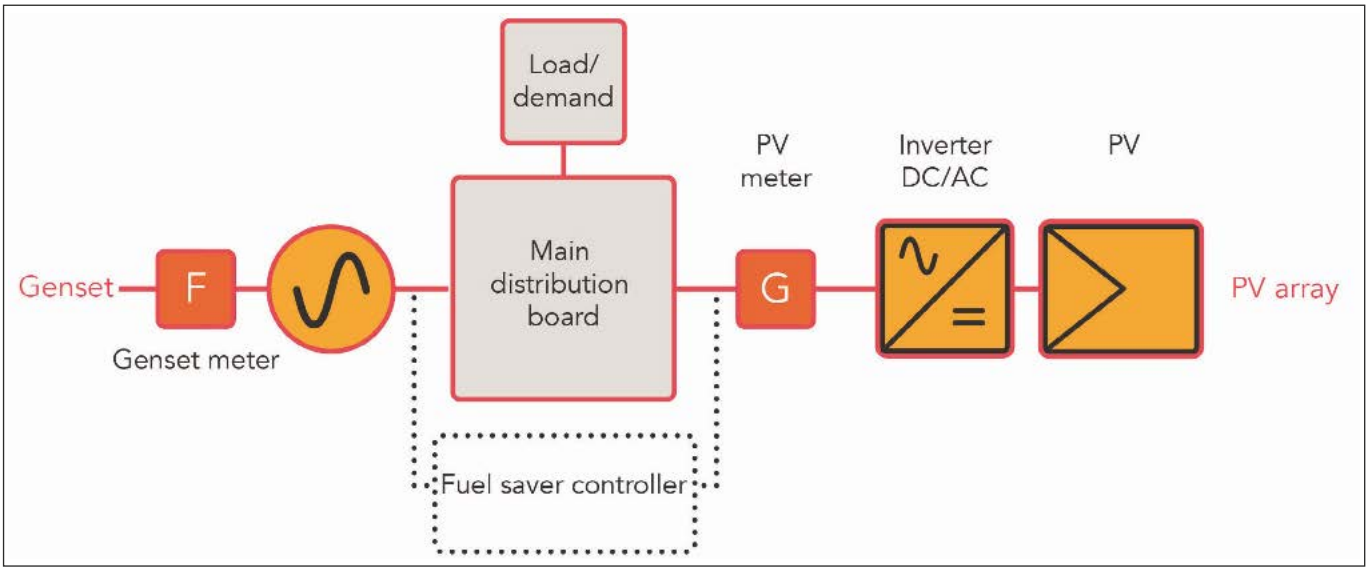
Like all renewable energy technologies the up-front investment is the major cost. However, once a PV system is installed there are no significant on-going costs, aside from cleaning and inspection.

In the example below, we sized a solar system to be as large as possible but limited the size so that the business owner would be able to make use of all the electricity produced.

The result is a 1MWp system that will produce 1,600,000 units of electricity per annum. Over 25 years, with no upfront cost, the business will save over $10 million. 1 MWp generates enough electricity to power several hundred middle-class households.

Determining the economic benefits of a project requires a solid understanding of existing energy demand and costs, and a view on likely future demand. For this reason, it's important to choose a solar company with local industry knowledge who can develop a clear picture of an organisation's energy demand profile in order to create the optimum energy design solution.





The technology: The schematic shows the typical configuration of a hybrid solar system

Technical challenges

Sizing and unknown interfaces

Using solar PV in parallel with an intermittent grid and/or standby or bulk diesel generators presents additional challenges when compared to a standard grid tied PV system. The initial design challenge relates to the sizing of the system components which links back to the need to gather as much operational information as possible.

The more complex challenge covers interfaces. Linking an inverter based PV system to an existing electricity system for which there are no drawings where equipment is old requires careful design and installation.

Logistics

Many of the sites using diesel generators are remote and getting solar PV to these sites may require many truck loads over rough roads with uncertain off-loading facilities. However once the panels are installed on the ground the fuel is cost-free, whereas a generator needs a constant supply of expensive fuel.

Africa's largest solar carport

Solarcentury is currently building a solar carport using hybrid solar technology for Garden City Mall, a new 32-acre integrated residential, retail park, hotel and office development on Nairobi's Thika Superhighway. The clean solar electricity generated by the 858kWp system will be used by the retail tenants. The hybrid solar system will generate solar electricity in the daytime, meaning less is used from the grid; and when the grid is down, the solar system will reduce the consumption of costly diesel back-up energy.

Essentially, the system is able to operate in either mode. This hybrid system ensures a consistent energy supply whilst reducing diesel and grid consumption, so as well as providing clean energy, it will reduce bills for Garden City's retail tenants. Hybrid solar systems are perfect for urban areas where land is at a premium yet energy needs to be supplied near to demand. Installing the panels on the roof of a car park makes use of otherwise functionless roof space.

Looking ahead

Solar is an appealing prospect for a variety of businesses, from the largest cement factory in Kenya, to the family run business at the end of the street. In east Africa, agricultural businesses, manufacturers, mining companies and remote communities have all expressed interest in hybrid solar systems as a way to control energy costs and improve competitiveness. The fast growing economy in East Africa does not wait for power outages and almost every business in East Africa requires a standby generator.

The hybrid solar market in East Africa is more sustainable in the long term than the utility scale solar market which is predicted to grow quickly initially until the government quota is reached, and then slow down dramatically. Solarcentury's Nairobi office has been active in the region since June 2013 with a team of eight who are ready to deliver solar projects to businesses throughout East Africa. Solarcentury has a wealth of engineering and project management expertise, having delivered solar projects throughout Europe and the UK over the last 15 years.

SNEC 9th (2015) International Photovoltaic Power Generation Conference & Exhibition

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SNEC Spotlight

The 9th SNEC (2015) International Photovoltaic Power Generation Conference and Exhibition will be held this year from 28 to 30 April in Shanghai, China. In 2014 the exhibition attracted over 1,500 exhibiting companies from 90 countries. SNEC showcases PV manufacturing facilities, materials, PV cells, PV application products and modules, and PV project and system, covering every section of the whole PV industry chain. Solar International looks at some of the companies and their offerings at this prestigious event.

New energy-efficient manufacturing equipment from Rehm

Rehm Thermal Systems is once again participating in renowned international trade fairs and will present state-of-the-art plant and system technology in the area of solar equipment for the metallization of solar cells.

Fast Firing System – Best quality for best solar cells
The Rehm Fast Firing Systems for the metallization of crystalline silicon solar cells excel because of the high quality design. Many new features, for example the low energy consumption, thermal control and the smart software solutions, are responsible for an optimized process. These benefits permit easy maintenance and best results.

VOC Thermal Oxidizer – Award-winning technology
The new VOC Thermal Oxidizer removes fumes, smoke and other volatile components and organic compounds (VOCs), which develop during the metallization process.

With an optimal temperature flow and an effective heat recovery, this tool is very eco-friendly and sustainable. The VOC Thermal Oxidizer destroys the flue gas with an efficiency of up to 99,9 percent.

This kind of residue management is the most innovative cleaning system in the market. With our environmentally friendly concept and the excellent deposition results, the technology implemented in our Thermal Oxidizer was already awarded in 2011 with the Solar Award in the category “Excellence” (Product).

Protecto – Selective conformal coating applications
You can increase the quality and service life of your products by using a protective coating. Our Protecto conformal coating system protects sensitive electronic assemblies from damage caused by corrosion or other environmental influences, such as moisture, chemicals and dust.

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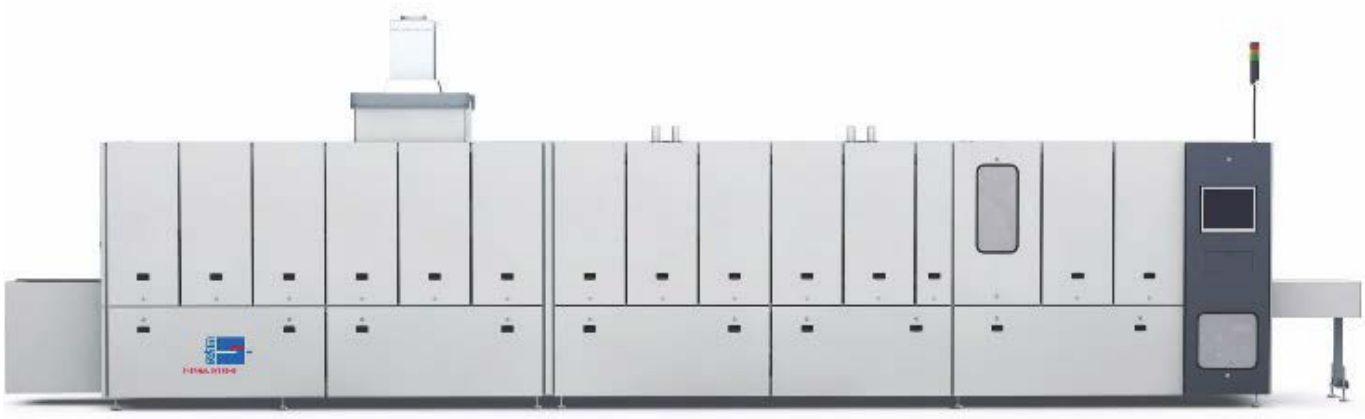


Please find the following images attached: 1.) Fast Firing System Model; 2.) Fast Firing System process; 3.) Schema Thermal Oxidizer and 4.) Protecto (Images: Rehm Thermal Systems).

centrotherm

Low-pressure diffusion technology offers cost savings

centrotherm is highlighting low-pressure diffusion system c.DIFF LP at SNEC 2015, which offer up to 40 percent per wafer for solar cell emitter formation. The cost reductions are attributed to almost a doubling of the systems wafer throughput to more than 140MW per year and overall lower media consumption.

Problem

The necessity of both cost savings and efficiency improvements is the main challenge in the mass production of c-Si solar cells. Among other things, this demands homogeneous high-quality emitters as well as high emitter sheet resistance (> 100 Ω/square) that is fundamental to exploit efficiency potentials of commonly used metallization pastes.

Solution

The low-pressure diffusion process enables high homogeneity even at emitter sheet resistance of up to 150 Ω/square and able to further exploit the efficiency potentials of both conventional and new metallization pastes (emitter resistance > 100 Ω/square). Furthermore, the centrotherm low-pressure diffusion technology opens up a broad corridor for new diffusion processes for solar cell manufacturers, especially through the fast and changing deployment of gases in the process tube.

Due to low pressure processing there is a high cost saving potential regarding materials and media consumption.
To further increase safety and process stability, centrotherm offers the c.DIFF LP with an optional POCl3 automatic refill system. The refill system furthermore reduces the costs related to the supply of POCl3, which in consequence leads to lower CoO.

Semilab Inline PL Imaging and Wafer Sorter

Semilab introduces the latest generation in inline PL imaging systems, for high throughput wafer inspection at 3600WPH. The primary application is for incoming wafer sorting, providing high resolution images from the as-cut bare silicon surfaces. A second implementation of the Inline PL hardware provides quasi-steady state measurement conditions, allowing inline imaging of J0 and implied Voc for passivation defect monitoring, with the same high throughput.

The inline PL modules can be stand alone, or integrated into Semilab's fully automated and flexible wafer sorting platforms. The PLI sorter uses a single metrology module with proprietary algorithms for efficiency prediction, and allows incoming wafer sorting based on customer specific criteria.

Alternatively the PLI module can be integrated into the wafer inspection module of Semilab's PVS series sorter shown above. This provides multi parameter wafer inspection and sorting based on physical and electrical properties of each wafer, including microcracks, holes, inclusions, edge chipping, contamination and defect detection in the silicon material. In addition wafer geometry, sawmark, total thickness variation, resistivity, conductivity type and lifetime measurement modules can be configured based on specific customer criteria. Finally on-the-fly laser marking of every wafer can be performed prior to sorting into the endstation.

The automation is also fully flexible, with options for loading to and from cassettes or coinstacks. In addition a buffer station and broken wafer chute can be configured within the layout, in order to maintain the full 3600WPH throughput during cassette changes or wafer breakage at the load station.

For further information please contact Semilab. www.semilab.hu

3D-Micromac AG On-the-fly laser processing system microSTRUCT

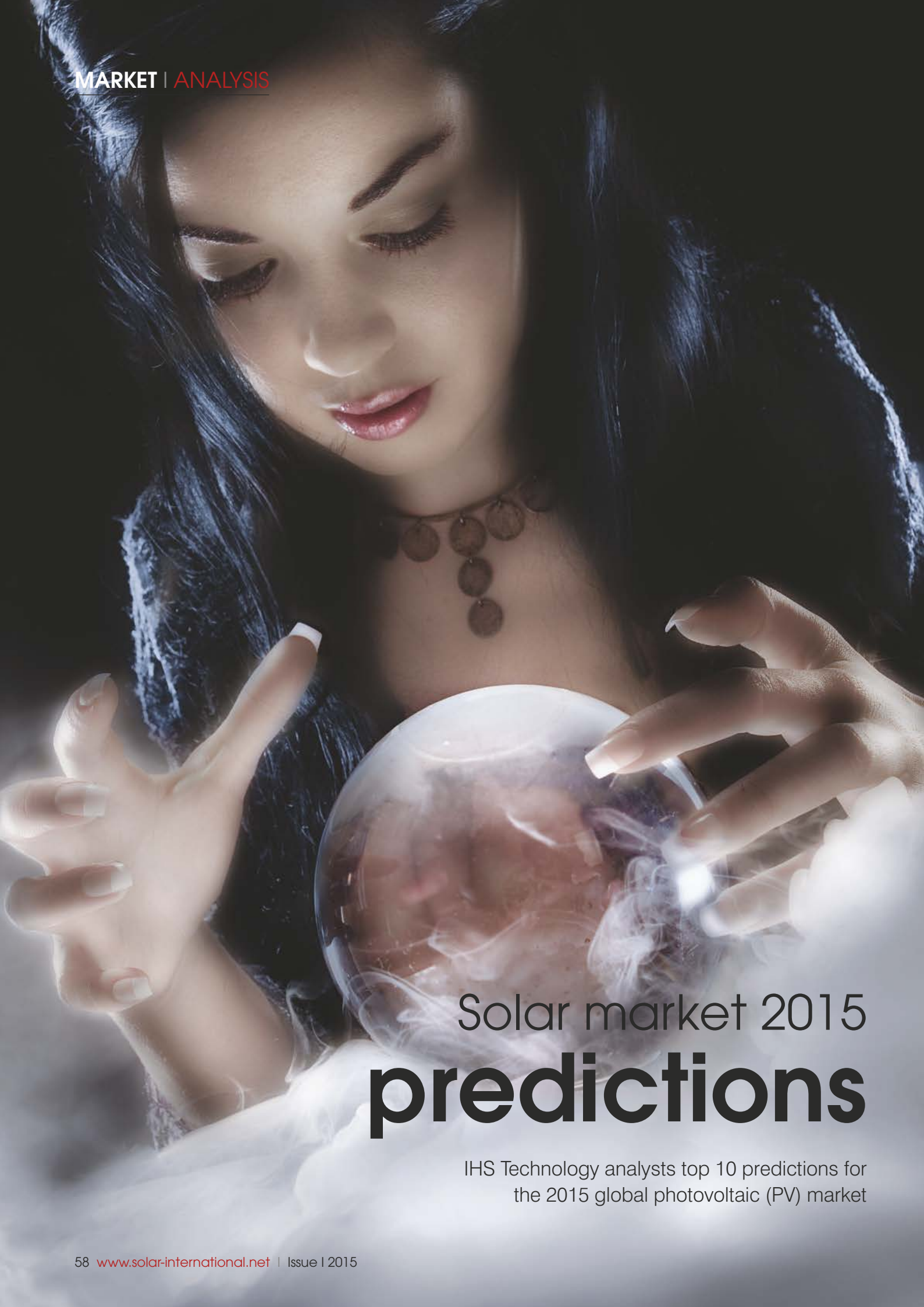
3D-Micromac's microSTRUCT OTF is a highly productive laser system for processing of mono- and polycrystalline silicon solar cells. Laser processing on-the-fly and an innovative handling concept enable maximum throughput and yield in the full-scale manufacturing of crystalline solar cells. The microSTRUCT OTF can be combined with arbitrarily many laser sources to match the system exactly to the respective process requirements. Because of its modular structure the system is perfectly suited for laser processing of PERC solar cells, selective-emitter, LFC, MWT, and EWT cells.

Benefits:

- Efficient machine design with 2 parallel working areas and on-the-fly laser processing
- Non-contact wafer handling
- High throughput and efficiency (≥ 3,600 wafer/h)
- Low cost of ownership and CAPEX

The microSTRUCT OTF is using the advantages of laser processing perfectly for increasing the efficiency of the solar cell. It meets cell manufacturers' demands for precise surface structuring, low operating costs, and very high availability. Furthermore, 3D-Micromac is going to present a novel method for cell separation by using TLS-Dicing. The thermal laser separation (TLS) allows the ablation free cleaving to separate solar cells with a high edge quality and a process speed of up to 300mm/sec.

Contact: http://3d-micromac.com



Solar market 2015 predictions

IHS Technology analysts top 10 predictions for the 2015 global photovoltaic (PV) market

WHILE 2014 remained a challenging time for the solar photovoltaic (PV) industry, it marked an inflection point in the market's development. According to information and analytics provider IHS, solar PV demand grew at a double-digit pace, largely due to policies in China and Japan; yet conditions remained extremely tough for suppliers.

"Through mergers, acquisitions and bankruptcies, the supplier base consolidated further, as companies struggled with debt-laden balance sheets and a rapid shift in their customer base away from their traditional markets," said Ash Sharma, senior research director for solar at IHS. "All signs point to a strengthening recovery of the solar industry in 2015, even if the recovery itself remains incredibly fragile."

Top 10 predictions for 2015 from the IHS solar research team:

1. Global solar PV demand is forecast to grow by up to 25 percent in 2015

Due to the ongoing cost reductions for solar PV, IHS forecasts that installation demand will grow at a double-digit rate of 16 to 25 percent and installations in the range of 53 to 57 gigawatts (GW). Geographically, the largest markets again will be China, Japan and the United States, while the largest contributors in terms of absolute growth will be China, the United States and India.

2. Concentrated Photovoltaic Solar (CPV) to experience accelerated growth

Starting in 2015, IHS forecasts an accelerated CPV market expansion of 37 percent, to reach approximately 250 megawatts (MW) of new installations. Installations of both high-concentration photovoltaic (HCPV) and low-concentration photovoltaic (LCPV) systems will expand at double-digit percentages every year through 2020.

3. Distributed PV (DPV) in China to fall behind expectations, but to grow

With challenges ahead for China's ambitious plans for DPV, IHS forecasts the country will struggle to achieve it aggressive targets. Even so, the market is clearly beginning to build momentum, and policies and business models are helping to accelerate growth. IHS forecasts that DPV installations in China will reach 4.7 GW in 2015, an increase of nearly 20 percent from 2014.

4. Grid-connected PV energy storage installations to triple

The PV power system is evolving away from the traditional and relatively simple system of one-directional flow—from large-scale conventional generators through transmission and distribution lines to consumers, to an increasingly complex mix of small, distributed generators and consumers at all points in the electricity grid. Annual installations of grid-connected PV systems, paired with energy storage, will grow more than threefold, to reach 775 MW in 2015.

5. Emerging markets mature – Chile will follow South Africa to reach 1 GW of installed PV capacity

IHS forecasts that Chile will be the next emerging market, after South Africa, to reach the milestone of 1 GW in installed PV solar capacity. Aside from Chile, other new emerging markets poised for rapid growth in 2015 are Jordan, the Philippines and Honduras. Conversely, great uncertainty still surrounds Mexico, Brazil and Turkey.

6. Monocrystalline technology to increase market share

Although monocrystalline technology will not threaten multicrystalline domination in the near future, IHS expects it will steadily gain share, benefiting from growth on rooftop installations, as well as increasing demand for higher-efficiency products. IHS forecasts the monocrystalline share of global cell production will increase to 27 percent in 2015, up from 24 percent in 2014.

7. Systems up to 100 kilowatts to account for 30 percent of global installations

There is potential in store for DPV in both established and emerging markets around the world. IHS forecasts distributed photovoltaic (DPV) systems—i.e., those sized 100 kilowatts (kW) or smaller—to account for 30 percent of global installations in 2015, with 15.7 GW projected, up from 13.2 GW in 2014. The largest market for these installations in 2015 will be Japan, with DPV accounting for nearly 70 percent of installations. The U.S. is also expected to install more than 2.2 GW of DPV in 2015, as net-metering and third-party ownership models continue to drive this market.

8. Second quarter (Q2) halt to U.K. utility-scale PV to trigger new wave of consolidation among European Engineering, Procurement and Construction (EPC) contractors

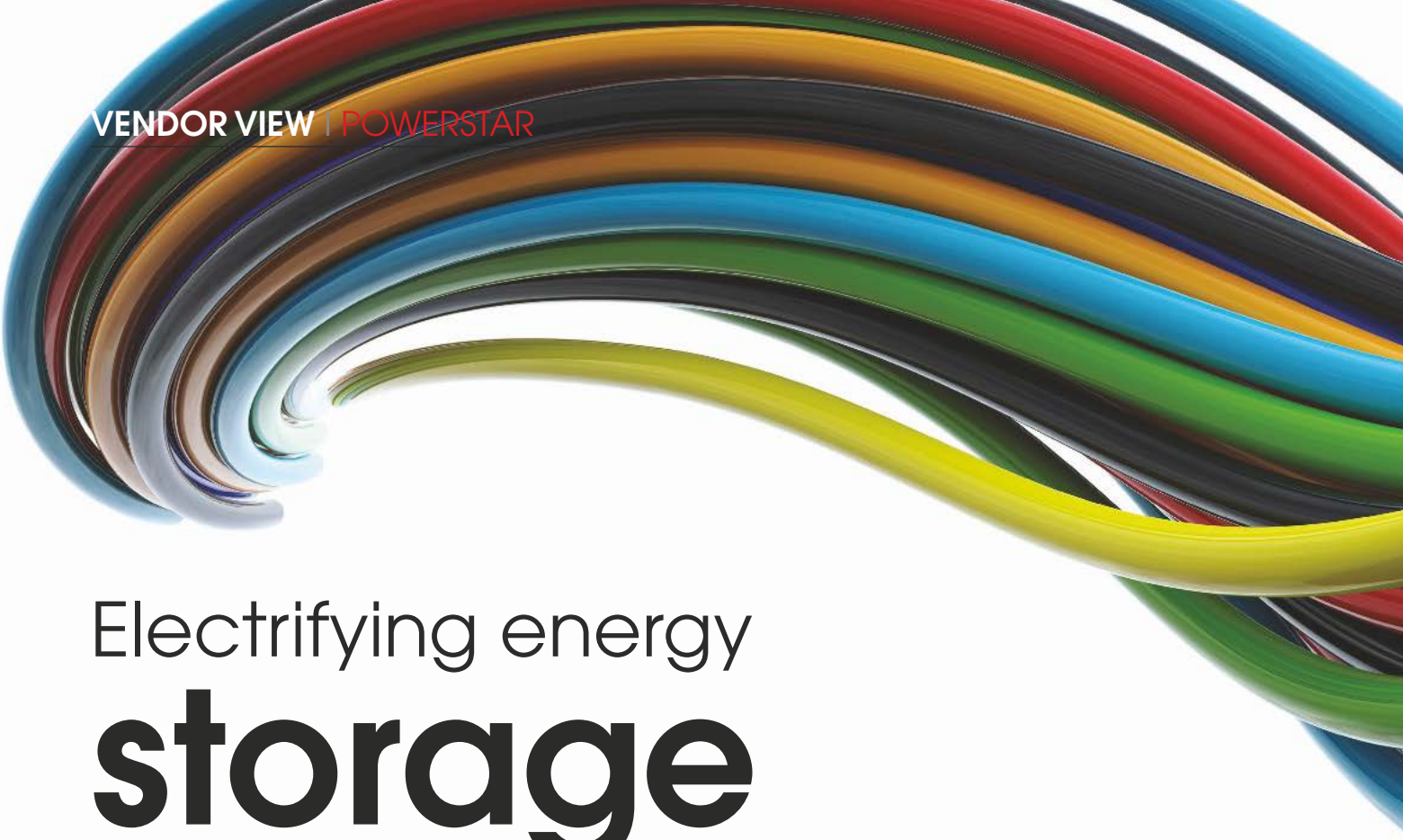
The clock is running down for integrators of large-sized solar systems in Europe, with the expiration of a U.K. incentive program bringing an end to a boom in utility-scale installations and triggering a flurry of consolidation. The U.K. in 2015 will dominate the utility-scale PV landscape in Europe by installing 1.4 GW of ground-mount systems, primarily under the renewable obligation certificates (ROC) scheme.

9. Three-phase string inverters to account for one-third of global solar inverter revenue

Driven by attractive prices in key PV markets, global revenue for three-phase string inverters is forecast in 2015, to reach more than $2.2 billion, equivalent to one-third of worldwide revenue for the overall market for inverters. Estimated shipments next year of three-phase string inverters will exceed 15 GW, up 31 percent from 2014. A surge is expected in important markets like China and Japan, whose combined shipments will account for 7.6 GW of the total.

10. California will become global leader in solar power penetration

IHS expects that by the end of 2015, California—the largest renewable power market in the United States—will attain worldwide leadership in market share of annual power generation received from solar PV. Following another year of strong utility-scale and DPV additions, solar power is expected to provide more than 10 percent of California's annual power generation in 2015. This penetration level would push California above other leading global solar markets, such as Germany and Italy, in terms of the share of total power generation sourced from solar PV.



Electrifying energy storage

A number of studies highlight that it is becoming increasingly essential to deliver a secure and reliable sustainable electricity network to meet rising demand. Meeting that goal is a challenge to energy policy and a recently launched UK energy storage solution is attracting interest from the commercial sector including a number of utilities.

VOLTAGE OPTIMISATION BRAND Powerstar, manufactured in Sheffield, England by EMSc (UK) Ltd has launched a new product called Powerstar Virtue, which the company believes will change the way companies and organisations use electricity, by enabling greater control and flexibility and giving maximum financial benefit to the energy user. The pioneering energy storage solution is the result of a dedicated cutting-edge research and development programme that has been ongoing for a number of years.

The National Grid is struggling to cope with the surge in demand for electricity. This increase in demand requires more cabling and pylons to support usage, a cost, which is ultimately passed onto electricity users' bills. This, coupled with the volatile nature of renewable generation sources highlights the need for flexibility and greater control of electricity usage. Energy storage is emerging as a much needed solution to address these problems, allowing energy generated during periods of low demand to be stored locally and used at peak times.

Powerstar Virtue takes this one step further by allowing energy saved from voltage optimisation technology to be diverted into storage.

A versatile solution, Powerstar Virtue can also be integrated with on-site renewable energy generation, to combine the energy saved from the voltage optimisation system with the electricity generated from renewable energy sources, in turn maximising the cost saving benefits from both.

Powerstar Virtue uses the patented Powerstar voltage optimisation technology and harnesses the induced negative power feedback to the supply, to charge a storage medium. In essence, the savings achieved from the voltage optimisation system are diverted into the energy storage system to be used at a time most beneficial to the electricity user. Due to the exceptionally easy way in which the availability of power can be predicted, Powerstar Virtue, can in effect, act as a Virtual Power Station (VPS). With this capability, users are able to use stored energy during times of high peak tariffs, whilst participating in national grid led initiatives like FDR, STOR and EDR.

Powerstar Virtue can also act as a full facility Uninterruptible Power Supply (UPS) system for up to two hours and due to the modular nature of the system, storage modules can be fitted post installation to match any future needs of the site.

Additional benefits of Powerstar Virtue include eliminating the use of inverters on renewable installations, this can help to reduce costs of renewable installations and improve return on investment.

Sites will also benefit from reduced harmonics, voltage phase balancing

and improved power factor, along with reduced maintenance costs of electrical equipment and a 100 percent savings guarantee, as offered with all Powerstar solutions.

Powerstar has been a pioneer in voltage optimisation since being established in 2001 and the brand is still the only voltage optimisation system to carry a patent on its design. The system was designed to address the imbalance between the high voltage levels that are typically delivered to a site by the National Grid – on average 242V - and the voltage actually required for optimum operation of electrical equipment.

The excess energy – on average 22V – is not only wasteful and expensive but overvoltage can also potentially damage or shorten the lifetime of equipment meaning Powerstar Virtue can cut down on equipment costs for the end user. Systems can be installed with minimum disruption to business operations. The voltage optimisation solution has been proven to make savings on LED lighting, as a tender awarded by the University of Melbourne confirmed. It has also demonstrated that significant savings – 6 to 10 percent – can be achieved when modern variable speed drives (VSDs) are concerned.

In 2012, the Powerstar HV MAX was launched, the first ever electronic-dynamic HV side voltage optimisation system. Powerstar Virtue represents a further first and the company hopes it is set to revolutionise the energy storage market. Powerstar's voltage optimisation system is designed to divert saved energy into storage, which can then be used at a time that maximises the financial and operational benefits offering users a proven energy saving, storage solution.

Integrated sub-fab systems

INTEGRATION of sub-fab components into a single unit, with a single controller, provides numerous benefits: better process reliability, safer operation, faster start-up, and reduced total cost-of-ownership. An integrated system supplier is able to define and control the best possible set-up of vacuum pumps, abatement system, exhaust pipe configuration and pipe temperature management to provide reliable and predictable performance.

Edwards' EZENITH system, for example, reduces footprint by 30 percent and exhaust pipe lengths by up to 60 percent, compared to the size and cost of separate pump and abatement systems, significantly reducing operating costs for semiconductor manufacturers. Installation for the EZENITH is also 60 percent faster, due primarily to the reduction by half of required utility connections; and simplified service of the integrated system further reduces the overall cost of ownership.

To optimize performance and efficiency, each EZENITH installation is customized to meet the customer's process-specific pumping and abatement requirements. Customization of the EZENITH has been key to its wide-spread adoption – Edwards announced the 1,000th milestone shipment of the EZENITH in 2014.

Turbo Pumps

Edwards' STP-iXA4506 large-capacity turbomolecular pump (TMP) is designed to deliver significant savings for cost-sensitive manufacturers of semiconductors, flat panel displays, LEDs and solar panels.

The pump's high speed (4300 l/s N2) and throughput (up to 4300 sccm N2), combined with its ability to efficiently pump both light and heavy gases, make the STP-iXA4506 ideal for a wide range of large-volume, high-flow applications, including semiconductor etch, LCD etch, glass coating, solar PVD and coating PVD. Its tightly-integrated design includes a completely sealed electronic module for robust, reliable operation in the most demanding factory environments. When needed, a thermal management system can be added to reduce the accumulation of deposits and particulates from process byproducts.

iXH Dry Pumps from Edwards

Both LED and compound semiconductor manufacturing processes typically use high flows of light hydrogen and highly-corrosive ammonia gasses. The iXH645H has been optimized to support these requirements with superior hydrogen pumping performance and a corrosion-resistant design, including a patented nitrogen purge barrier to protect the pump seals.

The high-temperature capabilities of the pump help prevent condensation of the phosphorous compounds which may be present. In addition, its advanced oil

lubrication and seal technology eliminate periodic maintenance requirements, while its thermal and motor design prevent overheating, motor overloads or zones of limited operation. The pump's optimized temperature control system ensures the pump is ready for process within approximately 30 minutes of start-up.

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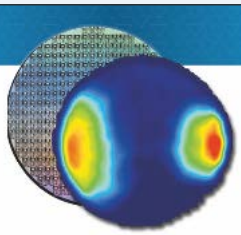

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