Fourth Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS

Automation focus: Fraunhofer IPA presents the most comprehensive analysis of requirements for the PV industry

Exclusive interview with First Solar's Bruce Sohn on manufacturing and what the future holds for the TFPV leader

SOLON puts forth module integration as the keystone for future innovation

LCOE drivers: SunPower outlines the economic benefits

CIGS manufacturing: Global Solar shows us the way

Second Quarter 2009 www.pv-tech.org

Publisher's foreword

Cost, cost, cost.

Depending on who you speak to these days, installed capacity for 2009 is projected to be anywhere from 3.5GW to 7GW. Regardless of what your crystal ball tells you at the moment, it is clear that ASPs are coming down across the board. Furthermore, the economic climate is forcing companies up and down the supply chain to reassess their costs.

The continued reduction of cost and improvements in efficiencies is a much-touted goal of manufacturers in the solar industry, one that is widely spoken of but rarely evidenced in the day-to-day practices of most companies. *Photovoltaics International* recently approached Solon and Global Solar, two manufacturing pioneers who are attempting to make this cost reduction goal a reality.

Global Solar executive Mark McIntyre reveals new information on his company's roll-to-roll CIGS manufacturing process (p.93) while the production executive team at **Solon** provides in-depth information on equipment integration in their very own c-Si module production lines (p.114). Both approaches focus on throughput to help achieve lower costs and enhance efficiencies.

There is no greater opportunity for cost reductions in the fabs than through factory automation. *Photovoltaics International* presents the most up-to-date and authoritative overview of automation practices specifically for the PV industry, written by the experts at **Fraunhofer IPA** (p.18). Continuing this focus, we have also included a paper on the new PV Equipment Communication Interface standard (PVECI), boasting dramatic implications for improving tool interface and highlighting the need for Manufacturing Execution Software (MES) in PV fabs. It is clear that over the next two years all competitive PV fabs will be implementing increased automation practices and MES systems.

Visions of a future where energy is harnessed from the sun to power our increasingly electricity-dependent world are fast becoming a reality as manufacturers, system integrators and project organisations continue to chase elusive grid parity goals. Our Power Generation section features **SunPower**'s delving into ways of measuring the Levelized Cost of Electricty (LCOE) accurately to present true ROI for large-scale solar power projects (p.140). In addition, **DERlab** discusses the requirements for a pan-European renewable energy grid (p.135).

Adorning the walls of **First Solar**'s corporate headquarters in Tempe, Arizona, is the slogan "MILESTONE MADE! TEN ONE ONE". 10 years in business, 1GW in production (and climbing), and 1 dollar per manufactured watt (now 93 cents). The bold achievements of First Solar in reaching these milestones need to be recognised and acknowledged, as the company continues to show the way toward a cleaner, greener future where utility executives will have an equal choice between a new gas power plant or a solar powered one. In this issue, Tom Cheyney gets an exclusive look at this industry giant through the eyes of "Copy Exact" pioneer, Bruce Sohn (p.86).

This is just a small sample of the tremendous array of papers we have in this issue as *Photovoltaics International* continues to provide the highest quality and most detailed editorial for the PV supply chain globally. With over 16 papers in this issue as well as the regular news and Product Briefings, we must once again thank our Editorial Advisory Board for helping us gather together the best contributing authors at the forefront of the solar industry.

Sincerely,

David Owen
Photovoltaics International

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Front cover shows wafers in a buffer-system that is integrated in a process unloader. Picture courtesy of AMB Automation/Amb Apparate + Maschinenbau GmbH, Langweid (near Augsburg), Germany.

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Photovoltaics International

Photovoltaics International's primary focus is on assessing existing and new technologies for "real-world" manufacturing solutions. The aim is to help engineers, managers and investors to understand the potential of equipment, materials, processes and services that can help the PV industry achieve grid parity through manufacturing efficiencies. The Photovoltaics International advisory board has been selected to help guide the editorial direction of the technical journal so that it remains relevant to manufacturers and utility-grade installers of photovoltaic technology. The advisory board is made up of leading personnel currently working first-hand in the PV industry.

Photovoltaics International would like to thank all of our advisory board members for their assistance in this issue and we look forward to working with you over the coming years.

Editorial Advisory Board

Our editorial advisory board is made up of senior engineers from PV manufacturers worldwide. Meet some of our board members below:

Gerhard Rauter

Chief Operating Officer, Q-Cells AG

Since 1979, Gerhard Rauter – a native Austrian – had been working in managerial positions for Siemens AG at different facilities in Germany. In 2005 he became Vice President of Operations & Production with responsibility for the technology transfer between plants at home and abroad. As Vice President and Managing Director at Infineon Technologies Dresden GmbH & CO.OHG he was in charge of the Dresden facilities and their 2,350 employees since 2006. His main responsibilities at the Dresden facility had been in the fields of Development, Production and Quality. In October 2007 Gerhard Rauter was appointed as Chief Operating Officer at Q-Cells AG, being in charge of Production, InterServices, Quality, Safety and Process Technology.

Takashi Tomita

Senior Executive Fellow, Sharp Solar

Takashi Tomita has been working at Sharp for 34 years and is widely recognised as a fore-father of the solar industry in Japan. He was responsible for setting up Sharp's solar cell manufacturing facilities in Nara and silicon production in Toyama. Takashi's passion for solar power has led him to hold numerous posts outside of his roles at Sharp, including: Vice Representative at the Japan Photovoltaic Industry Association; Committee Member of Renewable Energy Portfolio Standard of METI; Adviser Board Member of Advanced Technology of Nara; Visiting Professor of Tohoku University; Adviser of ASUKA DBJ Partners (JAPAN) and Adviser of Global Catalyst Partners (US).

Rodolfo Archbold,

Vice President of Operations, Evergreen Solar

Rodolfo Archbold joined Evergreen Solar in August 2007 as Vice President of Operations. Prior to joining Evergreen Solar, Mr. Archbold served as an operations consultant at Teradyne, Inc., a $1.1 billion global leader in semiconductor test equipment, and at other leading electronics manufacturing firms. In this role, Archbold developed strategy and execution plans designed to improve global operations and supply chain design, reducing manufacturing costs and increasing responsiveness across global supply chain networks.

Dr. Kuo En Chang

President of Solar Division, Motech Industries, Inc.

Dr. Kuo En Chang joined Motech in 1999 as Chief Technology Officer and became President of the Solar Division in 2008, with responsibility for all technology and manufacturing. Motech is the sixth largest solar cell producer in the world. Before Dr. Chang joined Motech Solar, he worked on secondary battery research at the Industrial Technology Research Institute (ITRI) for more than three years. Dr. Chang holds a Ph.D. degree in Metallurgical & Materials Engineering from the University of Alabama.

Professor Eicke R. Weber

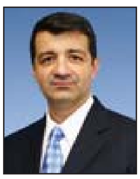
Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg

Professor Eicke R. Weber is the Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. Weber has earned an international reputation as a materials researcher for defects in silicon and III-V semiconductors such as gallium arsenide and gallium nitride. He spent 23 years in the U.S. in research roles, most recently as Professor at the University of California in Berkeley. Weber is also the Chair of Applied Physics, Solar Energy, at the University of Freiburg, and during his career has been the recipient of several prestigious awards including the Alexander von Humboldt Prize in 1994, and the German Cross of Merit on ribbon in June 2006.

Dr. Zhengrong Shi

Chief Executive Officer, Suntech

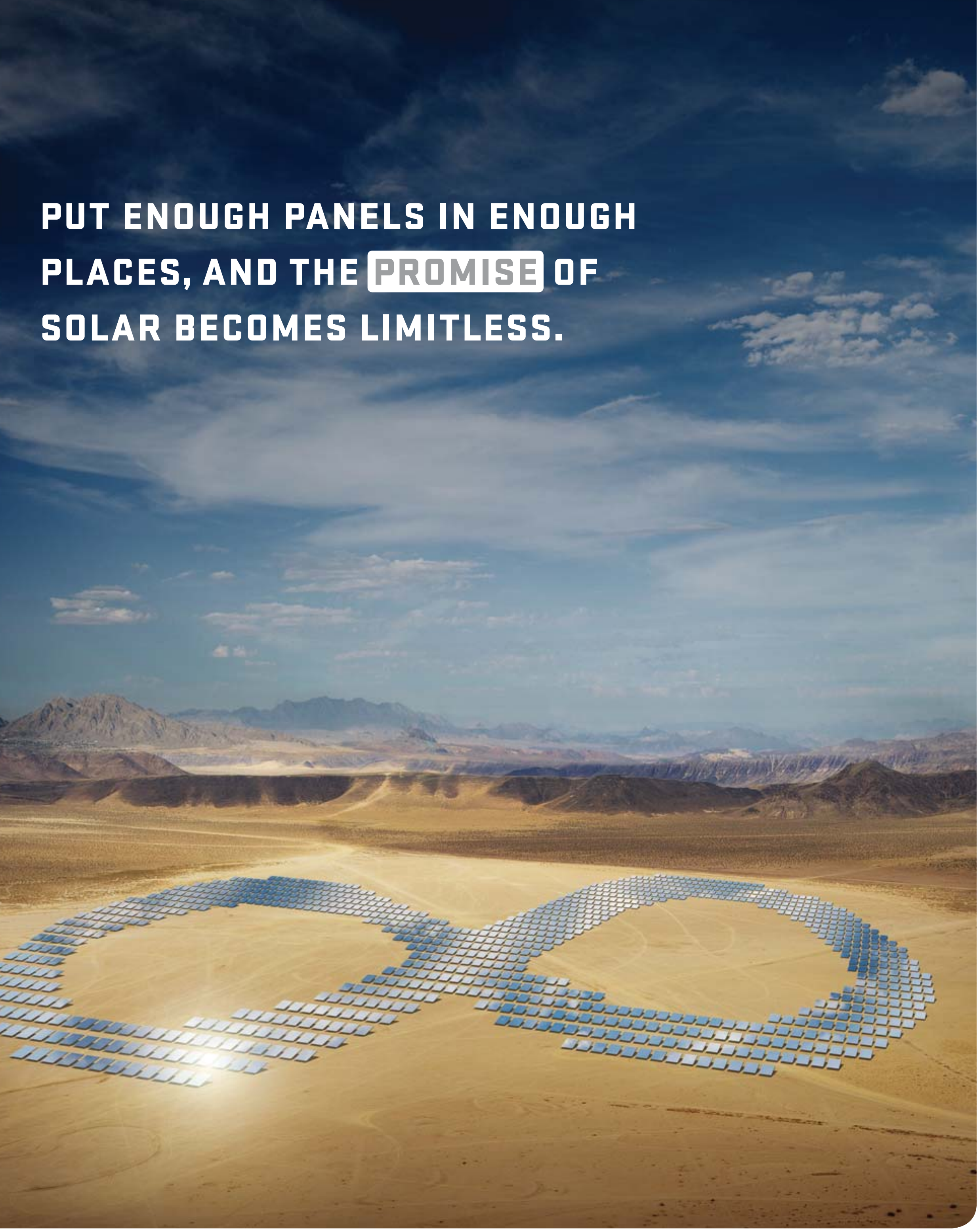
Dr. Zhengrong Shi is founder, CEO and Chairman of the board of directors of Suntech. pPrior to founding Suntech in 2001, he was a Research Director and Executive Director of Pacific Solar Pty., Ltd., the next-generation thin-film technology company, before which he was a Senior Research Scientist and leader of the Thin Film Solar Cells Research Group in the Centre of Excellence for Photovoltaic Engineering at the University of New South Wales in Australia. Dr. Shi holds 11 patents in PV technologies and is a much-published author in the industry. His work has earned him such accolades as "Hero of the Environment" (*TIME* magazine 2007) and "Corporate Citizen of the Year" at the China Business Leaders Awards 2007. A member of the NYSE advisory board, Dr. Shi has a Bachelor's degree in optical science, a Master's degree in laser physics and a Ph.D. in electrical engineering.



Dr. John Iannelli

Chief Technology Officer, Emcore Corp

Dr. John Iannelli joined Emcore in January 2003 through the acquisition of Ortel. Prior to his current role as Chief Technology Officer, Dr. Iannelli was Senior Director of Engineering of Emcore's Broadband division. Currently, Dr. Iannelli oversees scientific and technical issues, as well as the ongoing research to further Emcore's technology. He has made seminal inventions, has numerous publications and has been issued several U.S. patents. Dr. Iannelli holds a Ph.D. and M.S. degree in applied physics from the California Institute of Technology, a B.S. degree in physics from Rensselaer Polytechnic Institute, and a Master's degree in Business Administration from the University of Southern California.



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The SolarMax S Series

The SolarMax S series offers a wide range of string inverters for private homes and central inverters for solar power stations. Our products are based on many years of experience and continuous optimisation and are characterised by cutting-edge technology, high quality, reliability, maximum yields and an excellent price/performance ratio.

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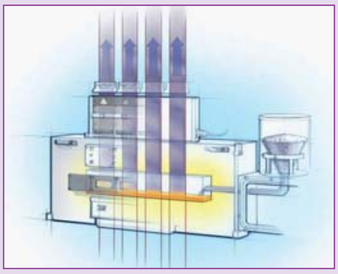
Contents

Fab and Facilities

News

Evergreen Solar shifts manufacturing future to China, targets US$1/W in 2012



String Ribbon solar cell manufacturer Evergreen Solar is planning future expansions in China, with the aim of reaching a manufacturing cost of US$1 per watt by the end of 2012. The aggressive goal is in tandem with ramping a new plant in China to 500MW in that time frame. This is being planned with another PV manufacturer, Jiawei Solar (Wuhan) Co., and the Wuhan Donghu New Technology Development Zone Management Committee, part of the Wuhan provincial government in Wuhan, China.

Jiawei will process String Ribbon wafers into Evergreen Solar-branded panels on a subcontract basis as part of a framework agreement. The structure of the agreement will see Evergreen Solar reimburse Jiawei for its cell and panel production costs, plus subcontractor commission fee. The price paid to Jiawei is to be negotiated on an annual basis.

Legal restrictions that had been in place with Q-Cells and other partners in String Ribbon licensee Sovello over a joint venture agreement will not apply to the new agreement. "We are starting our own factory in China, and we are using a subcontractor in China. So, the minor prohibition that existed under our Sovello agreement does not exist here," said Terry Bailey, Evergreen Solar's sales and marketing VP. The Wuhan government is expected to guarantee the financing required from banks and other potential lending agencies in China as well as provide yet-to-be-revealed incentives for locating the operation in the province.

"With the support of the Wuhan Management Committee, we will seek financing for about two-thirds of the total cost, reducing our portion of initial capital required to between US$15 million and US$20 million," noted Richard M. Feldt (pictured), Chairman, CEO, President of Evergreen Solar. Initial capacity for the Evergreen String Ribbon plant is expected to be approximately 100MW and reach about 500MW by 2012. However, the timing and scale of the planned expansions will be finalised in 2010. Final contractual agreements were close to being signed, though there appears to be a minor delay within the Wuhan government.

By any measure, Evergreen Solar has had a challenging first quarter. Aside from the legal proceedings ongoing with the collapse of Lehmann Brothers bank, Evergreen declared a non-cash charge of US$43.9 million against a deposit given to a polysilicon start-up in France, Silicium de Provence, which went into voluntary bankruptcy in early April. Other charges generated a cash burn-rate of nearly US$100 million in the quarter.

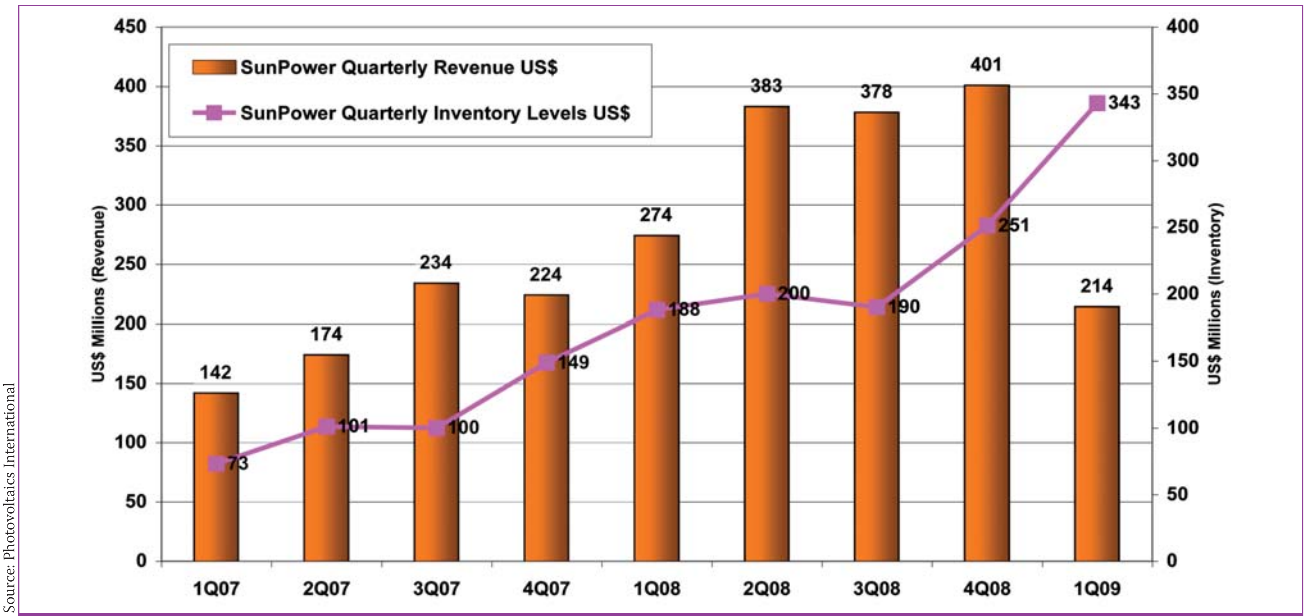
For larger-scale industrial/commercial and utility-scale projects in the future, Evergreen Solar expects to be able to leverage the lower base production costs from China to meet and competitively compete for that business, especially against thin-film technologies.

SunPower cuts production expansion plans as module inventory rises and sales fall

SunPower would seem to have been hit by the 'perfect storm,' judging by its recent release of quarterly financial results. The company cited that the impact of the harsh winter in Germany, the collapse of the Spanish market, by far its biggest revenue generator in 2008 (74%), and continued constraints of project finance and overall tight credit environment have caused the slump.

The result was a significant decline in revenue for the first quarter, coming in at US$214 million, compared to US$401 million in the fourth quarter of 2008. However, inventory levels also mushroomed, increasing by 37% to US$343 million in the first quarter of 2009.

In response, Tom Werner and other SunPower management said in a recent conference call that the company would delay capital expenditures on previously announced production expansions in the Philippines. Executives said that the last three lines at Fab 2, though installed, will not be ramped in the current demand environment. SunPower will also push back part of its Fab 3 ramp in Malaysia until 2010.



SunPower Corp.: quarterly revenue and inventory (US$ million).

Capital expenditure will therefore be lower than previously guided. SunPower now expects spending in the range of US$250 million to US$300 million, down approximately US$100 million for 2009.

However, the company said that it was working closely with equipment and materials suppliers to reduce the lead time required to place and receive capital equipment orders, to allow it to react quickly to changes in the demand environment and therefore not miss out on future market opportunities.

Furthermore, SunPower was in discussions with vendors to change the terms and conditions of existing contracts to reduce its cost structure and improve cash flow.

JA Solar starts construction of new integrated solar cell plant

JA Solar Holdings has broken ground on its Phase II, ingot, cell and module facility in Yangzhou, China. According to Chinese news reports, the production plant will cost approximately US$100 million and be completed by the end of 2009. The reports suggested the new plant would increase JA Solar's production capacity by 300MW.

The new expansion project would seem to be inline with JA Solar's planned capacity of 875MW by the end of 2009, up from 600MW in 2008. The company claims a solar cell production line costs US$10 million, suggesting approximately 6-8 lines could be added.

Everbrite Solar chooses Ontario site for thin-film PV module plant

Everbrite Solar has chosen Kingston, Ontario, as the site for its new amorphous/microcrystalline-silicon thin-film solar PV manufacturing facility – said to be the first of its kind in Canada. The unit of Everbrite Industries is working with several financial advisers to raise CAD$500 million for investment in the highly automated, 150MW annual capacity factory.

The timeline for the construction and production ramp of the new factory has not been disclosed by the company nor were any specific details of manufacturing processes, actual module conversion efficiencies, power output, manufacturing costs, or module pricing. Everbrite Solar will use a turnkey TFPV module production line from an "unnamed overseas manufacturer." Scherre is also quoted as saying first modules could ship by the end of 2010, if all the financing is lined up.

Everbrite said that it will invest up to CAD$25 million to build an experimental thin-film manufacturing facility to which Queen's researchers will have access for their studies.

From left: Holger von Hebel, Birgit Diezel, Franz Fehrenbach, Dr. Angela Merkel, Prof. Hermann Scholl, Dr. Siegfried Dais, Ludwig Reiff.

ersol starts construction of €530 million crystalline solar cell and module plant

Attended by the German Federal Chancellor Angela Merkel, ersol Solar Energy AG, a subsidiary of Robert Bosch GmbH has held a groundbreaking ceremony in late March for its new €530 million crystalline solar cell and module plant in Arnstadt, Germany.

Production is expected to start at the beginning of 2010, and the facility will be fully ramped by 2012. ersol's crystalline-based capacity will be increased to 630MWp, compared with the approximately 200MWp reached in 2008. The new plant will be capable of producing 90 million solar cells per year, according to the company.

"This investment is part of our increasing activities in renewable energies. These energies are increasingly gaining in significance, and will be integral to the energy mix of the future. Bosch recognized this at an early stage, and is already a major supplier to the wind-power industry, as well as of solar collectors and heat pumps for heating systems," said Franz Fehrenbach, Chairman of the Board of Management of Robert Bosch GmbH.

Research and development activities will be also be expanded as part of the new investment by Bosch.

Total, GDF Suez mull construction of solar wafer plant in France

Energy multinational Total and GDF Suez are planning to build a solar silicon wafer plant in eastern France. The factory, to be located in the Moselle region near the German border, would have an initial investment of €70 million and employ up to 100 workers. The companies said the project is subject to both parties' respective corporate approvals and to the necessary administrative authorizations.

Total and GDF are already partners in the solar industry through their common subsidiary Photovoltech, a crystalline-silicon cell manufacturer based in Tienen, Belgium. Each holds a 47.8% interest in the company.

Total also has minority interests in U.S. organic PV developer Konarka and Swiss thin-film PV R&D company Novacis.

Applied Materials to expand thin-film, c-Si R&D facility in China

Applied Materials is set to expand its 'SunFab' thin-film module and c-Si testing and R&D facility in Xi'an, China, after a tour at the facility, which was opened in 2008 by Chinese Vice Premier Li Keqiang. Claimed to be the first facility of its kind in China, Applied Materials said it had recently broken ground on phase two of its new 'Global Solar R&D Center,' which will include R&D, engineering, demonstration, validation and training for both crystalline silicon and thin-film solar equipment and processes.

"There is a tremendous opportunity for the United States and China to work together to our mutual benefit and to make solar a more meaningful part of the energy supply of both countries," said Charles Gay, President of Applied Solar and co-chair of the Renewable Energy Working Group for the U.S.-China Clean Energy Forum. "With the government's support and commitment we can help make solar a more affordable option and grow the market for solar panels throughout China."

At the 5th China SoG Silicon and PV Power Conference (5th CSPV), held in conjunction with SOLARCON China, Chinese PV leaders pushed for greater internal demand for solar energy deployment as part of the stimulus packages as the majority of PV products that include, wafers, cells and modules are exported.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China Vice Premier Li Keqiang (front centre) leans forward to watch as an engineer (sitting) demonstrates sophisticated tests being performed on solar panels at the Applied Materials SunFab Solar Module Reliability Testing facility, Xi'an, China. Also viewing the demonstration are: Shaanxi Governor Yuan Chunqing (front 2nd right); Xi'an Party Secretary Sun Qingyun (front right); Gang Zou, General Manager of Applied Materials Xi'an (front 2nd left); and Barry Quan, President of Applied Materials China (front 3rd right).

"Vice Premier Li's visit to Applied underscores the importance the Chinese government is placing on renewable energy and in particular solar," said Barry Quan, President of Applied Materials China. "We are honored that he chose to visit our facility and look forward to working closely with the government in Xi'an and at the national level to help accelerate the utilization of solar throughout China."

Dow Corning selects South Korean site for second solar application centre

Dow Corning has chosen JinCheon, South Korea, as the site of its second Solar Solutions Application Center, joining its first PV application centre, which opened in Freeland, MI, in May 2008.

At the centre, engineers and scientists will work with customers to develop, evaluate and pilot materials solutions used to manufacture photovoltaic panels. The facility will include material development and characterization labs, an industrial-scale pilot line for photovoltaic module assembly, and environmental aging and testing capabilities.

The lab portion of the Korean application centre is scheduled to open in late 2009, with the pilot production equipment coming online by early 2010, according to Dow Corning. The company did not disclose the amount that it intended to invest in the new application centre nor the projected capacity of the module pilot line that it plans to build there.

"With almost 60% of solar module producers based in Asia, this centre will play an important role in the global solar industry growth as well as manufacturing growth in Asia," said Eric Peeters, global executive director of the company's solar business unit.

Solar-Fabrik begins phase I module production at 200MW automated plant

Solar-Fabrik has officially opened its new state-of-the-art photovoltaics module plant (Plant III) in Freiburg. The first phase of the expansion (60MW) increases Solar-Fabrik's total module production to 130MW, while the second phase of expansion is expected to take place in 2010. Plant III has a nominal planned capacity of 200MW and covers 15,000m^2 of production floor space.

"Almost the entire production volume for the year was already sold at the beginning of 2009," noted Günter Weinberger, CEO of Solar-Fabrik. "The high degree of automation increases the efficiency and the productivity, and enables the quality standards to be increased even further."

"We have developed the concept for the line in conjunction with one of the market leaders for fully automatic production


Solar-Fabrik Plant III Phase I module production.

systems for photovoltaics," commented Andreas Blochel, Head of Production and Process Technologies: "All components in the line are state-of-the-art."

The highly automated plant employs transverse soldering equipment and an innovative connection socket concept for the modules as well as fully automated solar wafer handling to reduce breakage.

Roth & Rau boosts equipment services business with Ortner acquisition

Roth & Rau AG has acquired Ortner cleanroom logistic systems GmbH for an undisclosed sum in an effort to meet increasing demand from customers to support crystalline and thin-film equipment servicing, spare parts and other support activities. Ortner, based in Dresden, is a specialist in tool installations and automation. Ortner's existing management and skilled workforce will continue to operate the business as a subsidiary of Roth & Rau.

"We are seeing increasing demand for services from our customers. Building up our competence and capacities in this area will enable us to extend our range of products and services as one of the leading suppliers of photovoltaics technology and equipment," commented Dr. Dietmar Roth, CEO of Roth & Rau AG.

Ortner was said to have a turnover of €6.1 million in the 2007/2008 financial year.

SolarWorld to expand U.S. capabilities, start construction on new Oregon building

SolarWorld will begin construction soon on a new building adjacent to its Hillsboro, OR, production plant. The 210,000 square-foot facility, scheduled for completion in November, will house a combination of logistics and manufacturing activities.

The green-field structure, the second phase of the company's buildout at the site, will increase the overall plant space by 44%. SolarWorld's main building – a converted former Komatsu semiconductor factory now home to an integrated solar-cell fab said to be the largest of its kind in North America – measures about 480,000 square feet. The company holds 100 acres of property at the Hillsboro location. The move keeps the company on track to reach its goal of ramping 500MW of annual cell-making capacity in Hillsboro by 2011 and of eventually employing some 1100 workers there.

Company spokeswoman Anne Schneider told PV Tech that details of the revamped production flow, the timing of the manufacturing ramp, including the dates of arrival and installation of new

equipment, have yet to be determined. The new building will be split 50:50 between logistics and production functions, she added.

Solaxis, Solardach construct solar power plant in Moers, Germany

In a joint collaboration, Solaxis GmbH and Solardach GmbH have constructed a solar power plant in the city of Moers near Duisburg, Germany on the roof of Riedel Recycling that features solar modules with a total capacity of 837kW. Jamain Riedel, the youngest member of the Riedel family, symbolically flipped the switch to activate the solar power plant. The plant marks Germany's largest photovoltaic plant using thin-film technology on a pitched roof.

The official inauguration was held on March 21, and was followed by a spring festival, which around 120 people attended. In addition to project partners, customers and suppliers, Norbert Ballhaus, the mayor of Moers, was also in attendance.

A Germany subsidiary of the Swiss inverter manufacturer Sputnik Engineering provided technically support for the project, where four SolarMax central inverters were used. The roof has been covered with over 10,000 cadmium-telluride modules from First Solar.

Inauguration of the Solaxis, Solardach plant in Moers, Germany.

Solar Array Ventures chooses New Mexico as site for PV panel factory

Solar Array Ventures has raised US$210 million to move from its Austin, TX, incubator digs to a greenfield site in Bernalillo County near Albuquerque, NM. SAVe (the PV company's acronym of choice) plans to break ground on a thin-film solar panel manufacturing facility this summer and have production rolling by late next year. According to the CFO Everett 'Buddy' Rogers, one of main reasons that the start-up chose to base its operations in the Albuquerque area is because the local "economic development group took them seriously very early on." The incentives offered to SAVe total nearly US$200 million. The Albuquerque Journal reports that "Bernalillo County Manager Thaddeus Lucero said the commission is set to take its first action Monday on a US$175 million industrial revenue bond (IRB) package for the company – the largest IRB in the county's history."

"Since we want to break ground this summer, to be able to do that, we have to finalize the equipment manufacturer so we can design the building itself around that equipment," he continued. "The architects that we're working with have worked with both Oerlikon and Applied Materials, so we think we'll be able to move pretty quickly. We have what I would call an 80% basis of design using both lines; that way, once we get closer to a finalized contract with either supplier, we can move in that direction very quickly."

Whatever the brand of turnkey line, SAVe is looking at a "60 or 70MW" dual-/tandem-junction a-Si module line initially, to be outfitted in the 225,000 square-foot building. Most of its US$210 million war chest will be invested in the plant and equipment, with a smaller portion allocated for "working capital and soft costs," according to Rogers. The PV firm will start with 25 acres, with an option for 25 more, which would provide enough "room to do multiple plants out there."

Product Briefings

vogt

vogt offers full factory life cycle support services

Product Briefing Outline: To meet increasing demand for production services in the PV industry, Dagmar Vogt has established vogt-factory life cycle support GmbH in Berlin. As a member of vogt group SE, the new company will complement the planning and realization services offered by PV factory specialist ib vogt. The new services are divided into four areas: labour support, logistics support, process optimization and process consulting. vogt-factory life cycle support will act as a central point of contact, drawing on a network of experienced partners.

Problem: Following a successful pilot phase, a PV manufacturing plant will automatically shift its focus to increase productivity and quality. However, optimization and production cost reduction demand multiple disciplines working in tandem to produce the desired results. Workforce levels and expertise are required in the fields of benchmarking, bottleneck identification, automation improvement, project management optimization/scheduling, cost-of-ownership reduction programmes, quality optimization analyses and roadmaps for preventive maintenance and implementation.

Solution: vogt-factory life cycle support GmbH offers a full spectrum of support services for process optimization that includes a comprehensive preventive maintenance concept which is claimed to reduce unplanned downtime and lead to yield improvement resulting from wafer breakage reduction, as well as enhanced availability and throughput. For technical production problems, an expert in the relevant field is identified and then tasked to resolve the problem using experience gained in resolving numerous similar problems.

Applications: All areas of c-Si and thin-film fab process optimization and cost reduction.

Platform: The new services comprise labour support, logistics support, process optimization and process consulting.

Availability: Currently available.

EBARA Precision Machinery

EBARA offers integrated pump and abatement systems for c-Si and thin-film manufacturing

Product Briefing Outline: EBARA Precision Machinery Europe offers a full scope of Dry Vacuum Pumps and Gas Abatement Systems, combining them to provide customized solutions for the PV industry. EBARA can handle requirements for silicon wafer and thin films, and also offers project planning, system engineering, installation, maintenance, consulting and training,

Problem: A large part of PV equipment for the production of c-Si and thin-film solar wafers and panels handle harsh, toxic and pyrophoric process gases under vacuum conditions. The pumping and abating of these gases has to be performed effectively from the perspective of pumping speed, energy and N_2 consumption, operational reliability, safety and waste disposal.

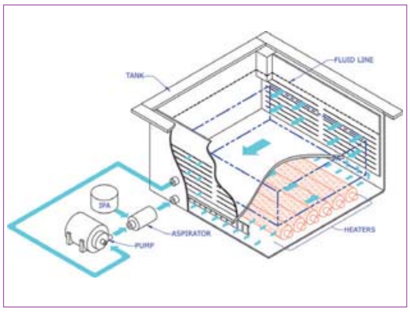
Solution: EBARA offers a wide scope of Dry Vacuum Pumps (ESR, ESA and EST series) with outstandingly low energy and N_2 consumption; pumping speeds up to 3,000 m^3/h; vacuum levels down to 10-3 mbar and excellence for particle handling of solar processes; abatement systems for waste gases like PFCs (G5-type burner washer scrubber) and for SiH_4 (dynamic oxidation scrubber S-DOC and E.DOC). The Airgard wet scrubber is ideally suited for H_2S/H_2Se removal in CIS applications. EBARA Roots pumps can be combined to big pumping stations to pump down the heavy gas load of equipment for TCO processes and for amorphous/microcrystalline tandem thin-film layer formation. On the abatement side for TCO and tandem thin-film layer formation, the burner washer G5-type abatement and the SiH_4 dynamic oxidizer S-DOC, combined with a Keller particle filter, are the most advanced solution ensuring maximum uptime and ease of waste removal.

Applications: Crystalline and thin-film solar cell manufacturing.

Platform: Dry Vacuum Pumps include ESR, ESA and EST series. Point-of-use abatement systems include G5-type burner washer scrubber for PFCs and the Airgard wet scrubber for H_2S/H_2Se removal.

Availability: Currently available.

Heateflex Corporation



Heateflex texturing tank enables uniform heating for better etch solution

Product Briefing Outline: Using Heateflex Corporation's patented 'Heateflex' heating coil and laminar flow design, the heated tank provides uniform heating during the texturing process. The modular design provides ease of maintenance, while the tank itself allows for removal of nuisance bubbles common to other heating methods.

Problem: The texturing process can be impacted by variations in process temperature and chemical concentration. Other critical factors that contribute to the texturing process are mechanical agitation, reduction of bubbles on the silicon surface, and process and equipment purity. These critical factors must be controlled in order to optimize the texturing process to obtain the desired results.

Solution: The Controlled Flow, Texturing Tank is specially designed to implement the texturing process in a production environment, giving the user better control over the critical parameters needed to improve the texturing method. This innovative tool shortens the process time by causing a more uniform flow across the surface area of the solar cell substrates. In a static tank, solar cells see no flow on their surface. By introducing flow in a shorter amount of time and with more consistent results, the patent-pending Controlled Flow, Texturing Tank also removes and eliminates more bubbles from the surface of the solar cell substrates.

Applications: Increase corporate profits by increasing solar cell conversion efficiency and improved production yields; achieve better control of the texturing process to improve manufacturing and optimize processes.

Platform: Heateflex products are built to accommodate the stringent demands of the semiconductor and related high-technology industries. The company uses the highest quality non-contaminating components, designed to meet or exceed SEMI, UL, and CE requirements.

Availability: Currently available.

Location Briefings

Solar Valley

Location: Bordering the states of Saxony, Thuringia and Saxony-Anhalt in Germany, the Solar Valley provides access to important markets in Germany, Spain, Italy and the rest of the EU (operating in the EU economic zone).

Introduction: Central Germany is already one of the leading solar regions in the world, with two-thirds of German solar production firms located in the area. The region is responsible for the production of 80% of German and 16% of globally produced solar cells: one in ten of the solar cells manufactured worldwide is made in Saxony-Anhalt. The core of the 'Solar Valley' is situated around Halle-Bitterfeld. Q-Cells AG – the world's largest solar cell producer – is based in Bitterfeld-Wolfen.

The Solar Valley centre for silicon photovoltaics has the highest density of companies involved in the photovoltaic industry.

Companies such as Q-Cells, Sovello, Sontor, PV Crystalox, ersol and SolarWorld are collectively backing the "Made in Germany" quality and the sunny outlook in the German Solar Valley.

Infrastructure:

- The joint project will provide research funds worth a total of €120 million in the next five years.
- Saxony-Anhalt acquires one-fifth of its energy from renewable energy sources.
- The solar industry in Saxony-Anhalt can benefit in particular from the expertise and knowledge of the excellent universities and research institutes in the country.
- Equipment and material supply companies have operated in the region for over 30 years supplying the semiconductor and automotive industries.

Key features/incentives: Around 60 worldwide leading PV companies have set up in the Solar Valley and are taking advantage of the numerous benefits in know-how and experience. Almost €200 million was invested for research and development in 2007 alone. The focal point is the CSP, the "Fraunhofer-Center für Silizium-Photovoltaik (Fraunhofer Center for Silicon Photovoltaics)", where crystallization experiments and microstructure analysis for the characterisation of silicon wafers as well as material-related experiments during the manufacturing process and operations are carried out.

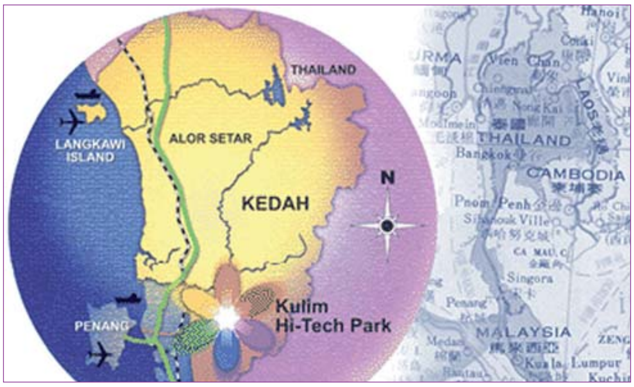
Key tenants

Q-Cells, ersol, SolarWorld, Sovello, PV Crystalox.

What they say: "Saxony-Anhalt embraced the solar industry at an early stage and supported companies and research institutions. These investments are paying off now – supported firms are growing and newcomers are setting up shop."

Dr. Reiner Haseloff (pictured), Minister of Economics, on the Solar Valley winning an excellence cluster award of €40 million in 2007.

Kulim Hi-Tech Park



Location: Situated at the centre of the Northern Region in Kedah Darul Aman, the Park is very close to the North-South and East-West Highways. It is 27km from the North Butterworth Container Terminal and 45km from Bayan Lepas International Airport.

Introduction: The Kulim Hi-Tech Park (KHTP), officially opened in 1996, is the first high-technology industrial park in Malaysia. The Park is situated in Kulim, Kedah Darul Aman, in the north-west of Peninsular Malaysia and comprises a total land area of approximately 1,700 hectares (approximately 4,000 acres). One of the primary aims of the Kulim Hi-Tech Park is to propel the country towards realising the goals of the Vision 2020, for Malaysia to be a fully industrialised nation by 2020.

Infrastructure:

- There is an abundant clean and potable water supply from three reservoirs, supplying more than 85,000 cubic metres per day.
- Air Products STB Sdn Bhd supplies specialised gases through underground pipelines from their distribution plant in the Park.
- Scheduled industrial waste disposal is provided by Kualiti Alam Sdn Bhd.
- Telekom Malaysia provides 60,000 lines through their fibre optics network while MIMOS Malaysia's premier internet service provider is also operating from the Park.
- Reliable, stable and quality power is provided by an independent company within the Park. The power provided exceeds the requirement of the Park's tenants.

Key features/incentives: The Park has been servicing large-scale semiconductor facilities including Intel and Infineon on site for many years. This has created a mature supplier infrastructure for much of the equipment and materials required for establishing photovoltaic manufacturing facilities.

High-technology companies receive:

- Total exemption from corporate tax at the statutory income level for five years.
- Investment Tax Allowance of 60% on qualifying capital expenditure for five years. The allowance can be offset against a 100% statutory income for each assessment year and the unused portion can be carried forward.

Key tenants

First Solar, Air Products, Q-Cells, Applied Materials, DB Schenker, Entegris, Von Ardenne.

What they say: "Dedicating this plant today represents a major milestone for First Solar. Our expansion into Asia enables us to achieve cost reductions through economies of scale in a high quality manufacturing environment."

Bruce Sohn (pictured), President of First Solar.

Overview of automation in the photovoltaic industry

Kevin Reddig, Fraunhofer IPA, Stuttgart, Germany

ABSTRACT

The aim of this paper is to provide an overview of the methods of automation and their application areas. Current technologies and their applications in both crystalline and thin-film technology will be the main focus, with detailing of the value chain, starting from the feedstock to the finished product. For ease of discussion, the focus is on the part of the value chain where discrete manufacturing on the substrates takes place. The paper will show different philosophies of automation and highlight their advantages and disadvantages, and will contribute a commentary on future developments. Throughout this paper, we have given a step-by-step breakdown of the applications of automation in the PV manufacturing industry, from automation for crystalline technology to automation for thin-film manufacturing.

Introduction

The photovoltaic industry has been increasing tremendously in recent years. Global production volume has risen from 1.7GWp in 2005 to 7.1GWp in 2008 (estimated 9-10GWp in 2009), made possible by increased demand and the resulting provision of capital.

Compared to other industries, photovoltaics is just beginning to activate and exploit its full potential. With the currently predominating technology based on rigid substrates, such work paces as are seen in other industries could never be achieved for the photovoltaics industry. Nevertheless, many acceleration methods can and certainly will be introduced to decrease the overall production costs.

In this context, factory automation was and still is a key enabler. Were it not for the introduction of automation, many factories would not have been established and ramped so quickly. However, automation is not the end in itself and therefore this paper will also deal with its limitations.

"Were it not for the introduction of automation, many factories would not have been established and ramped so quickly."

As this paper will only give an overview of automation in the industry, it does not claim to be a complete report. Future contributions to *Photovoltaics International* by Fraunhofer IPA and others will address more specific aspects of automation.

Definition and purpose of automation

The most common approach is to introduce automation into production to reduce costs by enabling a faster and cheaper processing as well as by facilitating 24/7 manufacturing. One result of automation is the reduction of the workforce, often required in regions with comparatively high wages. Automation can also ensure

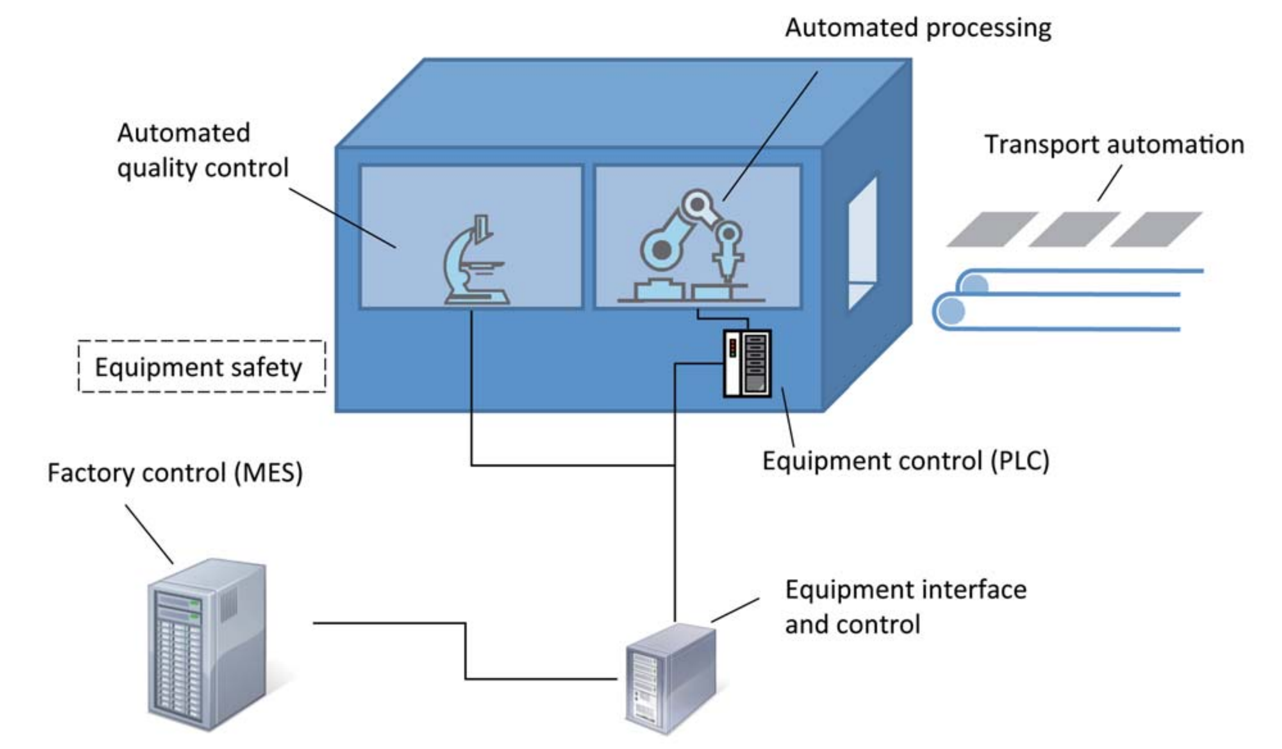


Figure 1. Aspects of automation in photovoltaic manufacturing.

product quality, staff safety and better environmental conditions. Cost reduction is a well-known necessity, and the sheer amount of substrates processed in today's larger factories usually calls for an elevated degree of automation. In terms of quality requirements, wafers and substrates are delicate products that can easily be damaged if not treated properly, while there are further crucial considerations to be taken into account in relation to the safety of operators.

Factory automation is a complex and integrated interaction of different systems, not only in the physical transport of a product from A to B, but must comprise software and hardware that interact perfectly. Such a system contains equipment that has to meet the requirements of the automated process, material flow, consumables, communication and control systems.

Integrated automation systems in a factory typically have to provide the following functions:

- Automated processing: interfacing appropriately with the manufacturing environment to carry out processes in an automated manner.
- Physical availability of the required materials: the automation system typically comprises elements that 'care' for the automated transport and provision.
- Measurement and control: sensor signals and quality data are used to both control the process flow and to control and adapt the individual production units.
- Interfaces: different types of equipment have physical interfaces as well as control interfaces to allow for automated access as well as for human interference.
- Safety: the automation system must also provide safety measures for the protection of humans, the protection and quality assurance of materials and for overall environmental safety.

Different views on automation

A manufacturer is not only interested in more cost-effective production methods, but also has to consider location-specific factors such as labour costs and regulations. The introduction of automation increases capital expenditure, and brings with it the risk that the flexibility of the production line might be reduced. Moreover, there is an increased dependency on the equipment itself.

Automated equipment usually utilises actors, sensors and corresponding equipment control. The more automated a procedure is and the more information is gathered regularly from these procedures, the more complex the equipment is in terms of the components used and the equipment control. Especially in a manufacturing environment, technical components can deteriorate faster than expected, leading to greater equipment supply and training requirements as the technology is updated more regularly. For the maintenance of such equipment, the availability of qualified personnel in a factory must be guaranteed.

Automation unfolds its strength when standardized procedures have to be executed more or less exactly in the same manner. A visual check of wafers or substrates by a human operator can often unveil deviances which otherwise might remain undiscovered. Nevertheless, manufacturers generally wish to have control over their processes by applying automation.

> "Automation unfolds its strength when standardized procedures have to be executed more or less exactly in the same manner. A visual check of wafers or substrates by a human operator can often unveil deviances which otherwise might remain undiscovered."

Labour costs can be comparatively low in some regions, thus permitting the employment of more operators in the manufacturing line and reducing the need for some aspects of automation. Chinese company Suntech is an example of such a strategy in that it endeavours to apply as many manual processes in the cell production as possible. The consequential effects are reduced investment costs and an increased flexibility.

Cost of automation and future factories

The costs of automation usually do not contribute very much to the manufacturing costs. In the thin-film industry, for instance, the costs of automation typically contribute 1-3% to the total investment, which itself has a share of roughly 25-35% of the total production costs; measured according to cost per watt peak, it is well below 1%. The equipment costs in crystalline wafer and cell manufacturing are usually below 25%; for module manufacturing they are below 10%. Depending on the degree of automation, the resulting costs also make up less than 1% of the total costs for cells and modules.

Large factories can also reduce the costs tremendously due to better purchasing conditions of the required materials. For thin-film technology a share of 50% of the total costs is assumed for all required materials; for crystalline technology, usually more than 60% has to be calculated for the material (including silicon). Should the company need to purchase silicon products (polysilicon, wafers or cells) the share will increase further. In the case of module manufacturing, this sums up to more than 75% if cells are bought on the market. (Due to the current economic situation, the cost of cells has decreased.)

Therefore, future factories will definitely increase in size to leverage the benefits of the economy of scale, which will also affect the suppliers. In this situation of increased consumption, it will be beneficial to produce several kinds of material in nearby factories. This applies for substrates (glass or wafer), gasses and media or encapsulation materials. Factories in the gigawatt range might as well operate a dedicated glass production line that will introduce new requirements into the integrated automation solution.

Operation of such a large factory will require further developments, including:

- Compliance with standards
- Capability for interaction with higher control systems
- Ability to perform quick maintenance and repair.

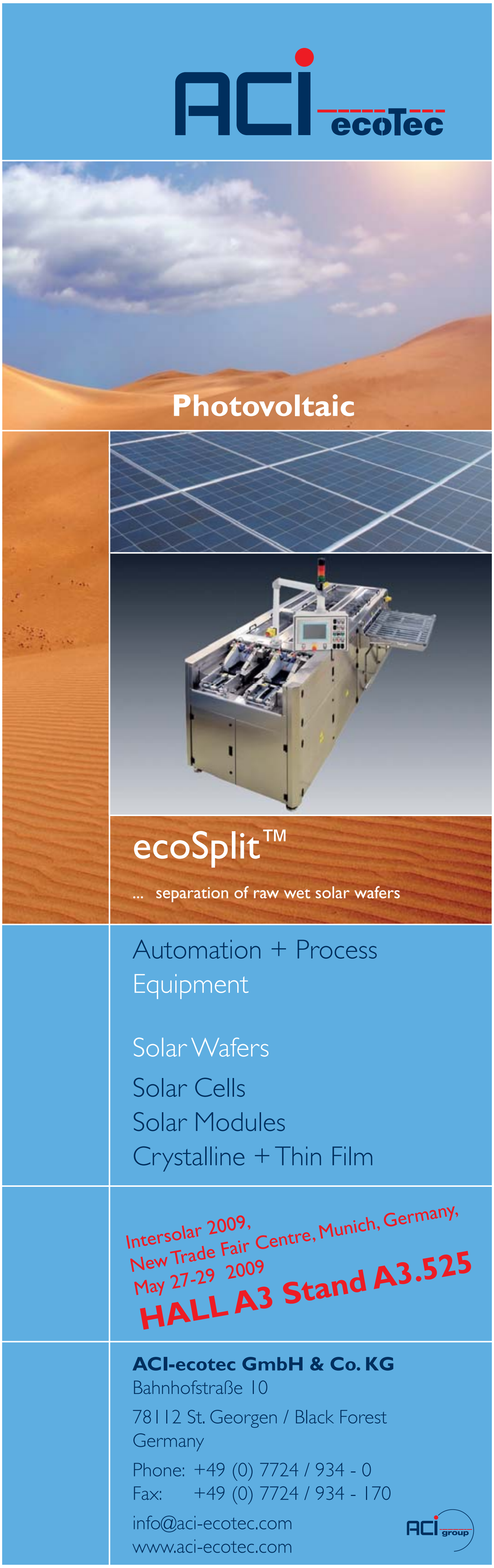
Standardization

Standardization in manufacturing means the creation of a common comprehension of the technical characteristics of work pieces and the means of production. Standards are based on written specifications that describe how the features of the addressed area should be designed and require a large uptake in order for them to be introduced successfully and realized by stakeholders in their companies. Generally speaking, standards should be open and accessible to all stakeholders. Proprietary knowledge (e.g. patents) sometimes also creates a de facto standard, resulting in a monopoly in this area.

Standardization in manufacturing is usually viewed as a way of facilitating the build-up and the operation of factories. Standards are generally introduced to reduce the product costs, facilitate the entry of new market participants and to inspire customer confidence. By its nature, a standard is usually based on the mutual agreement of a large group of stakeholders, and often takes a long time to be adopted due to uncertainty on the part of the market participants, as well as a reluctance on the part of the stakeholders to bear the initial costs generated by the introduction of standards, coupled with concerns of a slowdown of innovation. Technologies that do not comply with a standard can be constrained as a result.

In the photovoltaics industry, standards can be applied with respect to automation in the following areas:

- Substrate dimensions and characteristics
- Carriers and other means of handling and transportation



ACi ecoTec
Photovoltaic
ecoSplit™
... separation of raw wet solar wafers
Automation + Process Equipment
Solar Wafers
Solar Cells
Solar Modules
Crystalline + Thin Film
Intersolar 2009,
New Trade Fair Centre, Munich, Germany,
May 27-29 2009
HALL A3 Stand A3.525
ACI-ecotec GmbH & Co. KG
Bahnhofstraße 10
78112 St. Georgen / Black Forest
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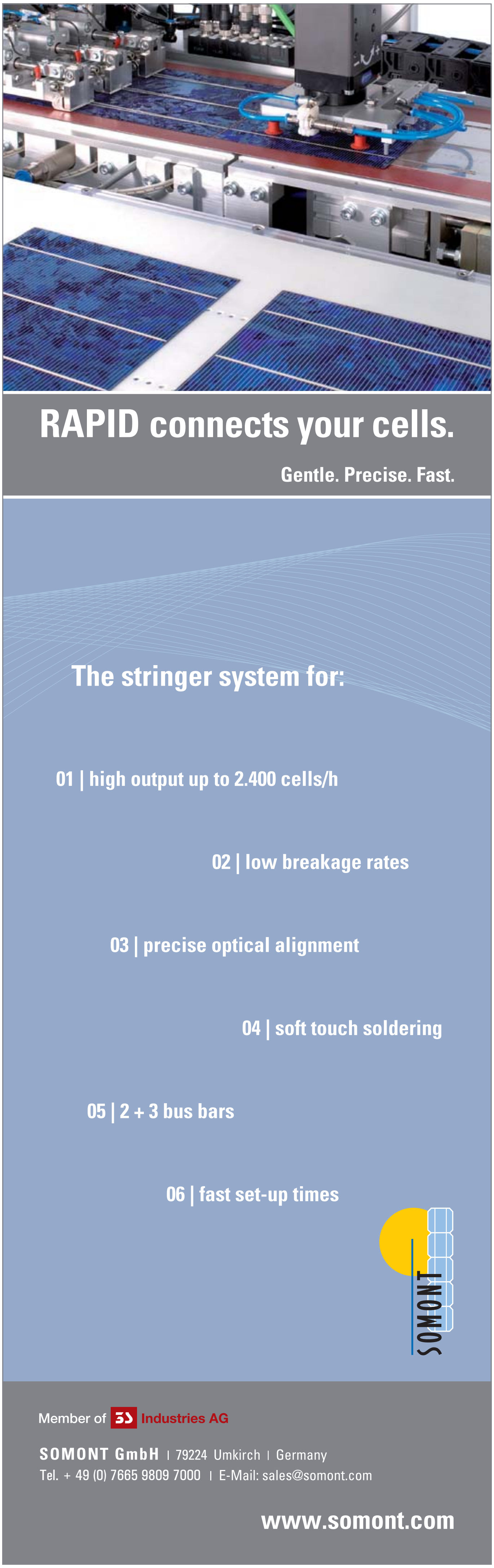

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02 | low breakage rates
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- Loadports of equipment and interfaces for consumables
- Equipment interfaces for control and data collection.

The latter area has been tackled by a group of stakeholders who created a standard published by the semiconductor association SEMI [1]; the other areas are currently being investigated by different interest groups.

However, many suppliers and manufacturers have developed their own methods of handling and transport, and will undoubtedly be reluctant to alter them without seeing a long-term benefit.

In the long run, several experts nevertheless see the necessity for an agreement of certain automation standards. In order to achieve this, two vital factors have to be considered:

- A standard usually does not succeed if stakeholders wish to introduce proprietary products and methods.
- If different solutions already exist, some stakeholders will need to give up certain proprietary solutions and adapt to a common standard.

Manufacturing control

Due to the demand for an efficient line control, Manufacturing Execution Systems (MES) are being considered more and more often by manufacturers. One of the first functionalities used is the collection and the analysis of the production and process data, and as a result, the Statistical Process Control (SPC) is quickly becoming one of the most used functionalities of the current MES.

From the standpoint of process equipment, the interface to a higher factory control (usually MES) is the main obstacle to full integration. The full functionality of the above mentioned standard will allow the achievement of active control in terms of the process start and stop or the recipe changes. Most of the process and automation equipment are controlled by a PLC (Programmable Logic Control) which, when used in the creation of the equipment interface, is currently regarded as very expensive, but will undoubtedly decrease as the demand for such interfaces increases.

> "Many suppliers and manufacturers have developed their own methods of handling and transport, and will undoubtedly be reluctant to alter them without seeing a long-term benefit."

Material tracking is a necessity for a full factory control scenario, but remains a challenge, with frequent alterations of the shape and surface of crystalline substrates during the processing impeding permanent marking. Technical and economical barriers hamper the introduction of corresponding methods. The tracking of glass substrates (especially in thin-film production) is quite simple as cost-efficient laser marking and readers are available for substrate tracking. Such systems are widely used in thin-film manufacturing solutions.

From an economical point of view, single substrate tracking is critical, as large amounts of data need to be gathered and analyzed. One disadvantage of a batch tracking approach is the difficulty of mixing of lots and batches in production lines which impairs the usage of the production data and a very close coupling with the MES.

Future factory control solutions must take into account the short cycle times in photovoltaics, and that cost reductions and process simplification are the predominant goals of all manufacturers. By achieving the stabilization of manufacturing processes, the quality and the process control in mass manufacturing will only have to be used at certain steps.

Challenges and expected developments in automation

Photovoltaic modules are generally viewed as commodities that must bring with them a guarantee of quality and a warranty, leaving the buyer to consider such crucial factors as price and availability as the main decision-making criteria. In terms of manufacturing and automation, the key to success will be to increase the throughput while maintaining reliability and quality. The manufacturing processes will further accelerate, the factory capacities will increase and the substrate sizes will also finally increase, forcing automation to adapt to meet these requirements.

Suppliers of automated process equipment will have to increase uptime for a higher overall utilization of the production line and increased throughput. Nevertheless, the process equipment will still have to be maintained and altered during its lifecycle. In order to compensate for downtime and other process deviations, substrates have to be stored or rerouted. In interconnected lines the material flow then has to enable the transfer of products to equipment that is capable of carrying out the same process step. Likewise, the control system has to track the material as well as balance the capacities of all manufacturing equipment.

Experienced manufacturers usually plan new production lines on the basis of gained experience and individual requirements. Such manufacturers seldom use turnkey

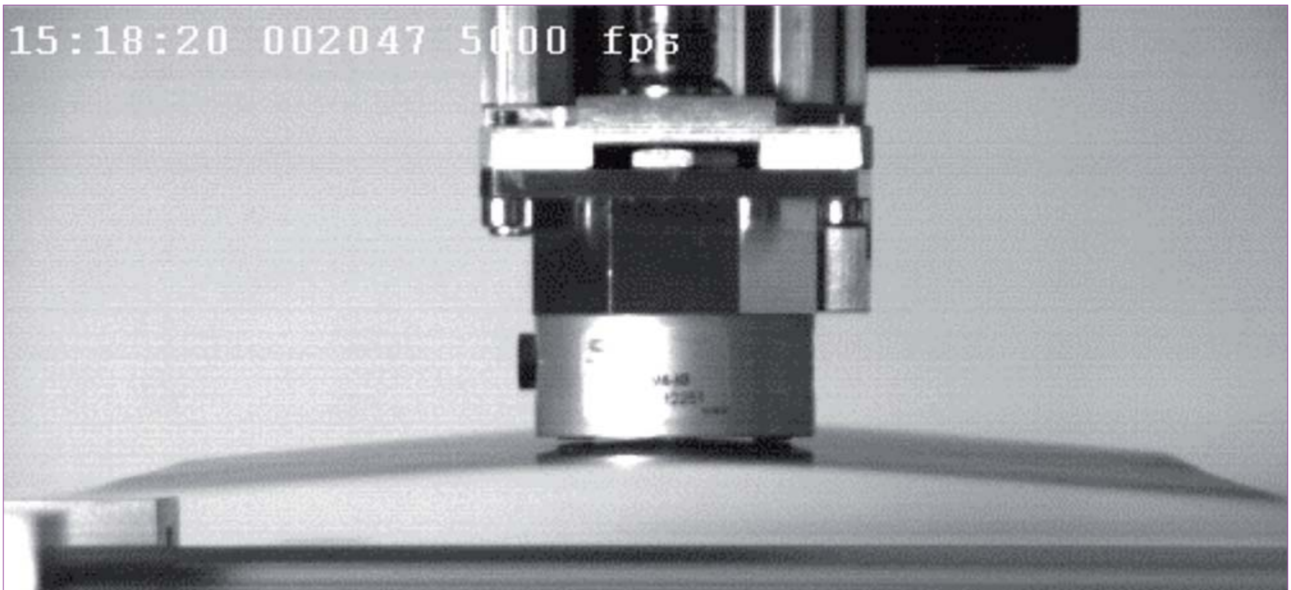

Figure 2. Visualization of gripper performance at Fraunhofer IPA test facilities.

offers from equipment suppliers, choosing instead to select particular components to build up their manufacturing lines. An increase in demand for these equipment types will definitely call for a modularity of such tools, allowing manufacturers to make the best choice concerning their own requirements.

Challenges and developments in crystalline technology

With the throughput of factories set to increase in both size and speed, current crystalline technology processes that usually have a cycle time of more than a second per wafer will use automation to increase the speed of all operations. As a result, the two main objectives will come into conflict with each other: a stress-free and gentle handling of more and more fragile wafers on the one hand and a continuous reduction of the cycle times on the other hand. Some stakeholders try to overcome this challenge by paralleling the handling and the multi-loading of the process equipment; however, the majority are engaged in finding new or optimized gripper and handling solutions.

The thickness of a wafer will be defined by considering silicon's prices and its yield, but thinner wafers will always be desirable in crystalline technology. A closer look at the production and its characteristics might propose a lower limit of about 150µm. This is defined by the current technology of cutting wafers with wire saws and the increased breakage rate of thin wafers during further processing. There appear to be three possible future scenarios for the development of thinner wafers: thickness will be reduced, wafer size will be increased, and wafer/cell design will change.

> "Experienced manufacturers seldom use turnkey offers from equipment suppliers, choosing instead to select particular components to build up their manufacturing lines."

All comparable industries have followed the path of increased wafer size, and the PV industry should follow suit. The shortage of silicon and the struggle for a higher yield and uptime of the current sizes has delayed this development; however, many suppliers have overcome this problem by designing their equipment to be able to process on wafers with an edge length of 210mm. Once a main producer successfully introduces such an increased wafer size, many others will follow suit to tap the full resulting cost-saving potentials.

Inline manufacturing looks set to dominate, as the loading and unloading of carriers is time-consuming and more stressful for the wafers. Furthermore, there is an increased need for automation equipment. "Every avoidable handling step needs to be eliminated. Once a wafer is placed on a manufacturing line it should run all the way through" said Dr. Andreas Reischl from Schiller Automation at the Photon Expo fair in Munich. Nevertheless, many stakeholders prefer batch processes for reliability and cell efficiency reasons.

All encapsulation materials for module manufacturing certainly leave room for the cost reductions of larger quantities and new technologies, but the costs of the encapsulation material most likely cannot be reduced as quickly as those of the cells. An important aspect is that module manufacturers have to issue the guarantee of their products for at least 20 years. Markus Steinkötter from Sunnyside upP adds: "Module manufacturing and automation face two major challenges. On the one hand we have to transform the processes into a continuous flow to reduce the production costs. On the other hand we are in need of equipments which can also be operated in less developed regions in order to open new markets."

Automation for the PV industry – a step-by-step guide

Automation for crystalline technology

In crystalline photovoltaics, the central focus of the manufacturing is on the wafer. One important aim of automation in this sector is to ensure a maximum output of good wafers and cells. (Automation of the ingot manufacturing process is intentionally omitted in the following discussion.)

Crystalline wafer manufacturing

Wafer manufacturing starts with the preparation of the ingots by cutting them into manageable semi-squared (monocrystalline) or squared (multicrystalline) silicon blocks as well as grinding and polishing the edges and surfaces, usually requiring several manual handling operations. Cutting the wafer out of an ingot involves the ingot being glued to a workpiece holder – the first instance of automation in the process – which is then incorporated into the wire saw. Such solutions already exist in some factories.

Figure 3. Manual placement of a silicon ingot on the adhesive.

The transport of the ingot to the wire saw is done manually with the aid of handling devices. An automated solution would have to be heavy-duty as the ingots are quite heavy and the equipment deals with a lot of contaminating fluids. The insertion and the extraction of the workpiece holder into the wire saw also need to be controlled by operators.

Figure 4. Silicon ingot in a wire saw, ready for process start.

The separation of the wafers after the sawing is a tricky process, where the sawn ingot is thickly covered with slurry (typically silicon carbide dissolved in glycol). After pre-cleaning of the entire wafer stack, the wafers are still separated by hand in many factories, while wafer sizes exceeding the average hand-span call for automation. After the wafers are separated, they are cleaned and dried on conveyors through the different cleaning basins.

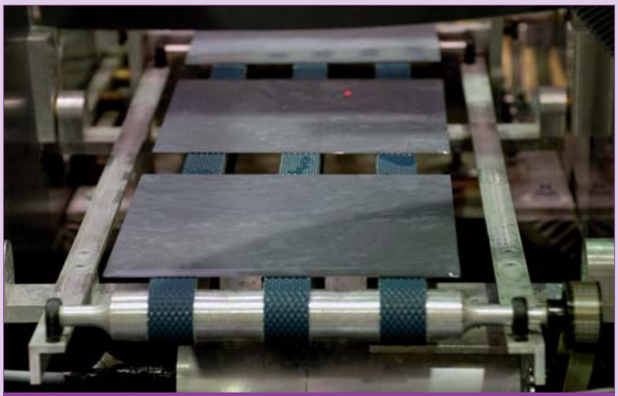

Figure 5. Wafer after separation (Fraunhofer IPA).

Figure 6. Wafer being transferred and sorted (Solarworld/OregonDOT).

Although inline cleaning is very common some manufacturers also use a carrier based batch cleaning in which the carriers are dipped and rinsed in different basins. After being cleaned and dried the wafers are tested and sorted into quality bins, packed and delivered to the cell manufacturers – an additional handling step for the wafer manufacturers and the cell manufacturers who have to unpack the wafers.

Cell manufacturing

The biggest difference of automation in cell manufacturing is the type of production processes that means whether they are primarily based on batch or inline manufacturing. Usually manufacturers base their decision on previous experiences and the requested cell quality. In the following we will go into more details about the characteristics of the two alternatives.

Batch manufacturing

Process steps such as etching, diffusion or deposition are executed in batches of (typically) 100 wafers that are moved from process to process using automated handlers, some of which require chemical resistance and temperature resistance. The frequent reloading of wafers involves gripping several wafers at once or else extracting the wafers from a carrier one by one.

Figure 7. Styrofoam box of wafers ready for cell production.

Step-by-step guide continued

Figure 8. A quartz bot being loaded into a diffusion furnace (SEMCO).

The frequent reloading of wafers involves gripping several wafers at once or else extracting the wafers from a carrier one by one.

The transport of carriers can be done manually, supported by PGVs (Person Guides Vehicle), or automatically, often using conveyors where the carriers are placed upright onto the conveyor belt with utmost care to prevent breakage.

The lack of standardized interfaces is a concern, in that several suppliers and manufacturers have developed their own carrier system that ends up being a unique solution customized only for one manufacturer or even a single factory. Although there were some standardization activities in the past, they have yet to be mutually accepted.

Inline manufacturing

Figure 9. Manufacturing of cells (Solar World AG).

The aims of inline manufacturing are speed and the facilitation of the wafer handling. Equipment is available for all process steps except the antireflex coating (ARC) with silicon nitride in the PECVD process, which is carried out in a kind of batch process. For batch building, the picking and placing of single wafers can be either carried out by scara robots or by special solutions such as delta kinematic robots.

The first step is the separation of dry wafers from a stack, typically carried out by grippers and pressurized air, which supports the separation of the wafers. Transport is then left to the o-rings and conveyor belts.

Buffers are usually used between the process steps to increase the overall utilization of the production line and can double as stacker solutions, allowing wafers to pass through if the succeeding process is in operation. The stacker will gradually store the wafers if the following process step cannot be carried out. One disadvantage of such a solution is the uncertainty of when the stacker can be emptied and the resulting risk of a long-run storage of individual wafers.

Module manufacturing

From the perspective of automation, module manufacturing is quite diverse as it involves handling of several different material types. The material costs of a module, excluding the wafer, have an average share of more than 80% of the total module costs. For this reason, a high yield of all materials used is required for a profitable operation.

Figure 10. Wafers being dispersed onto several conveyors (AMB).

Figure 11. Wafer in stacker buffer (AMB).

The core process steps in module manufacturing are the tabbing and stringing of the cells as well as the lamination with a substrate (typically glass). Interconnection of cells is usually done automatically, for fragility reasons, by a stringer that can connect up to 12 cells. Feeding can be performed either manually or using automation.

The cutting and the lay-up of the various foils used can be done manually or with the aid of semi- or fully-automated equipment. After substrate assembly, the structure is transported to the lamination equipment, usually roller and belt conveyors.

Figure 12. Inside view of a stringer (Somont GmbH).

Process steps following lamination can also be automated. However, many manufacturers prefer manual operations for tasks like edge trimming and the setting of the junction box. The finished modules are often framed and handled by means of 6-axis robots both for uniformity and human safety reasons.

Challenges and developments in thin-film technology

Compared to crystalline technology, the mass manufacturing of thin-film products is still in its development phase (with the exception of First Solar). Manufacturers started to use technology developments in this sector with the help of pilot lines to further enhance efficiency, yield and throughput. Several equipment suppliers developed their own solutions, mainly based on silane, and now offer turnkey solutions. Other thin-film technologies such as CI(G)S and CdTe are now developing in a similar way.

Process stabilization will remain with higher module efficiencies and yield improvement as a main goal for manufacturers as equipment can have long down times and modules are subject to considerable fluctuations in terms of their efficiency. Once process engineers have accessed process and quality data, the close monitoring and adaption of the equipment processes and recipes is crucial, perhaps even for each individual process run. Equipment interfaces and methods gathering and correlating process and quality data are therefore highly desirable, as are interfaces that can control the production processes automatically.

Automation for current factories mainly comprises solutions accumulated from the glass industry. Single lines are often rigidly coupled, with buffers in between. Future factories will have to incorporate more flexible solutions to maximize the utilization and reliability, with a clear need for equipment productivity to be on a high level and avoidance of idle time of a piece of equipment. Automation suppliers therefore have to work on reliability, user-friendliness and the repair capabilities of their equipment, which should only require specialist interference in the most exceptional cases.

> "Future factories will have to incorporate more flexible solutions to maximize the utilization and reliability."

In terms of factory layout and configuration, future factories and production lines will need a higher interoperability and more opportunities for the exchange of substrates, thereby enabling the establishment of larger factories that benefit from a better balance of production capacities. Stefan Huttelmaier from Schiller Automation says: "...future factories will have to adapt automation to the requirements of the manufacturing processes. Mixed variants of equipment cluster as well as fixed linked processes will be developed to achieve the maximum throughput in a factory." Such equipment clusters can be advantageous for the facilitation of operation and maintenance.

A major step will also be the scaling up of substrate formats, as already introduced at Applied Materials. When equipment suppliers and manufacturers successfully establish the processes to homogeneously deposit on larger substrates, automation suppliers will have to provide solutions for an efficient transport and handling.

The advantage of the roll-to-roll production concept is the continuous feeding of the substrate material as well as the reduced footprint of the equipment. For this concept, automation must be designed for lightweight materials such as metal or polymer foil. With the long-run stability of the modules a major issue to be tackled, production methods for the potential scenario of flexible solar cells becoming a niche market still need to be decided.

Visions for the future

Regardless of their individual technologies, future factories and their automation will have to meet certain requirements, some of which are outlined below:

Production costs

The production costs of one module have to be well below €1

Step-by-step guide continued

Automation for thin-film manufacturing

Thin film automation usually deals with the transport and the processing of glass substrates, the sizes of which *typically* can vary from 0.6m to 1.1m in width and from 1m to 1.4m in length (and larger), with *some* of the methodology originating from the glass industry. Current thin-film manufacturing lines are quite small: compared to a typical float glass line, which produces 500-700 tons of glass per day, a typical thin film factory with a capacity of 60MWp/a processes 28-35 tons of glass per day.

In most thin film factories the material handling and the transport are based on conveyors. These conveyors connect the process equipments (deposition, scribe, cleaning, etc.) – often based on a single substrate processing – with each other. The entire line is therefore typically coupled in a rigid manner with the possibility of using buffers, bifurcations and access points in between. Some equipment suppliers also offer batch-processing equipment, which provide the opportunity of transporting and storing the substrates in cassettes. Both solutions have advantages as well as disadvantages (see Table 1). For the present, the conveyor and the cassette based manufacturing will continue to exist in parallel as well as in mixed applications.

The buffering of substrates in thin-film production lines is not a trivial task. The sheer size of the substrates requires large facilities that have to be able to lift heavy substrates. Buffers based on a LIFO (last-in-first-out) principle need a smaller footprint, but in this case, the substrates can end up remaining in the buffer for a considerable time. FIFO-buffers (first-in-first-out) typically require a larger footprint; in this case, the storage time of substrates can be controlled more easily. Generally, thin-film manufacturing demands the monitoring of the waiting times. If the defined time interval is exceeded between certain process steps, some layers might be influenced negatively by the climatic conditions existing in the manufacturing building. For this reason, other high-temperature process steps call for a subsequent cooling time before the next one can be carried out. Automation has to consider all these requirements. Therefore, it must provide fast transport, a sufficient amount of buffers, and capabilities to control the material flow.

Figure 14. Glass handling with a 6-axis robot (Schiller Automation).

Compared with silicon wafers, the identification of glass substrates is quite easy. Usually a dot matrix code is applied to the substrate with a laser, allowing the tracing and the tracking of each single product. As a result, special routes for substrates can be realized to use the individual substrates for engineering or as a measurement reference. If such a seamless traceability is demanded by the manufacturer, the automation solution also has to provide ID-readers at specific points as well as control systems that can modify the process plan or the recipes of the individual substrates.

Figure 13. Special transfer solution for unloading and loading of process equipment and cassettes (Schiller Automation).

	Single substrate	Batch
Transport	Proven, state-of-the-art	Cassettes, special solutions
Handling	Feed-in with conveyors	Substrate needs to be extracted from the cassette
Storage	Buffer solution	Transport carrier can be used as buffer
Line concept	Fixed coupled lines are most popular	Flexible concepts with clusters possible

Table 1. Advantages and disadvantages of manufacturing types.

per watt peak. Generally, this is already possible for all technologies. Today, thin-film modules could be produced on a large scale between €0.5 to €0.6 per watt peak.

Supplier capabilities

The supplier capabilities need to be enhanced to provide adequate equipment and services for the installation of large factories. With the support of standardization, the available quantity of equipment on the market will have to increase to meet future demand.

Reliability and uptime

Future automation solutions have to be comparable to other mature industry solutions that have an availability of 99.5% or more.

Thomas Schmidt, former COO of Q-Cells, whose role is now to support the implementation of production lines within his company TST-C, also sees many practical aspects: "The suppliers of automation solutions do not only have to improve the quality of the equipment and the services. Rather, the sufficient support at the manufacturer's site is a key factor for a successful implementation. This also includes the maintenance and the upgrading of the existing equipment in use."

Conclusion

The future of the photovoltaic industry has not been predictable from an automation requirements point of view. Unlike the semiconductor industry, the photovoltaics industry does not only compete with itself – it is up against technologies like solar thermal or wind energy, and in the future will also have to compete with traditional energy sources. As a result, the ultimate goal of photovoltaics is cost reduction.

> "The photovoltaics industry does not only compete with itself – it is up against technologies like solar thermal or wind energy."

Also, population in developing regions will need access to clean energy, otherwise global efforts for reducing CO_2 emissions will not be sufficient. This implies the increase in size – not only with respect to factories but also to companies. At the moment, manufacturers often lack the financial power to grow fast enough to reduce costs. Therefore, large manufacturers of other commodities might take the lead in mass manufacturing. In terms of long-term development, photovoltaic manufacturing is comparatively young and therefore there is enough potential to develop further.

Acknowledgments

The author wants to thank all contributors to this paper who brought their expertise and were partners of some very interesting discussions. Apart from individuals and companies mentioned in this paper, thanks goes to Christian Fischmann and Tina Kabus from Fraunhofer IPA.

Reference

[1] SEMI, Document 4557: SEMI Guide for PV Equipment Communication Interface.

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PVECI – a new PV standard supporting efficient and effective production

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ABSTRACT

The European PV committee of EPIA/SEMI released the new PVECI standard that describes a unified IT interface for PV equipment in March 2009. If used properly, it provides the PV industry with a powerful tool for reduction of IT-related issues – especially between the factory planning and the ramp-up phase – and establishes the basis for deploying advanced factory management and control software systems. The first part of this article describes the standard in detail while the second part focuses on the anticipated benefits regarding IT integration and outlines further possibilities of a pervasive production-IT landscape.

Introduction

Falling module prices paired with the oversupply of PV modules worldwide are some of the reasons for rising efforts to optimize production facilities and to generate approaches for differentiation between different manufacturers. A pervasive production-IT environment is considered to be a promising approach to support these efforts as it allows for a better understanding of processes in production and for the implementation of advanced monitoring and control strategies. The new equipment interface standard for the PV industry developed by SEMI's PV Group [1] is intended to support these strategies and is presented in the first part of this article. The second part outlines how the potential of this standard can be fully exploited by the PV industry.

"Similar to other communication standards, PVECI follows a layered architecture approach as conceptually described by the ISO-OSI reference model."

Part 1: a standardized equipment interface for PV

Read and write access to production equipment from the factory IT environment is an important prerequisite for implementing a pervasive production-IT landscape. This fact has been recognized by the PV industry during its transition to mass production. Baylies et al describe in [2] how the "PV Equipment Interface Specification" (PV-EIS) taskforce has been founded to develop common standards to make this functionality available to the industry in a unified way. The scope of this interface is to provide IT systems on factory management level – represented by the 'Host' in Figure 1, such as Manufacturing Execution Systems (MES) or engineering systems – the ability to monitor and control process equipment. The terms 'monitor and control' comprise tasks such as collecting logistics events, collecting process and measurement data, collecting equipment performance data, adjusting process parameters, etc. The term equipment denotes a – usually modular – mechanical entity that provides defined capabilities to support manufacturing processes, including transport, storage, process and analysis capabilities. Based on this definition, the generic equipment interface can be applied independent of the base technology used, such as crystalline or thin film, and basic operational concepts, such as inline or batch operation.

PVECI – at a glance

The *Guide for PV Equipment Communication Interfaces (PVECI)*, which is currently available in the form of the SEMI draft document #4557 [3], was officially released for publication as a standard by the European PV committee of EPIA/SEMI on March 10th, 2009 in Dresden and is expected to be officially published by the end of June 2009. It defines how to apply a suite of SEMI standards that relate to the PV industry. While PVECI attempts to maintain compatibility to existing interface packages implementing the referenced SEMI standards as far as possible, it was created with the goal of clarifying a number of known issues of these standards, to remove some legacy elements that are not required anymore and thus to simplify the task of equipment integration for the PV industry.Similar to

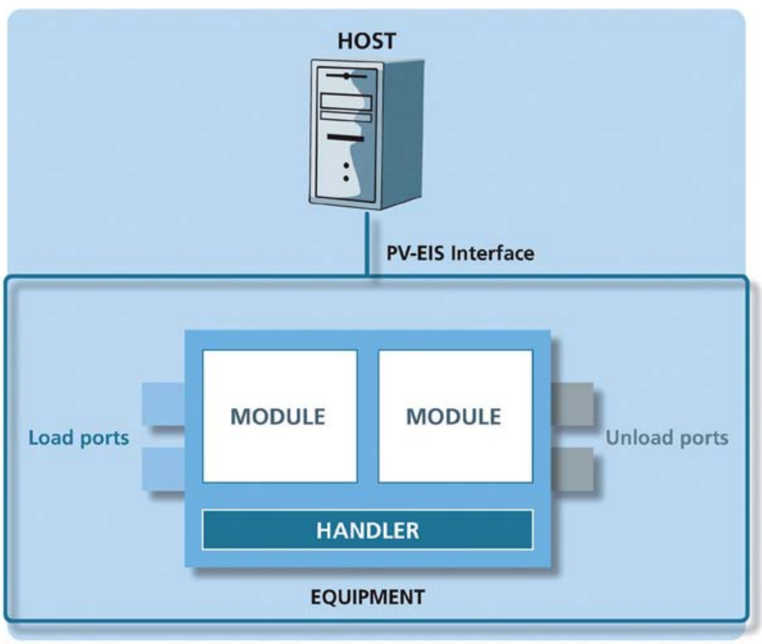

Figure 1. The equipment interface as defined by PVECI.

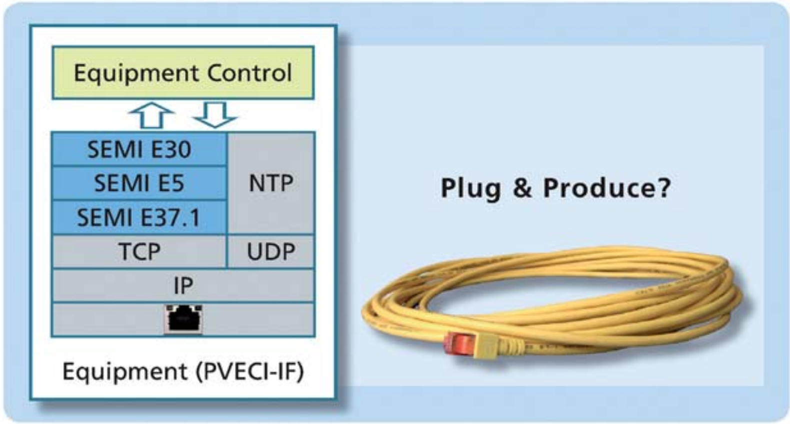

Figure 2. The PVECI protocol stack (equipment side).

```
S5F1 W
<L
      <B 0x57>          /* ALCD */
      <U4 42>           /* ALID */
      <A "Over Temp">         /* ALTX */
      >.
```

Figure 3. SECS-II example message (alarm: consists of alarm severity, alarm ID and alarm text).

other communication standards, PVECI follows a layered architecture approach as conceptually described by the ISO-OSI reference model. On the lowest layers, the physical layer and the data link layer in ISO-OSI terminology, PVECI requests PV equipment to provide an Ethernet interface that supports state-of-the-art communication data rates. The Ethernet interface is used to connect the equipment to the factory network. For the network and the transport layers, PVECI requires PV equipment to provide a standard TCP/IP-stack, which is configured as specified in SEMI E37 – "High-Speed SECS Message Services (HSMS) Generic Services". In conjunction with the subsidiary standard E37.1 – "High-Speed SECS Message Service Single Selected-Session Mode (HSMS-SS or HSMS-SSS)" – a point-to-point message transfer protocol is specified. This messaging service is used by upper layers to exchange self-describing, structured SECS-II messages as specified by SEMI E5 "SEMI Equipment Communication Standard 2 Message Content (SECS-II)". Furthermore, SECS-II defines a set of data formats independent of the CPU architecture (e.g. 4-byte unsigned integer), a dictionary of standard message items (e.g. the process program ID) and a dictionary of standard messages (e.g. alarm report send – S5F1 (see Figure 3)). On top of the E5 layer, any PV equipment generates and understands messages of the same format.

A common message format for all PV equipment worldwide is a good starting point; however, it is not sufficient to efficiently and effectively integrate equipment into PV production lines, as it still leaves multiple degrees of freedom. For this reason, PVECI requires PV equipment to implement SEMI E30 – "Generic Model for Communications and Control of Manufacturing Equipment (GEM)," which resides on top of E5. E30 describes the behaviour of manufacturing equipment as seen through the communication link. The generic behaviour is described in the form of a set of clearly specified automation features ('capabilities' in the GEM terminology) [6].

GEM provides three groups of capabilities:

- Capabilities for collecting and reporting data, such as Alarm Management, Dynamic Event Report Configuration and State Models
- Capabilities for host control of equipment, such as Equipment Constants, Process Program Management and Remote Control
- Miscellaneous capabilities, such as Documentation and Spooling.

PVECI makes a small set of adjustments to E30 GEM capabilities to simplify the implementation of the standard for the PV industry. As the major adjustment, PVECI clarifies the format of time stamps, requires that equipment use Coordinated Universal Time (UTC) for any time stamps worldwide, and also requires the implementation of a time synchronization mechanism based on the Network Time Protocol (NTP). These definitions provide factory operators the ability to make better use of collected factory data for time-based correlations. In addition to these adjustments, PVECI requires PV equipment suppliers to support the collection of data through the interface that is required to evaluate the equipment utilization based on SEMI E10 – "Specification for Definition and Measurement of Equipment Reliability, Availability and Maintainability (RAM)".

Part 2: making full use of the PVECI standard

Unfortunately, the idea of plug-and produce has not yet been realised, despite the presence of the new PVECI standard. However, if a set of basic rules for the factory planning and integration process is taken into account, PVECI has the potential to generate significant benefit for the PV industry. The phases 'requirement specification' and 'testing' are of particular relevance in this context. Part 2 mentions some examples from the semiconductor industry, as it has been through several learning cycles with the SEMI equipment communication standards.

Requirement specification

In the requirement specification phase, the PV manufacturers describe their requested IT interface capabilities in detail. The general behaviour (functional procedures), which is shared by all equipment types, should be described based on the PVECI standard. Some companies in the semiconductor industry use Tool Operation Procedures where the specification for the IT interface is defined within several modules referencing the SEMI standards [4]. When specifying the particular interface requirements for an equipment type, they just 'pick' the corresponding modules and thus minimize the necessary effort for creating a well-structured and well-defined specification document.

Testing

In the testing phase, the PV manufacturers verify whether the (interface) implementation fulfils the specified requirements. Requirements based on standards significantly simplify this phase, as standard compliance can be tested and verified based on generic tests for the different interface layers. One example with a high penetration of the semiconductor market is the *CCS Product Suite*, which provides a testing framework for SEMI factory automation standards [5].

Additionally, company-specific test sets on top of PVECI should be defined based on the functional procedures described in the requirement specification. This can, again, be realized with a modular solution using corresponding test libraries for each requirement module.

Automation Capability Management Process

Requirements specification and testing efforts unfold their full power if they are strongly integrated into the overall business process. This process is widely known as *Automation Capability Management Process* (ACM) in the semiconductor industry (see Figure 4). It starts with the requirements specification, includes the negotiation phase with diverse suppliers, covers the test procedures and targets to successful integration and further operation

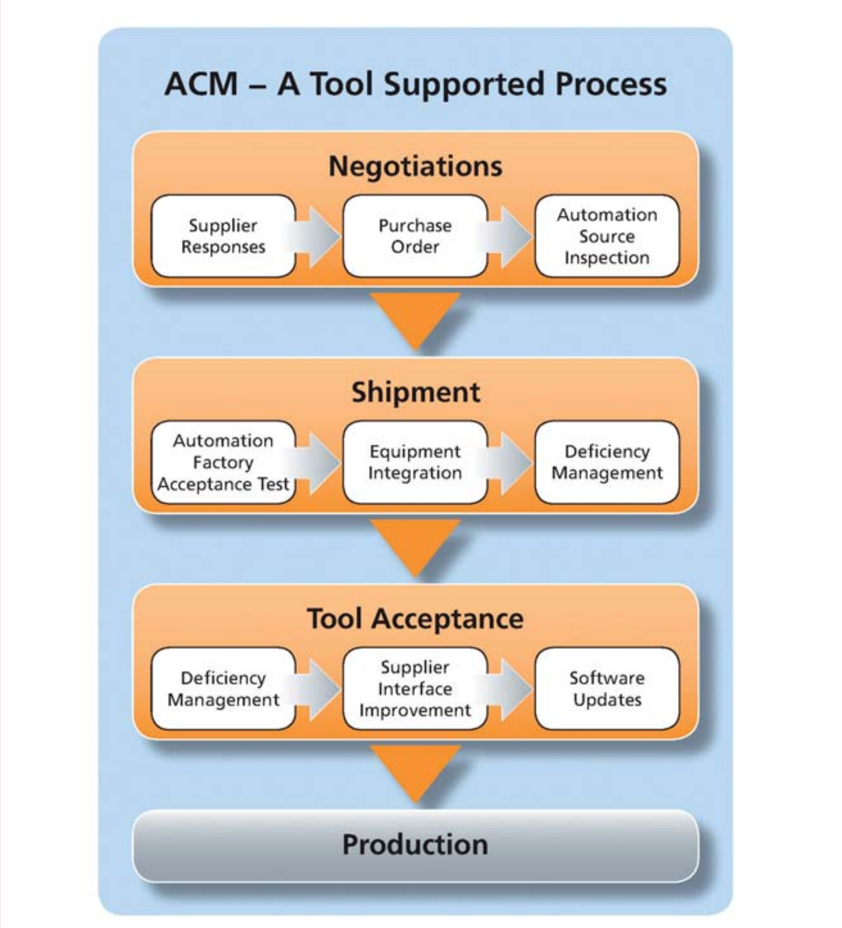

Figure 4. Automation Capability Management [4].

of the equipment in the IT infrastructure at the manufacturer's site.

As an integral part of the negotiation phase, each equipment supplier under consideration has to report the level of compliance to the requirements specification provided by the manufacturer. Judging from the aggregated compliance result of the response, the manufacturer is able to estimate the integration risk and effort more precisely. After the negotiation phase when a supplier for the equipment had been selected, the supplier's response becomes part of the contract – which is a solid basis for later enforcement.

The *Automatic Source Inspection* tests at the suppliers' site include testing of the general communication features and are performed only for a first of a kind EQ. The *Automation Factory Acceptance Tests* are performed for each EQ and include the tool-specific features. Fraunhofer IPA has developed a software tool which supports the whole ACM process starting from the definition of requirement templates and corresponding test sets, through the negotiation and purchasing process and the tracking of test results and deficiencies.

PVECI benefits

The obvious benefits of a unified IT interface specification for PV manufacturers are that they are no longer forced to specify, test, integrate and operate unique interfaces for each equipment supplier and that an enhanced level of IT functionality

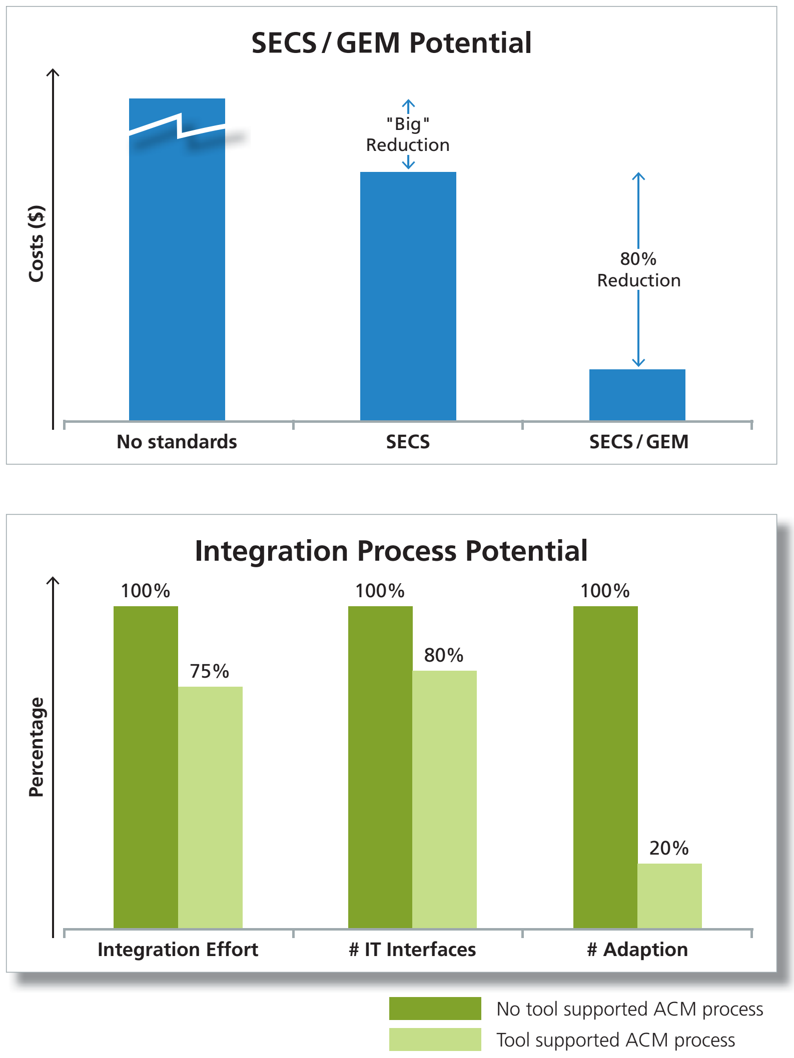

Figure 5. Benefits from IT standardization achieved in semiconductor industry.

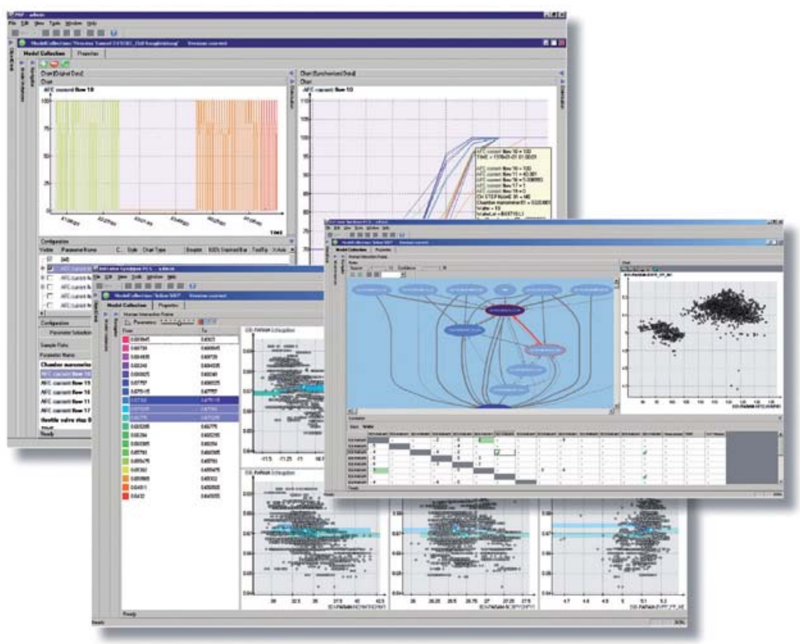

Figure 6. Example of an APC tool illustrating graphical impact analysis of equipment parameters on process or product results [7].

is assured for all equipment. Moreover, equipment suppliers are no longer forced to implement and maintain specific interfaces for each customer. 'Hard facts' – for example in terms of monetary benefits – are more difficult to gather. We will take a closer look at the benefits reported in the semiconductor industry below.

Although most semiconductor companies did not publish exact numbers for their savings achieved with the introduction of SECS-II in 1982, there are at least some numbers for the introduction of GEM in 1992. It enabled a cost reduction of approximately 80% for host-side software compared to the previous attempt (see Figure 5, top) [6]. Additional savings are reported after an effective, tool-supported ACM process, as mentioned above, had been put into place [4] (see Figure 5, bottom). Compared to a former factory setup of the same type, the number of required interface implementations was reduced by 20% and the number of adjustments required for these implementations was reduced by 80%. Thus, the total effort for the IT equipment integration was reduced by 25%. Although the benefits reported from the semiconductor industry are not immediately transferrable to the PV industry, they give valuable hints as to how to make the best use of the PVECI standard in the PV industry.

Using a pervasive production-IT landscape

Besides the support for widely applied features such as tracking and tracing, equipment performance tracking or maintenance management, PVECI simplifies the deployment of additional software systems such as state-of-the-art *Advanced Process Control* (APC) software. These tools allow for detailed examination of PV manufacturing processes – e.g. correlation analysis of settings and parameters – and may even trigger corrective actions.

Figure 6 gives some insight into a case study wherein process parameters collected from several process steps have been correlated with a performance indicator at the quality gate (Wp at the flasher). The APC software was used to calculate and predict the impact of single parameters (or combinations) on the target value, allowing the system to detect issues in processes or process chambers that were not evident by merely looking at the raw data. Furthermore, the system has been used to analyze correlations between process parameters and measurement results. In this context, the system evaluates the impact of process parameters on these measurement values and visualizes findings. This knowledge is useful to predict measurement results in order to optimize the sampling frequency.

These kinds of analysis and control capabilities are expected to be of increasing importance with the growing size of PV factories, increasing cost pressure and quality requirements.

Next steps

In order to complete PVECI in a timely fashion and thereby to provide added value to the PV industry as soon as possible, the PV-EIS taskforce decided to strictly follow a stepwise approach for creating the communication standards framework for PV. As the basic automation and communication capabilities are now available in a unified way based on PVECI, the PV-EIS taskforce is currently moving on to complement the guide with specifications supporting single-substrate tracking. Support for single-substrate tracking has been identified by the PV industry as a major issue to be tackled to improve traceability on the one hand, and to enable more sophisticated process monitoring and control capabilities on the other. These capabilities are expected to generate significant competitive advantages in the future. Therefore, the PV-EIS taskforce has initiated activities to make use of the extensibility mechanisms of PVECI to incorporate single-substrate tracking features into the interface, and to specify an additional interface for horizontal communication that supports propagation of substrate information within inline equipment without having the need to read an ID from the substrate.

Conclusion

It is now up to the PV industry to exploit the potential of the new PVECI standard. Creating a standard document is only the first step; bringing it to life in the industry is the difficult second step. The field is prepared – implementation packages are ready for use, the first equipment suppliers offer PVECI interfaces out of the box and the first factories utilizing the standard (or at least large parts thereof) went live or are in the process of going live. From today's perspective, PVECI is on a good way to being successful.

References

[1] PV Group [available online at http://www.pvgroup.org].

[2] Baylies, W. et al 2008, 'Structuring standards for the photovoltaic manufacturing industry,' *Photovoltaics International*, 2nd Edition, pp. 151-155.

[3] *SEMI Draft Document #4557: Guide for PV Equipment Communication Interfaces (PVECI).*

[4] Dreiss P. 2007, 'System für die modellbasierte Integration von Anlagen in die Halbleiterfertigung,' *Jost Jetter Verlag, Heimsheim*.

[5] The PEER Group, Inc. [available online at http://www.peergroup.com/CCSProducts.aspx].

[6] Ghiselli J. 2008, ´SEMI GEM / SECS Training for Photovoltaic Industries,' Fraunhofer IPA.

[7] acp-Information Technology GmbH (acp-IT) [available online at http://pcs.acp-it.com].

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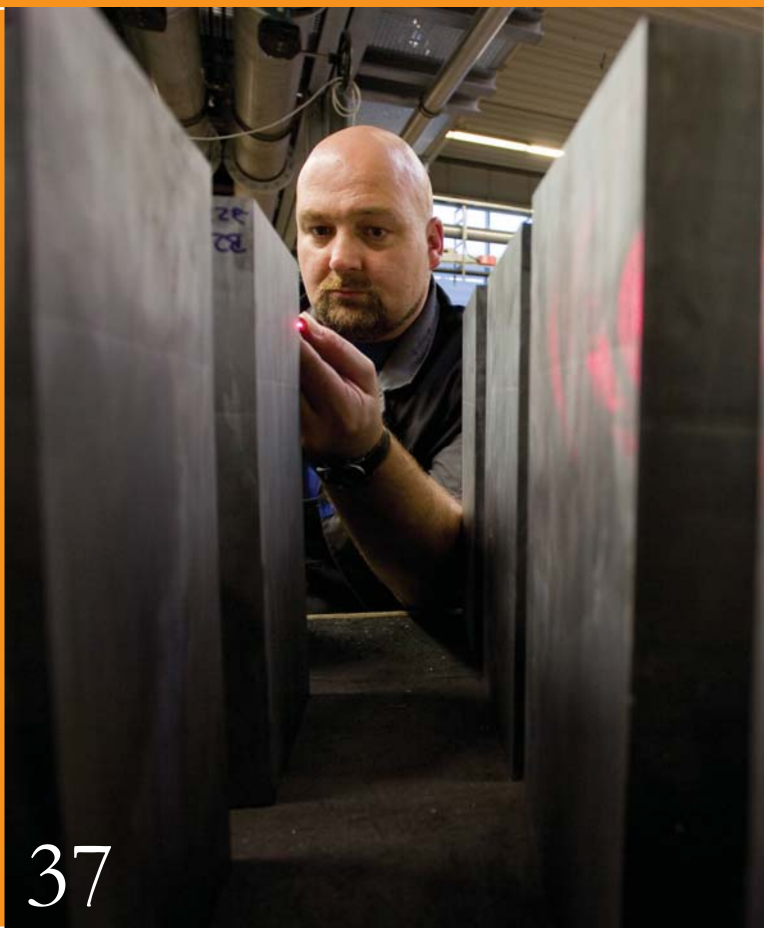
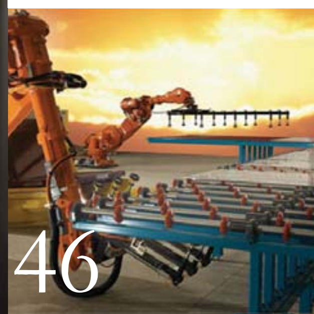
Materials





News

Canadian Solar notes challenges to UMG suppliers as polysilicon prices fall

Canadian Solar executives said during a conference call to discuss fourth quarter and year-end financial results that polysilicon prices had fallen to between US$110 per kg and US$130 per kg. This had enabled the module manufacturer to renegotiate UMG silicon feedstock prices to approximately US$60 per kg, maintaining a US$50 per kg margin between the two feedstocks. Canadian Solar uses UMG silicon in its 'e-modules' and has already secured contracts for these lower (15%) priced modules in 2009, equating to 120MW.

Dr. Shawn Qu, Canadian Solar.

The challenge for UMG suppliers, acknowledged by Dr. Shawn Qu (pictured), Chairman and CEO of Canadian Solar during questioning by financial analysts, is that he expects polysilicon prices to drop to approximately US$70 per kg, pushing UMG pricing to between US$15 per kg and US$20 per kg by the end of 2009.

At the recent Photon Technology Show, held in Munich, Germany at the beginning of March 2009, Photon Consulting market researchers noted that the significant increase in polysilicon and lower than anticipated demand due to project finance constraints amongst others could see prices fall to as little as US$30 per kg. Although the supply chain dynamics have become complex and highly changeable, financial analysts were concerned in the conference call that should polysilicon prices fall to US$50 per kg or below, UMG's cost advantages could simply evaporate, destroying the UMG market in its path.

Dr Qu countered this line of argument to some extent, noting that Canadian Solar was working closely with its two UMG suppliers to improve the quality of the material to boost conversion efficiencies of cells as well as internal efforts that had already seen over 1% efficiency improvements in the last year. Dr Qu also noted that cell efficiencies using UMG silicon had reached 14.7% in 2008, up from 13.3% in 2007, with a clear roadmap to take efficiencies up to 15.5%, though no timeline was given.

"We expect to achieve wafer to module processing costs of US$0.60 per watt and polysilicon to module processing costs of US$0.90 per watt by the end of Q2 2009," noted Dr Qu.

Polysilicon News Focus

Wacker's polysilicon revenues reached record high in 1Q09

Wacker Chemie AG's first-quarter 2009 financial results may have seen overall sales decline 14% compared to the same quarter a year ago, but polysilicon revenue on a quarterly basis exceeded €300 million for the first time and EBITDA rose by 136%. Polysilicon was the largest contributor to Q1 2009 sales and earnings, Wacker said.

Wacker benefited from the strength of its polysilicon business, especially from customers based in Germany. First-quarter sales

WACKER's Poly 7 and Poly 8 expansion at Burghausen.

in Germany reached €220.8 million, up 3% from the same quarter in 2008. Polysilicon expansion plans would seem to be on target. Wacker spent approximately €100 million in the quarter to boost future capacity at its Burghausen and Nünchritz facilities.

REC lowers polysilicon production forecast, cuts solar module production

A host of challenges would seem to be troubling Renewable Energy Corp (REC). After posting a 14% increase in revenues to NOK 2,013 million in the first-quarter 2009, the company saw its profits decline by 29%, due to spot market buying of polysilicon, higher expansion and ramp-up costs, and a build-up of module inventory as demand weakened.

The company noted in a conference call to discuss financial results for the first quarter that many customers are finding the financial conditions difficult, while PV module distributors and installers have become increasingly reluctant to hold and finance inventory. REC also noted that weak demand has caused module prices to fall 20% in the quarter.

As a consequence, REC plans to significantly reduce PV module production this quarter, cutting levels by 50%. The company expects approximately 180 temporary and contracted employees to be affected by short-term layoffs. However, REC said that due to contracted shipments in the second half of the year, production of cells and modules should return to normal levels in that period.

Problems continued with its polysilicon expansion at Moses Lake, forcing the company to completely shut down production to repair cracks in a reactor discharge pipe. REC noted that it had discovered design weaknesses that could lead to material fatigue, causing further failures. The company will now work with project manager Fluor to design the necessary modifications to the reactor discharge pipe, resulting in no production for Silicon III plant in Q209.

This will result in a reduction in expected polysilicon production in 2009. Originally, REC expected production to reach between 10,000 and 11,000MT this year, now the company expects that figure to be approximately 9,000MT. This is of course dependent on Silicon III coming back online successfully in the third quarter.

Timminco to curtail silicon metal production, reduce workforce

Timminco said that it will temporarily curtail production of silicon metal because of difficult market conditions and reduced demand for silicon metal in the chemical and aluminum industries. The upgraded metallurgical silicon (UMG) manufacturer added that this revamped operating mode will be implemented at the start of the second quarter, with the hope of preserving cash flow and decreasing working capital levels. The reduction in silicon metal production will result in a temporary workforce reduction, according to the company. During this period, it will supply silicon metal to customers from existing finished goods inventory.

Timminco will continue to produce solar-grade silicon, although at levels in line with customer orders. The company said it will also defer further capacity expansion of its solar-grade silicon plant, pending recovery of demand for the material.

The group shipped 424 metric tons of solar-grade silicon in the fourth quarter, an increase of 41% from the third-quarter 2008, generating revenue of US$27.7 million. For the year, the group shipped 1045 metric tons of solar-grade silicon, resulting in revenue of US$64.6 million.

PV Crystalox meets 2008 wafer shipment guidance but cuts polysilicon target for 2009

PV Crystalox Solar PLC has posted silicon products revenue of €273.8 million for 2008, an increase of 28.6% compared to the previous year. Wafer shipment volumes increased by 21% to 230MW, inline with upgraded guidance given last year. Wafer shipments were 190MW in 2007. However, PV Crystalox revised its production targets for polysilicon at its new plant in Bitterfeld, Germany, from 900MT for 2009 to 450MT.

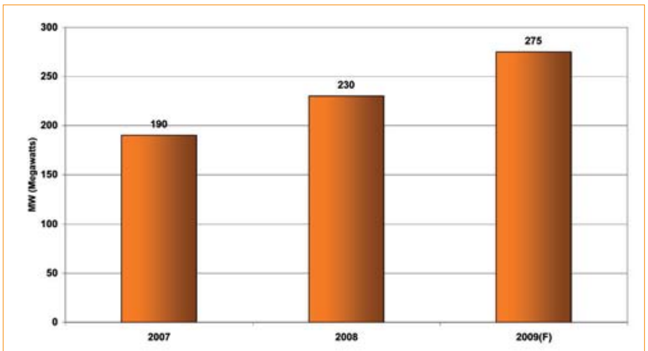
The company said that production would start at the new plant in May, 2009 and the revised production levels were inline with current wafer production requirements. PV Crystalox noted that its production target for 2011 remains at 1,800MT.

Ingot production was said to be expanding as planned to 350MW by mid-2009 with expansion of wafering capacity that included the use of a subcontractor in Japan.

PV Crystalox noted that newly contracted wafer volume is equivalent to 900MW over the period 2009-2011 and complemented wafer supply agreements signed in 2007. PV Crystalox also noted that it had signed seven new wafer supply agreements in the year with predetermined prices and volumes. Customers include Q Cells, Suntech, Schott Solar and the Intel spin off, SpectraWatt. Wafer shipments of 275MW are expected in 2009, with the majority of the 45MW increase occurring in the second-half of the year.

Cost reduction plans were also on track. PV Crystalox said that 65% of shipped wafers in 2008 were 180µm thickness, reaching 82% of shipments in the first two months of 2009.

Wire thickness had been reduced from 140/150µm to 120µm with new ingot saws cutting kerf loss by more than 90% in comparison with the sawing equipment used previously.



Source: Photovoltaics International

PV Crystalox wafer shipments (MW).

Sunways cancels polysilicon and UMG-silicon supply deals

The rapidly changing supply and price dynamics of polysilicon has led to PV module manufacturer Sunways AG making a string of changes to previously announced polysilicon and UMG-silicon production partnerships.

In early February 2009, Sunways cancelled a wafer supply deal with Swiss Wafers that had only been signed in October 2008. This cancellation is a result of what appears to be better prices on offer from LDK Solar.

Sunways has now announced the cancellation of a polysilicon production partnership with the Schmid Group, general contractor for a plant that was to be built in Saxony, Germany. Delays in this project were recently reported, according to a presentation made at the recent Photon conference and exhibition, which was held in Munich, Germany at the beginning of March 2009.

However, as Sunways noted in a press release: "From today's point of view, the production of high purity silicon as raw material for the manufacture of solar cells no longer is a strategically and economically reasonable option for Sunways. Sunways will, however, maintain the trusting relationship with the Schmid Group and observe the project's further development."

Due to falling polysilicon prices, Sunways has also terminated a development and potential supply deal with Solarvalue AG, which was initiated in late 2007 with the aim of producing UMG-silicon. Solarvalue was not able to supply this UMG material to Sunways within the allotted time, according to Sunways.

Sunways's comment stated: "No further obligations of any kind will arise to Sunways AG from the termination of these two projects. Against the background of the changed situation in the markets for raw materials, Sunways AG considers it reasonable at this stage to ensure the supply of raw materials through a combination of purchases in the spot market and long term supply contracts."

China's polysilicon industry sees multiple ramps and orders

Contributing further to the worldwide polysilicon oversupply, but indicating a positivity that flies in the face of the current economic climate, the Chinese polysilicon production industry looks to be doing well with several new ramps and orders announced. A Cleantech report shows the activity in various regions of the country.

Fushun Koshuha Foundry Co. Ltd. has embarked upon a potential 10,000-ton high-purity polysilicon project with U.S. company PPP and a Japanese firm. The project, which has secured an investment of US$1.2 billion, was scheduled to start construction in April and to be completed in October 2011.

Jiangsu province's Xuzhou, Yangzhou and Lianyungang regions will be the focal points for the province's polysilicon activity, with plans to subsidize 260MW of solar power and reach an annual polysilicon production capacity of 30,000 tons by 2011.

Tongwei Co. Ltd. is nearing the second phase of its 3,000-ton polysilicon project in Sichuan province. Groundbreaking for the second phase could happen as soon as the first half of 2009, with a third 6,000-ton phase tentatively planned for before late 2010. Including the late-2008 first phase of 1,000 tons, this would bring the company's total output to 10,000 tons per annum.

In Shangyu, Zhejiang, Zhejiang ProPower Silicon has commenced construction on a solar grade polysilicon project that is expected to start production in September 2009. Annual capacity of 1,000 tons should be reached by December 2009, with potential for expansion to 5,000 tons in 2010.

Suntech buys minority stake in Asia Silicon

Suntech Power Holdings has recently acquired a minority stake in Asia Silicon from an existing shareholder for approximately US$8.1 million, the companies announced. "We are very pleased to cement our relationship with Asia Silicon," said Zhengrong Shi, Suntech's Chairman and CEO. "Asia Silicon has all the makings of a world-class polysilicon producer, due to the utilization of the most advanced production equipment, their expert technical team, and industry leading cost structure. By combining Asia Silicon's low-cost polysilicon with Suntech's high conversion efficiency technology, we believe that we will be able to achieve grid parity in many parts of the world within the next two or three years."

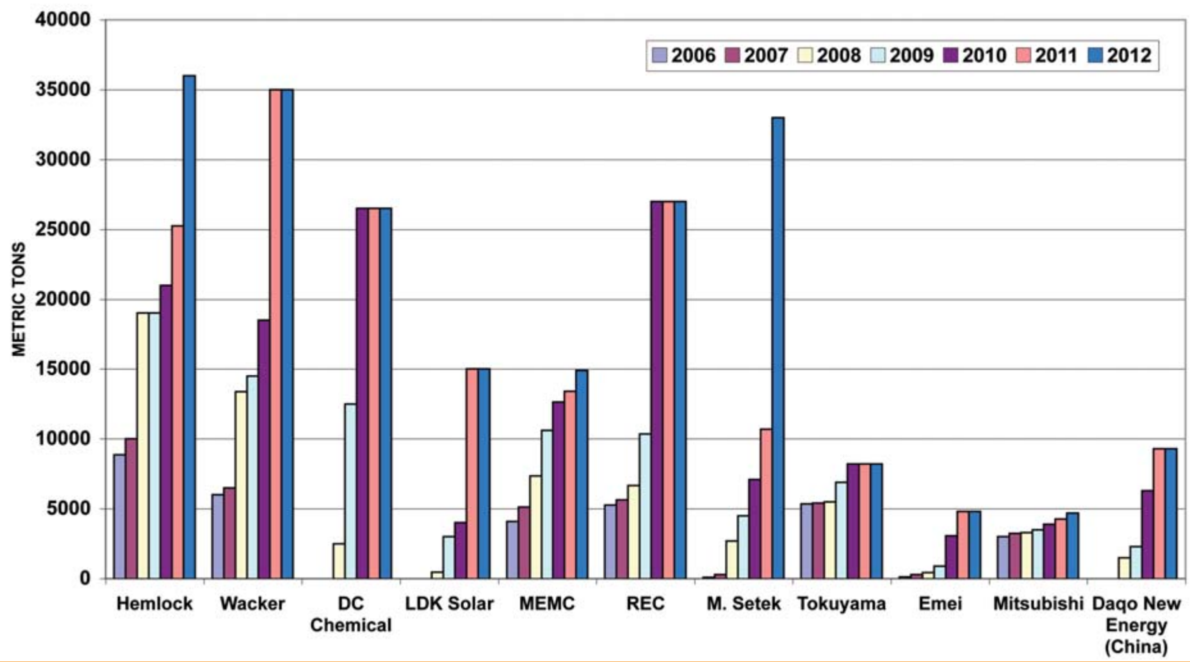
Asia Silicon polysilicon plant in Qinghai, China.

Suntech already has an agreement to buy high-purity polysilicon from Asia Silicon, for a total value of up to US$1.5 billion over a seven-year period. During the term of the contract the price of the poly is set to decrease to below US$40 per kilogram.

Asia Silicon is ramping a state-of-the-art polysilicon plant in Qinghai, China. The company began production of high-purity polysilicon at the end of 2008 and has set a target of 2000 metric tons of annual production capacity by mid-2009. Tests on the initial products show excellent quality that can meet both solar- and electronic-grade requirements, the company said.

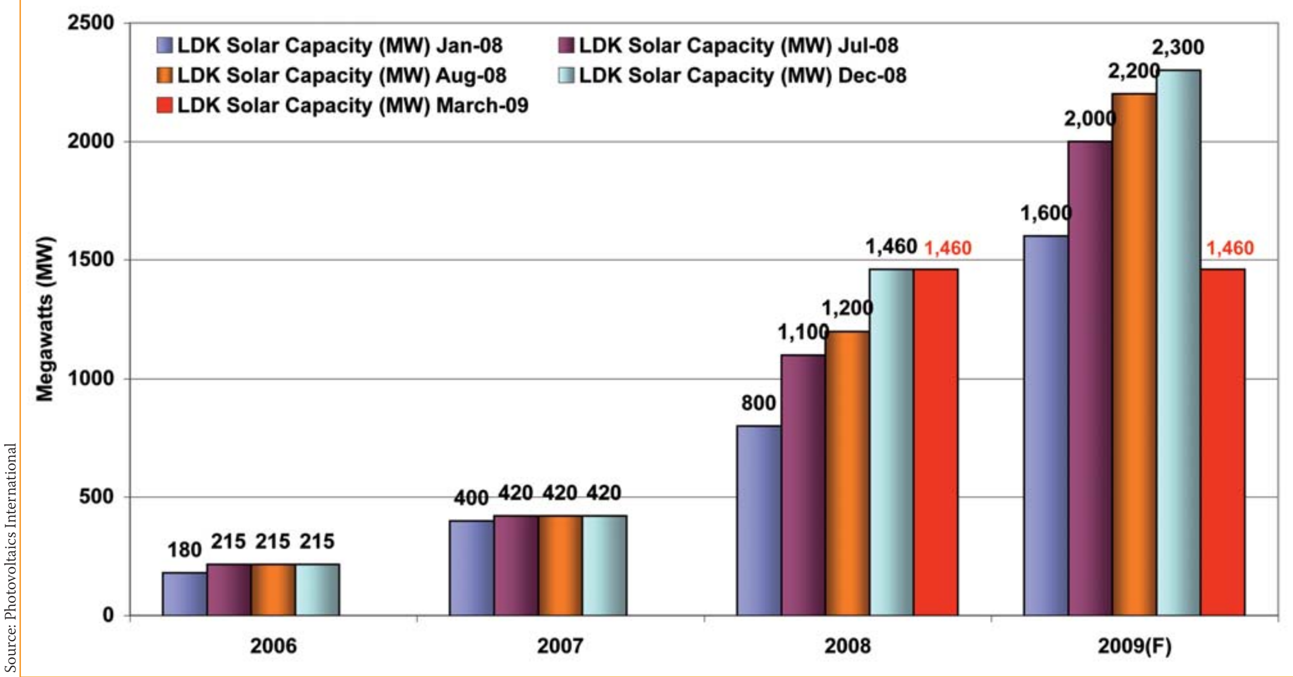
LDK Solar focuses on cost reduction, not expansion, for 2009

Major solar wafer producer LDK Solar has shifted its business strategy from aggressive capacity expansions to one of production cost reductions for 2009. The continued uncertainty of the growth levels in the photovoltaics industry for the year have turned LDK Solar hyper-conservative, cutting polysilicon production targets



Source: Photovoltaics International

Revised polysilicon production plans.



LDK SOLAR Capacity Ramp Projections March 2009.

as a consequence of delaying previously planned plant ramps and holding wafer production at 2008 final capacity levels, until demand visibility returns.

Annualized wafer production capacity increased by more than 1GW, reaching 1.46GW at the end of 2008. Wafer capacity in 2007 was 420MW. Wafer shipments reached 818MW in 2008, nearly a four-fold improvement over 2007.

Broken down, the majority of planned spending will focus on the completion of 'Train1' at LDK's 15,000MT polysilicon plant, ramp of capacity at its smaller 1,000MT polysilicon plant that was recently completed and a small share of the CapEx budget targeting optimization of its wafer production. Due to the spending being construction focused, the majority of spending will be first-half-year loaded.

Train 2 & 3 of LDK's 15,000MT polysilicon plant have in effect been put on hold, with manpower resources being shifted to Train 1 completion and ramp by the end of the second quarter of 2009. Executives said that any further development of the large polysilicon plant would be based on market demand.

Total polysilicon production for 2009 had previously been guided in the range of between 3,000 and 5,000MT in 2009, which has now been further reduced to between 2,000 and 3,000MT for the year.

Hoku makes a further customer revision to polysilicon supply deal

Hoku Materials, Inc., a subsidiary of Hoku Scientific, Inc., has announced an amendment to the polysilicon supply agreement with Wealthy Rise International, Ltd., a subsidiary of Solargiga Energy Holdings, Ltd., which would reduce the total volume of polysilicon sold to Wealthy Rise by up to US$136 million over 10 years.

In addition, the amended contract alters when Hoku is required to begin shipping pol ysilicon until June 30, 2010. Wealthy Rise is able to terminate the agreement if Hoku has not begun making shipments by October 31, 2010, while Hoku can terminate the agreement if Wealthy Rise does not make its payment in time.

Wealthy Rise has given an initial deposit of US$7 million. Additional deposits are required in June, August, October and December of this year. Each of these will be US$3.3 million, while a final payment of US$200,000 will be made after the first shipment is received. Hoku will also provide a security interest to Wealthy Rise in the company's polysilicon assets. This gives Hoku a chance to repay US$20.4 million as a credit against product shipments over a period.

Hoku has recently amended its contract with Jinko in addition to announcing a new 10-year polysilicon supply agreement with Shanghai Alex New Energy Company, Ltd.

Silicon Genesis touts 20 micron thick solar cell 'foils'

Using its proprietary PolyMax kerf-free wafering technology, Silicon Genesis said that it has produced the first-ever 20 µm thick solar cell 'foils.' The company characterizes the robust, flexible 125mm square monocrystalline silicon substrates as neither a thin-film nor a wafer, given the foils' unique form factor and physical attributes.

The 20µm thick foil combines the advantages of the low polysilicon utilization of thin-film PV with the high-efficiency potential of mono c-Si, according to SiGen. The company believes that the foil will extend the reach of conventional silicon PV absorber technology well into the future.

The mono c-Si foil is the result of the continuous development of SiGen's recently demonstrated pilot-line production of full-size wafers with thicknesses of 150 and 50µm. These pilot capabilities are now being used for development of high-volume manufacturing equipment.

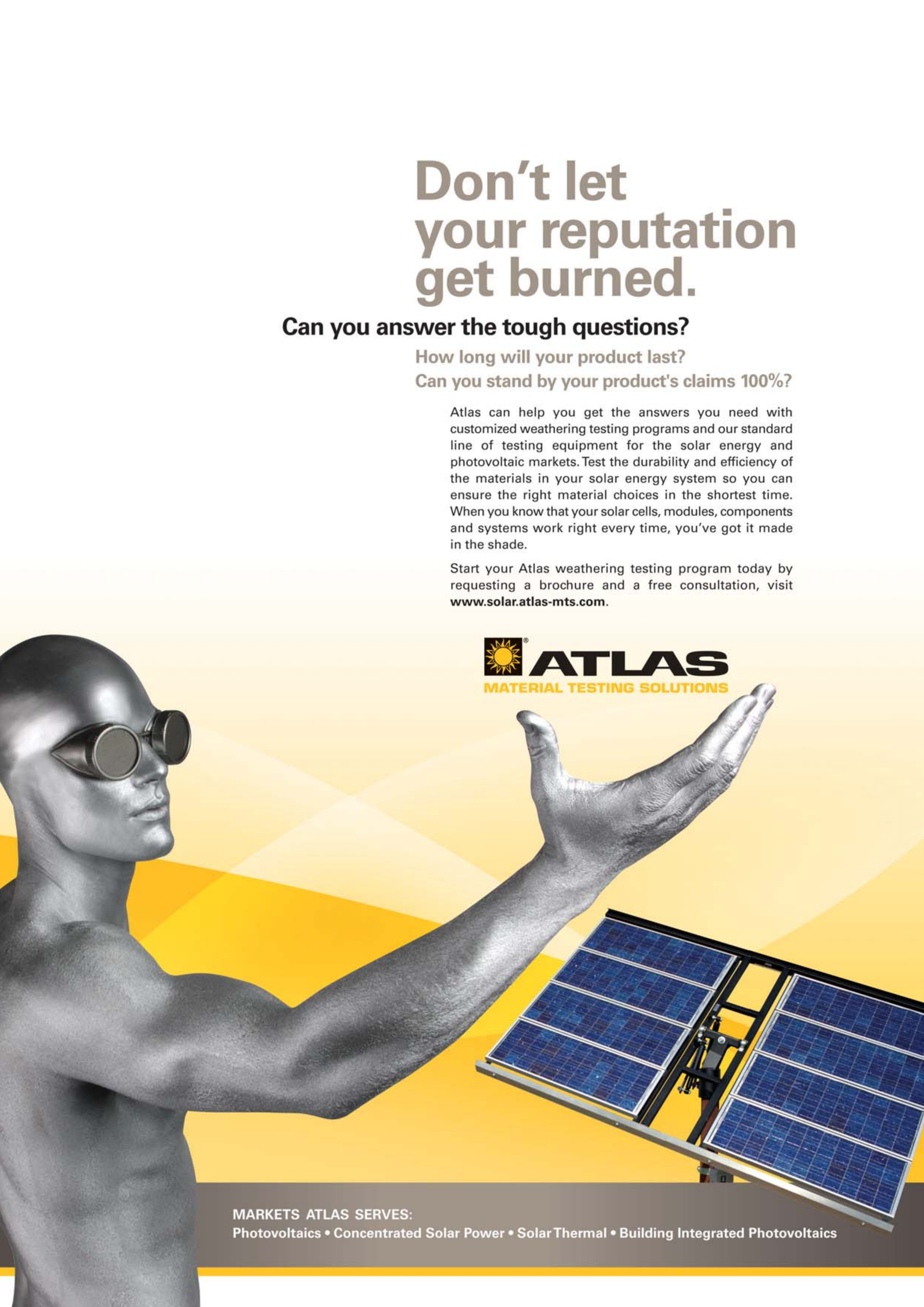
Other Materials News Focus

Air Products wins bulk and specialty gases contract with CHINT Solar

China based thin film start-up, CHINT Solar has selected Air Products to supply both bulk and specialty gases at its new thin-film photovoltaic (PV) facility in Binjiang District, Hangzhou, China. The contract includes the supply of hydrogen, nitrogen and argon, as well as specialty gases such as silane, nitrogen trifluoride (NF_3) and dopant mixtures. CHINT Solar is planning to reach 210MW in thin film production in 2010 and 380MW production capacity in 2010 that includes crystalline silicon solar cells.

Masdar PV selects Linde Group for 'SunFab' thin-film gas supply

A long-term gas supply deal has been signed between Masdar PV and Linde Group, which also includes gas storage,



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Conergy's Frankfurt (Oder) facility.

MEMC to review polysilicon expansion plans

Caught with dramatically lower demand for semiconductor silicon wafers and a below seasonal demand for solar wafers, MEMC is to review its capital spending and polysilicon capacity expansion plans, executives said in response to questions from financial analysts in a quarterly conference call. MEMC had previously announced plans to boost polysilicon production from the current 8,000MT per annum, reached at the end of 2008 to 15,000MT in 2010.

The company has US$1.3 billion in cash but it has not been as aggressive as other major polysilicon producers in adding capacity and has been losing market share in recent years.

Although executives would not be drawn on giving specifics, MEMC has experienced pricing pressure and acknowledged that recent job cuts were intended to better balance operational costs with future expected wafer demand.

MEMC has also had to renegotiate solar wafer prices with several major customers in light of the rapidly increasing global supply of polysilicon and the huge declines in spot market prices, even though long-term wafer contracts are well below spot price comparisons.

The wafer producer also acknowledged that it would review its current outsourcing strategy for solar wafer production, which could be brought in-house via possible acquisition of some or all of its current suppliers.

MEMC and Conergy: the ongoing saga of a polysilicon dispute

The module manufacturer wanted a new one-year deal struck with MEMC to reduce costs. As restructuring continued at Conergy AG, the PV module manufacturer was in talks with MEMC to renegotiate its long-term solar wafer supply contracts worth approximately US$4 billion over a 10-year period.

Conergy said it had already written down the prepayments made to MEMC in its annual accounts and could expect high one-time costs, but it would 'open up new options for the future.'

Hopes of a revision to Conergy's 10-year wafer supply agreement with MEMC evaporated as soon as they were raised, with MEMC noting in a press statement covering first quarter financial results that the 'contract remains in full force and effect.' In a conference call to discuss financial results, MEMC executives said that Conergy had already been advised that the existing contract would remain in place.

Conergy has now launched court action against MEMC over what they call anti-competitive contract terms. Although few details have been revealed over the specific reasons, Conergy believes court action is justified as there were a number of invalid clauses in the contract but in particular 'anti-competitive contractual provisions' that rendered the entire contract invalid.

Conergy said that talks with MEMC had broken down over 'various auxiliary conditions,' without elaborating.

Due to the current growing oversupply of polysilicon and underutilisation of wafering capacity in the market, Conergy believes it has ample access to material required for production needs at its Frankfurt (Oder) module plant (pictured above).

Conergy said in a statement that the fall in polysilicon prices had turned the market from a 'seller's to a buyer's' and that legal doubts had emerged over the enforceability of some contractual provisions of the contract, without specifying what these provisions maybe. As a result, the contracts could be invalid, according to Conergy.


MEMC's St. Peter's, MO facility.

What they say

"Conergy's profitability comes first for us," said Dieter Ammer, Chief Executive Officer of Conergy AG. "The contract with MEMC signed by the previous management board does not reflect in any way the very strong decline in market prices for wafers. In addition, we have strong doubts about the legal structure of the contract. We would be prepared to accept the high costs of cancelling the contract because, on the one hand, they are not cash-effective and, on the other hand, they would improve Conergy's profitability on a sustainable basis onwards. Of course, we would prefer an amicable solution."

distribution systems and on-site gas management services. Supplied gases include nitrogen (N_2), hydrogen (H_2), silane (SiH_4) and chamber cleaning gases, as well as argon (Ar) and helium (He). Masdar PV is currently investing US$200 million in a thin-film plant in Erfurt, Germany. Masdar PV is using Applied Materials' 'SunFab' thin-film technology aand plans to build a 'copy exact' plant in Taweelah near Abu Dhabi. Combined capacity when fully ramped is expected to be 210MW. Lessons learnt at the Erfurt plant will be migrated to the plant in Abu Dhabi.

Air Products, Best Solar sign second thin-film PV gas supply deal

Air Products and Best Solar have signed a letter of intent for the supply of liquid bulk and on-site gases to the Chinese PV manufacturer's new amorphous-silicon thin-film photovoltaic facility in Nanchang City, Jiangxi Province. The agreement between the two companies includes the long-term supply of hydrogen, nitrogen, helium, and argon gases.

When the facility comes on-stream at full capacity, it will have a module manufacturing capacity of 330MW per year.

The companies also signed a turnkey gas supply contract to provide on-site, liquid bulk gases, specialty gases, and gas equipment to Best Solar's new 330MW, thin-film PV facility under construction in the Wuzhong Economic Development Park in Suzhou, Jiangsu Province.

Air Products scores thin-film PV gas supply deal with Taiwan's Green Energy

Air Products has begun supplying bulk and specialty gases to Taiwan-based Green Energy Technology's new thin-film solar photovoltaic production facility, based on the SunFab line. The deal calls for the long-term supply of nitrogen and silane as well as the accompanying gas delivery equipment and piping.

Semilab acquires metrology companies to expand applications

KLA-Tencor may get the credit for being the most active acquirer of metrology/inspection tool companies in recent years, but is now not alone in the quest to further the consolidation that is needed. Semilab is hot on heels of KLA-Tencor in that respect with a recent spate of acquisitions and news that it has now acquired both Advanced Metrology Systems (AMS) and QC Solutions. The company did not disclose financial details, except that the deals were cash transactions.

In 2008, the company purchased the assets of SOPRA SA, SSM and Boxes Cross implant and metal thickness metrology technology from Applied Materials. In the new round of acquisitions, AMS sticks out, known for its specialised almost custom metrology solutions for leading-edge semiconductor characterization work. QC Solutions offers non-contact measurement technology, known for epitaxial and implanted silicon wafer analysis.

Atlas's PV Center of Excellence adds to list of services

Atlas Material Testing Technology's Solar/PV Center of Excellence in Phoenix, Arizona has added two further services to its portfolio. Services for solar simulator classification and I-V Curve tracing will aid solar companies to substantiate product warranty and efficiency claims.

The solar simulator classification service is provided via Atlas's use of a portable, high speed, multi-channel OL 770 device to verify that testing instruments meet the standards of simulator classification for PV testing. The verification process meets the requirements described in IEC 60904-9, Photovoltaic Solar Simulator Performance Requirements for qualifying solar simulation for IEC 61215 testing.

Using a self-contained Daystar DS-100C I-V curve tracer, Atlas's second new portal service provides accurate I-V curves for a single PV module up to 50kW. The tracer auto-scales to 600V and features 10 and 100A current ranges, as well as facilitating normalization, plotting, analysis and printing of the I-V curves.

Product Briefings

Pall Corporation

Pall claims 95% water re-use for new water recycling system used for wafering

Product Briefing Outline: Pall Corporation has introduced a new generation of fully automated separation systems for the reclamation of water and silicon sludge from the spent grinding/sawing water. The system design follows a modular concept and comprises a dynamic membrane filtration (MF) unit, combined with physicochemical pre-treatment of the spent process water.

Problem: Shaping of silicon ingots prior to wafering comprises several cutting and grinding operations and requires a large quantity of water that acts as a cooling liquid, lubricant and as a carrier for the silicon particles. The spent process water leaves the tools highly contaminated by silicon particles.

Solution: The systems completely clarify the contaminated process water. Typically 90-95% of the contaminated process water is transformed into particle-free permeate ready for re-use. The remaining concentrate may be directly discharged, or mixed with other wastewater streams, or further treated to meet discharge regulations as well as to de-water the silicon debris. The system improves sawing/grinding performance due to controlled, advantageous process water specifications. De-watered silicon debris with low chemical contamination can be collected for potential feedstock for silicon re-use. The cost of ownership of the reclaimed water ranges from US\$0.50 per m^3 for small systems to US\$0.25 per m^3 for large systems.

Applications: Reclamation of water and silicon sludge from the spent grinding/sawing water.

Platform: The system design follows a modular concept and comprises a dynamic membrane filtration (MF) unit, combined with physicochemical pre-treatment of the spent process water. The capacity of the standard systems ranges from $3m^3/h$ to $36m^3/h$ (up to 140MWp p.a.). Higher capacity systems are available on demand. System prices depend strongly on capacity and options selected as well as on the number of redundant components.

Availability: Currently available.

Applied Materials

Applied Materials' 'MaxEdge' wire saw system first with dual-wire management system

Product Briefing Outline: Applied Materials has launched a new unified platform for slicing ingots into ultra-thin wafers that caters for both high volume production and R&D applications. Applied's HCT 'MaxEdge' wire saw system is the first in the industry to employ a dual-wire management system that is claimed to offer significantly higher throughput (double) and load capacity than competitive systems. The compact footprint requires less factory floor space and fewer operators for equivalent megawatt output, helping to drive down the cost of manufacturing photovoltaic (PV) cells by up to US\$0.18 per watt, according to the company.

Problem: By making thinner wafers, PV cell manufacturers can reduce the amount of silicon per wafer and lower the cost-per-watt of solar electricity. To produce thinner wafers, traditional wire saws must reduce the ingot length (load) and the cutting speed.

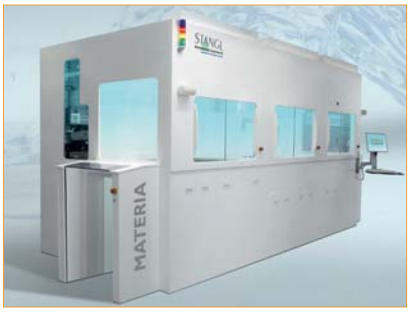
Solution: MaxEdge's breakthrough dual-wire management system employs four independently-controlled direct drive motors and advanced process control to lower wire tension, reducing wire wear and decreasing ingot scrap and unplanned downtime. Reduced tension also allows smaller diameter cutting wires to be used, resulting in significantly less silicon loss without compromising yield. The system has the ability to cut wafers as thin as 120µm in high-volume, day-to-day production.

Applications: c-Si ingot slicing down to 120µm.

Platform: MaxEdge is claimed to enable the of use thinner wire for larger loads at higher cutting speed than any other system; 45% larger loads compared to the previous model, the B5, and up to double the load of the leading competitor. The system's throughput and load improvements enable a reduction in the number of systems needed for a given capacity.

Availability: Currently available.

Stangl Semiconductor Equipment AG



Stangl's new wet line removes silicon-chunk surface contaminants

Product Briefing Outline: Stangl Semiconductor Equipment AG is introducing a new wet chemical etching tool, the Materia Pce, for removal of surface contaminants from chunks of polysilicon or upgraded metallurgical silicon (UMG) as a result of the crushing process.

Problem: Higher conversion efficiencies for solar cells are a key element of reducing the cost per watt. Polysilicon and UMG material with reduced impurities enables higher cell efficiencies, as removal of contaminants is required before cell processing begins.

Solution: The Materia operates in a batch mode by loading the chunks into baskets, which are moved by linear robots through various chemical and cleaning process stations. Each basket can accommodate 25kg of silicon chunks, varying in diameter from 10 to 180mm. After the treatment, the chunks are rinsed and dried to remove any traces of chemicals. This CE-compliant wet bench is designed to etch 5 to 20µm on the peripherals of the chunks to get rid of the organic residues and metallic contaminated layers. According to Stangl, the Materia can be configured to support polysilicon production volumes from 500 to 2,500 tons per year. The setup offers flexibility in terms of the main chemical agents used for etching. The etching device is designed to handle alkaline as well as acidic etchants, and features a process sequence combining both types. It uses HF and HNO_3 as acidic media and NaOH and KOH as alkaline agents.

Applications: Cleaning of polysilicon or upgraded metallurgical silicon.

Platform: The device, which occupies 7.2 × 2.3m of factory floor space, can process two to 10 baskets per hour with an uptime of more than 95%. Stangl is offering additional accessories at an extra charge, such as chemical supply systems, process engineering, custom-built baskets and loading/unloading containers, and RFID chips for tagging products.

Availability: Currently available.

centrotherm SiTec GmbH

centrotherm photovoltaics extends crystallization furnace development

Product Briefing Outline: centrotherm SiTec GmbH, a subsidiary of centrotherm photovoltaics AG, is planning the launch of a new crystallization furnace for the manufacture of multicrystalline ingots, which can contain up to 450kg of polysilicon.

Problem: In the crystallization furnace, polysilicon particles are initially smelted in a quartz crucible at over 1450°C. The smelted silicon is then turned into multicrystalline ingots based on the principle of directional solidification. With the continued demand and popularity of multicrystalline wafers, furnaces of increasingly larger size are required to reduce overall ingot costs with higher throughput and overall productivity, while improving quality by the reduction in impurities. Emphasis is also placed on low power consumption to reduce manufacturing costs.

Solution: centrotherm SiTec has developed a high-performance furnace that is distinguished by a higher output compared to existing models on the market. In tests, the company claims that the performance parameters achieved exceed expectations at this stage. In addition to significantly optimized energy usage, the crystallization furnace provides a solid basis for future modular extensions, according to the company. The crystallization furnace can contain up to 450kg of polysilicon, and has an optimized hot zone for a quartz crucible of 880mm x 880mm x 420mm, which allows for an efficient silicon smelting process and optimized crystallization process management.

Applications: Multicrystalline ingots, quartz crucible of 880mm x 880mm x 420mm.

Platform: 450kg furnace capacity.

Availability: The first crystallization furnaces will be supplied to customers in the first half of 2010.

QComp Technologies, Inc.

QComp's new glass loader enables precise location of slots and glass thickness calibration

Product Briefing Outline: QComp Technologies, Inc. has introduced a new insulated glass (IG) automatic load and unloading system to its glass handling product line. The new IG system uses a six-axis ABB robot and QComp's machine vision system to unload IG units from the production line and place them into slotted glass racks. QComp also provides a system that can pick single lites from slotted racks and load them onto the IG production line.

Problem: Glass handling is a process that is prone to breakages with the fragile IG products. Automation is a necessity for such a delicate task.

Solution: Utilizing an ABB six-axis robot and a proprietary vision technology developed by QComp, the system can precisely locate the rack slots to load and unload glass and can be calibrated for various glass and unit thicknesses. Capable of handling a large range of glass sizes, the QComp system also features seamless integration with line controls.

Applications: Insulated glass handling.

Platform: Six-axis robot and vision technology.

Availability: Currently available.

Morgan Technical Ceramics

Morgan Technical Ceramics' CVD business to offer PBN material for solar applications

Product Briefing Outline: Morgan Technical Ceramics' Chemical Vapor Deposition Materials business is to offer its 'Performance' Pyrolytic Boron Nitride (PBN) material for use in manufacturing of the photo absorption layer in thin-film photovoltaic (TFPV) cells. Performance PBN is used for crucibles and evaporation boats used in producing the TFPV cells, as well as for coating graphite heating elements used for material vaporization.

Problem: In solar cell production, thin-film deposition offers a simpler and more cost-effective alternative to using silicon wafers. Thin films use less material and are much faster and simpler than the complex and delicate process of slicing, dicing and placing of silicon wafers. However, cost of deposition must be reduced and the efficiency of the resulting PV cells sufficiently increased to cut costs.

Solution: In the TFPV deposition process, precursor vapours are transported from a source vessel into a deposition zone onto a heated substrate to deposit the PV layer. PBN ceramic is an excellent material because of its high corrosion resistance and non-reactivity with acids, alkalis, organic solvents, molten metals or graphite. Bulk impurity levels are less than 100 parts per million with metallic impurities less than 10 parts per million, and withstands 1800°C in a vacuum and 2000°C in nitrogen. Crucibles heated to 1200°C can be plunged into liquid nitrogen without visible damage.

Applications: The anisotropic conductivity of Performance PBN improves process performance for crystal growth, whether the growth method is Liquid Encapsulated Czochralski (LEC), Vertical Gradient Freeze (VGF), or Bridgman.

Platform: The PBN material is highly anisotropic (directionally dependent) in its thermal transport and very resistant to thermal shock. An excellent electrical insulator, PBN is stable in inert and reducing atmospheres up to 2800°C and in oxidizing atmospheres to 850°C.

Availability: Currently available.

Polymer development and selection criteria for thin-film and crystalline-silicon module manufacturing

Mark Thirsk, Linx Consulting LLC, Mendon, MA, USA

ABSTRACT

Although simple in concept, a photovoltaic solar cell is a difficult feat of technology in execution. The challenge of balancing cell structure design, material optimization and module technology to achieve efficient, low-cost modules that perform in aggressive environments for up to a generation is huge. The modules' structure has to support and protect a thin, fragile slice of semiconductor, while ensuring a stable environment free from contamination and moisture with little or no change in the incident light on the cell.

Key to the modules' performance are the first-level polymeric materials that contact the cell and conductor structures, hold the module together, and in many cases form the second-level protection of the cells from the environment. In this article we explore the industry dynamics in the supply of advanced materials for module assembly, the new technology directions, and how the market will develop over the next five years.

Module manufacturing needs

Modules are critical in protecting the various types of photovoltaic cells during the transport, mounting and life of the cells. With ever-decreasing thickness of the absorbers in the overall module build, the module is an integral part of the final electricity generating effort, and must be designed to protect the absorber while optimizing its efficiency. Furthermore, the module must meet the overall needs of cost, stability and weight required in the final installation.

> "Cell architectures vary in their choices for substrate material, and whether the substrate used for manufacture performs as a substrate or superstrate in the final module."

The market for cells in 2008 was still dominated by crystalline silicon cells of both the monocrystalline and multicrystalline wafer type. While there are multiple methods of creating these wafers (sawing, string ribbon growth, meniscus growth, cleaving, etc.), the methods used for these wafer-based modules is generally common in that a glass front panel provides the stability and the face to the sun, and the cells are embedded in layers of polymeric sheets to provide the cell insulation, protection and fixturing. Differences in the cells' interconnection from module to module derive mostly from the emitter architecture chosen by the cell maker, and whether the cells need to be contacted on both front and back, or just on the back. This article discusses this market segment as one despite these small differences in process and design, while focusing on the choices of the polymer films used.

The landscape of the thin-film segment is significantly different. There are many thin-film absorbers in production, and many more being developed. Cell architectures vary in their choices for substrate material, and whether the substrate used for manufacture performs as a substrate or superstrate in the final module. Additionally, the thin-film technology in question may be produced on a rigid substrate or on a flexible substrate – again, influencing the needs for any moduling materials. Finally, the thin-film absorbers vary from being stable, passivated inorganic materials that are tolerant to moisture and temperature, to being sensitive organic materials that require high degrees of protection from damaging radiation, moisture, oxygen and other environmental factors.

To put the moduling challenge in sharper perspective it is worth bearing in mind that the vast majority of modules are expected to survive in very harsh environments with a minimum of maintenance. By definition, the modules will be in direct sunlight with many years of high intensity UV exposure. Added to this, the modules will generally be exposed to all the variables of weather throughout the year, including rain, high and low temperatures, hail, snow, wind, sand and debris. Many modules are expected to withstand 20 to 25 years of exposure with precisely limited changes in performance detailed in the module delivery specification.

The only materials that regularly meet such stringent environmental challenges are ceramic (concrete, brick, tile, etc) or self-passivating metals (copper, aluminum, etc). Very few organic surfaces endure such high performance goals (perhaps with the exception of some fiberglass, bitumen, and a few speciality paints). A generic list of overall module requirements is given in Table 1.

C-Si modules

The generic crystalline cell module uses a well-proven design and material set to encapsulate and protect the cells. Cells typically consist of the following components and films:

Glass panel. Usually molded, structured low-iron soda-lime glass, sometimes tempered for strength. This glass is sometimes coated with an anti-reflecting layer, or a self-cleaning layer to improve the module performance.

Physical support of the cells
Mechanical protection
Radiation protection
Moisture protection
Electrical insulation
Oxygen protection
Shock protection
Sand and dirt protection
Manufacturable
Low cost
Architecturally attractive
Physical properties consistent with the cell (flexible or rigid)

Table 1. Module performance requirements.

Adhesive/encapsulant (front). An organic layer that adheres the glass to the front side of the cell, as well as physically encapsulating the cells and front-side interconnect metals. This film must be close to optically transparent at absorbed wavelengths, and must not degrade with exposure. Additionally, the layer must become liquid during module lamination to completely contact the cells.

Cells. Finished, tested wafers assembled into strings of cells with tinned copper strips and connections that will lead to the junction box.

Adhesive/encapsulant (back). An organic layer that adheres to the back side of the wafers and the backsheet material. It also physically encapsulates the silicon cells and back-side interconnect metals.

Backsheet. A high-performance (and consequentially often high value) laminated polymer sheet that combines multiple properties. This layer must provide electrical insulation of the cells, withstand UV exposure from the exposed front side as well as the backside, and protect the cells from moisture and contaminants.

Backsheet

Approximately 90% of C-Si modules use backsheets. The backsheet material choice is highly dependent on the final module performance expectations. Typically the insulation is provided by polyethylene terepthalate (PET), and high breakdown voltages will be achieved with thicker PET films. As PET is sensitive to degradation by UV, modules designed with longer lifetimes will typically protect the PET with layers of fluoropolymer. The most commonly used fluoropolymer today is PVF (polyvinyl fluoride), although PVDF (polyvinylidene fluoride) is gaining in acceptance. In some cases the fluoropolymer is only applied to the back of the PET, but for increased protection it is applied to the front and back of the PET.

Contrary to popular belief, the moisture protection of the PVF/PET/PVF laminate is poor, and backsheet laminators offer the option of including an aluminum layer in the backsheet to reduce moisture ingress.

Variants of this relatively simple PVF/PET/PVF sandwich are common. In some cases an adhesive layer may be included on the inside of the laminate to reduce the complexity of lay-up of the final module. PVF layers may be colored to offer better reflectivity, or more pleasing aesthetics. A notable exception in the global market to these backsheet lamination schemes is in Japan, where many modules have been designed for shorter overall lifetimes. These modules use several (2 to 3) layers of PET and do not commonly incorporate a fluoropolymer layer. To mitigate UV damage the outer layers of PET will often be of a differing composition, and include UV absorbing dyes or pigments to shield the inner layers from damage.

The backsheets are laminated by specialist manufacturers, and require adhesives to ensure good adhesion of each component sheet within the laminate. These laminates are typically epoxies, but other compositions such as acrylics have been evaluated.

Adhesive/encapsulant

The most commonly used adhesive in C-Si module manufacture today is Ethyl Vinyl Acetate. EVA is a crosslinking elastomeric and is supplied as a partially crosslinked sheet that is rubbery and tacky in feel. The sheet is often supplied with a backing sheet, which is removed just prior to use. The elastomeric nature of the film allows conformal coating of the cells, a process that is completed in the curing operation and conducted in a vacuum laminator. Since the reaction occurring in the laminator is a crosslinking reaction that is time- and temperature-dependant, there is an inherent cycle time in the process that can be in the order of 10 to 15 minutes per module. For this reason, EVA curing of modules is often carried out on parallel laminators, or, increasingly, in stacked vacuum laminators which process multiple modules at a time.

A concern with the use of EVA is the outgassing of relatively corrosive byproducts on curing. These byproducts can limit the life of the laminator diaphragms, and require increased pump maintenance.

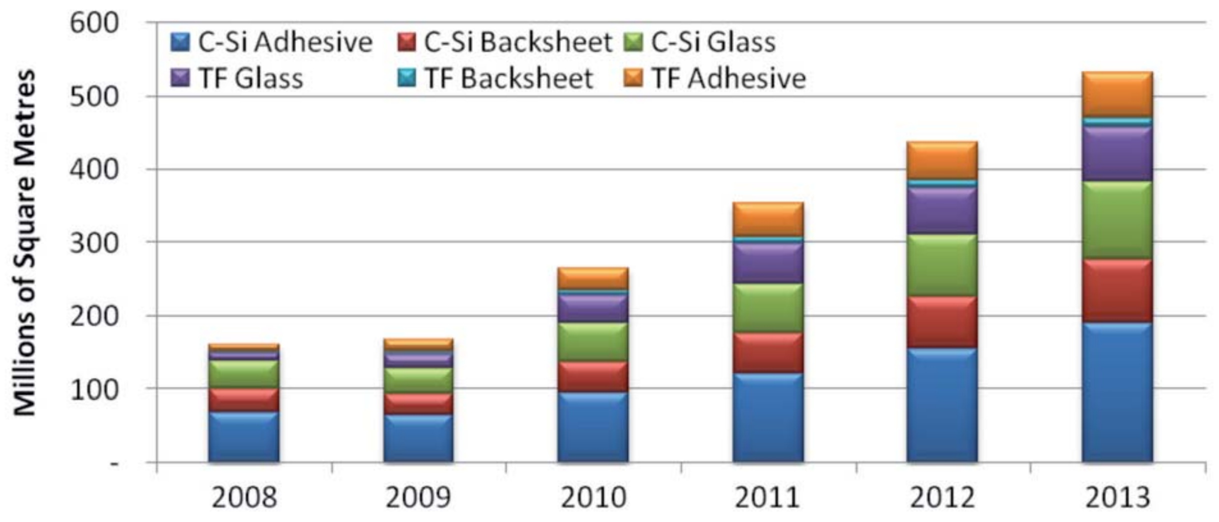


Figure 1. Moduling material demand (in millions of square metres).

An emerging alternative material for use as an adhesive is polyvinyl butyral (PVB), a thermoplastic. Having been used in thin-film glass-on-glass modules for some time, improved PVB materials are coming to market that show equivalence with EVA, without the requirement for long cure times. The PVB becomes liquid above the glass transition temperature, and care needs to be taken that the module is physically supported during lamination and cooling until the adhesive has solidified. PVB has the advantage of not needing the long cure, and can be applied in roll lamination.

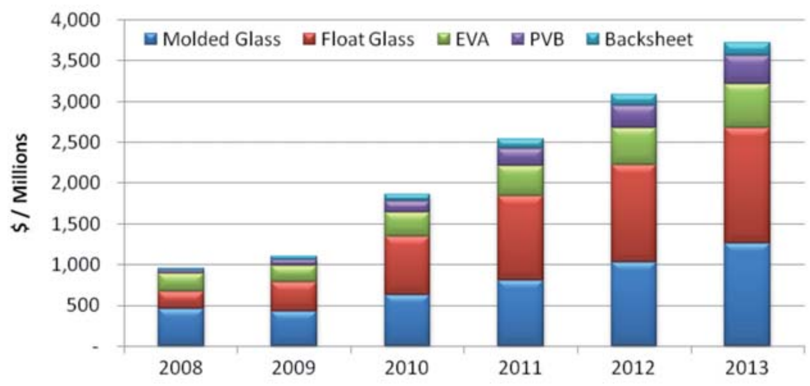


Figure 2. Moduling material market forecast.

> "A concern with the use of EVA is the outgassing of relatively corrosive byproducts on curing."

Challenging these film-based solutions is the promotion of a recent development of silicone-based encapsulants. These materials are applied as a liquid and cured in situ, resulting in encapsulants that have excellent stability, high transparency, and good moisture blocking characteristics.

Module quality

In the final analysis, the moduling approach for C-Si cells relies as much on proven technology as on the pros and cons of each technology, either established or novel. Accelerated testing of the finished modules is not perfectly predictive of their performance in use, and real-life testing is not an option for items with such long life expectancy. Thus, there is always hesitancy in introducing new processes and replacing known quantities with proven track records.

Thin film

The dominant moduling technology for thin-film absorbers is glass-on-glass. In this technology a glass sheet is used as the manufacturing substrate, and once complete, a second glass sheet (either a superstrate or substrate) is laminated to the completed cell on the glass sheet, providing front and back protection for the cell, and requiring only an edge seal to make the final module hermetic.

About 20% of thin-film modules use polymer-based encapsulants, either in the form of backsheets similar to c-Si technology, or as front-side protection for cells fabricated on substrates like steel as a transparent protection layer over the cell.

Glass on glass

The most common approach to thin-film modules uses a PVB film between two float glass sheets. The inherent strength and protection afforded by the two glass layers provides excellent protection for the absorber. In fact, in two common embodiments (tandem junction silicon and CdTe modules) there is no specified frame, and in some cases no edge sealant is used. These simple modules are laminated with niprollers and cured in an autoclave. This technique has been demonstrated in very large module dimensions (up to 2.5m on a side), showing savings in support frames and Balance of Systems.

Backsheet on Glass

Dual glass sheets incur a penalty in weight, which may be unacceptable on rooftop applications. An alternative approach is to laminate the cell and glass front with a polymer backsheet. On the face of it, this should not cause major concerns due to the generally unreactive nature of the semiconductor absorber; however, this technique is likely better suited to Si-based cells.

Frontsheet on glass or steel

In the case of some CIS/CIGS designs, and some specific Si-based dual and triple junction designs, the front side of the absorber must be covered by a transparent encapsulant. Commonly used encapsulants are fluoropolymer-based films such as ETFE, which offer good environmental resistance, as well as flexibility in the case of cells built on steel.

Market outlook

Linx Consulting, together with Alternative Energy Investing, have developed forecast models for the materials demand in the PV industry. Despite a poor prognosis for 2009, we anticipate that the cost competition in the down year will act to further spur growth in 2010 and beyond, and increased concern for the provision of alternative energy will drive subsidies and feed-in tariffs to support adoption of PV projects. Although overall growth may not parallel that seen in the past few years, we still expect double-digit compound rates and strong demand for moduling sheets and materials from 2010 onwards.

> "Any competitor in this market must include a continuous, relentless approach to cost reduction; at least until grid parity is reached to a broad extent."

Figure 1 shows a forecast for the various moduling materials in square metres. The largest segment by module area is that of the c-Si adhesive, since each module uses two sheets. Figure 2 is a forecast of the market growth for the materials shown in Figure 1. While dominated by the cost of glass, the predictions still show a US$220 million polymer market growing to more than US$1 billion in 2013.

New challenges

An underlying principle of the whole photovoltaic market is the continual need to reduce the cost per watt of power generation capability. Integral to this goal is the reduction of the purchase cost of modules. Since most of the components of the module are already based on materials that are largely commoditized (glass, aluminium, stainless steel, polymer sheet, etc.) the prices are largely market driven, and scale effects are mostly irrelevant. However, the cost of specialization of these materials will reduce as volumes increase, and the market prices will approach the commodity levels.

Despite this potential route to cost reduction, any competitor in this market must include a continuous, relentless approach to cost reduction; at least until grid parity is reached to a broad extent, but also to ensure competitiveness even after this juncture.

Product differentiation through technical performance is critical to developing improved module and cell efficiency, and thus the aggressive Levelized Cost of Energy targets needed to achieve grid parity must be met. Incremental improvements in technology will lead to cells and modules that are better suited to the segment needs, whether on-grid or off. These changes will take time to implement due to the inherent difficulty of knowing if they are durable for the intended life cycle of the modules, but the current module designs will likely not survive unchanged in the relentless quest for grid parity.

About the Author

Mark Thirsk is Managing Partner of Linx Consulting. Mark has over 20 years' experience spanning many materials and processes in wafer fabrication. He has served on the SEMI Chemicals and Gases Manufacturers Group (CGMG) since 1999, acting as Chairman between 2001 and 2003.

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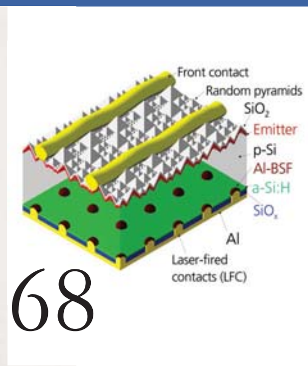
Cell Processing



News

Two-tier roughness could boost solar cell efficiencies by 2%

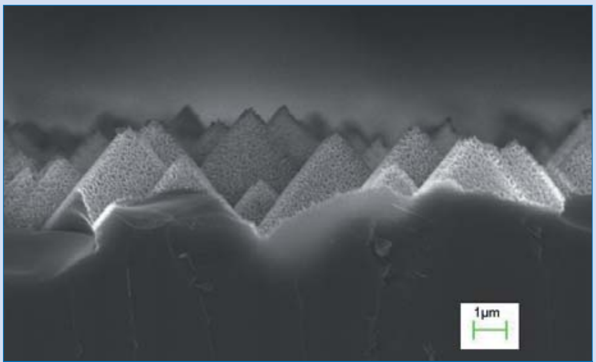
A process under development at the Georgia Institute of Technology could potentially boost conventional c-Si cell efficiencies by as much as 2%. Researchers are using two different types of chemical etching to create surface features at both the micron and nanometre scale that increase light absorption, reduce reflection and keep cells clear of stray particles.

"A normal silicon surface reflects a lot of the light that comes in, but by doing this texturing, the reflection is reduced to less than 5%," said Dennis Hess (pictured), a professor in the Georgia Tech School of Chemical and Biomolecular Engineering. "As much as 10% of the light that hits the cells is scattered because of dust and dirt of the surface. If you can keep the cells clean, in principle you can increase the efficiency. Even if you only improve this by a few percent, that could make a big difference."

The researchers use potassium hydroxide (KOH) solution to etch the silicon along crystalline planes, creating micron-scale pyramid structures in the surface. An e-beam process is then used to apply nanometre-scale gold particles to the pyramid structures. Using a solution of hydrogen fluoride (HF) and hydrogen peroxide (H_2O_2), the gold acts as the catalyst, producing controlled nanometre-scale features. The gold is removed via a potassium iodide (KI) solution and the surface coated with a fluorocarbon material, perfluorooctyl tricholosilane (PFOS).

Technical challenges remain before potential commercialisation is possible. The nano-scale structures are inherently fragile and prone to damage and destruction.

"Because the structures are so small, they are fairly fragile," Hess noted. "Mechanical abrasion to the surface can destroy the superhydrophobicity. We have tried to address that here by creating a large superhydrophobic surface area so that small amounts of damage won't affect the overall surface."



A silicon pyramid structures etched for one minute using a hydrogen fluoride/hydrogen peroxide/water solution. The resulting structure has roughness at the micron and nanometre scales.

R & D News Focus

Suntech teams with Swinburne University for next-generation cell research

Joining research forces with Swinburne University of Technology in Melbourne, Suntech's CEO Dr. Zhengrong Shi will lead the collaborative effort with the University's Centre for Micro-Photonics Director, Professor Min Gu.

"The project will be based around the development of nanoplasmonic solar cells," said Professor Gu. This new technology allows for the efficient collection of solar energy in a wider colour range than those currently being developed in other laboratories. "These will be twice as efficient as the current generation of cells, and will also cost significantly less to run."

Dr. Shi said, "This relationship will combine Swinburne's high quality research with Suntech's ability to rapidly commercialize new technologies into cost effective applications. Nanoplasmonic technology has the potential to take solar to the next level."

Funding will come in the form of a US$3 million dollar contribution to the venture from Swinburne University, with a further US$3 million coming from Suntech.

IMEC plans partnership on boosting longevity of organic photovoltaics

Independent nanoelectronics research institute IMEC and specialty chemicals and materials firm Cytec Industries Inc. are to collaborate on research to extend the lifespan of organic photovoltaics beyond the current five years to make them more viable in the market. Research will focus on the intrinsic stability of organic solar cells by improving nanomorphology of the active material blend. The Institute for the Promotion of Innovation by Science and Technology in Flanders is cosponsoring the research, which will run for two years and will end in March 2011.

Spire, NREL partner on 42% triple-junction concentrator solar cell development

Spire's wholly-owned subsidiary, Spire Semiconductor, LLC, has been awarded a US$3,706,359 contract by the National Renewable Energy Laboratory (NREL) for the development of next-generation manufacturing technology to produce 42% efficient III-V triple-junction tandem concentrator solar cells.

The resulting technology will be used in the platform for Spire's "Triathlon" series of concentrator solar cells. The 18-month contract payment consists of US$2,960,850 in government funding and a US$745,509 cost share.

GreenVolts, NREL join forces to commercialize advanced multijunction solar PV cells

Concentrator photovoltaics company GreenVolts and the National Renewable Energy Laboratory have joined forces to develop inverted metamorphic (IMM) advanced multijunction solar cells and bring the technology to market. GreenVolts has inked a licensing deal with NREL to commercialize the lab's patents, and the U.S. Department of Energy has allocated US$500,000 toward the effort.

IMEC organic photovoltaic cell.

The two-year cooperative research and development agreement (CRADA), which will be done in multiple phases, will facilitate the transfer of NREL's IMM cell technology to GreenVolts, so that the San Francisco-based CPV company can develop a customized cell tailored to its optical system and accelerate the widespread commercialization of the technology through its high-volume manufacturing partners.

The IMM technology has shown cell conversion efficiencies of 40.8%, one of the world's highest, and holds promise for further substantial increases. GreenVolts says that a customized solar cell will foster the optimization of its Carousol CPV system by increasing efficiency and reliability while reducing the overall cost of energy.

Entech Solar joins forces with Fraunhofer CSE for back-contact cell testing

Entech Solar's research has led it to enter into a collaborative agreement with Fraunhofer USA's Center for Sustainable Energy Systems (CSE) to evaluate the possibility of incorporating high-efficiency back-contact silicon solar cells into Entech's 20x concentrating solar systems.

Working with Freiburg, Germany's Fraunhofer Institute for Solar Energy Systems (ISE), Fraunhofer CSE will implement research into the feasibility of this potentially efficiency-boosting addition to Entech's current cells.

The organisations will simulate, design, and test prototype back-contact silicon solar cells and make recommendations in regard to Entech's mass production of such products.

Cell Production News Focus

Suntech pushes Pluto tech to 19% efficiency on monocrystalline solar cells, 17% on multi cells

Suntech Power Holdings said it is 'routinely' using the Pluto technology to produce solar PV cells with conversion efficiencies of approximately 19% on monocrystalline silicon cells and 17% on multicrystalline cells. The company also confirmed that third-party test results from the Fraunhofer Institute for Solar Energy Systems ISE in Germany show conversion efficiencies of 18.8% for monocrystalline cells and 17.2% for the multicrystalline cells manufactured on Suntech's 34MW Pluto production line.

The patent-pending Pluto approach, based on the PERL (passivated emitter with rear locally diffused) cell technology, has been developed by the University of New South Wales in Australia and has achieved world-record lab efficiencies of 25%. Researchers believe that the Pluto design can push power output by approximately 12% above conventional screen-printed cells.

A low-reflectivity texturing technology ensures that more photons can be absorbed throughout the day even without direct solar radiation, and thinner metal lines on the top surface reduce shading loss.

The company's 34MW Pluto PV cell line is fully operational; it expects to have 100MW of installed Pluto capacity within two months.

Suntech also said it expects to receive industry certification for Pluto-based modules in the second quarter and plans to ship more than 50MW of the modules in 2009.

Advent Solar touts high cell efficiencies on mono, multi and UMG solar cells

PV module manufacturer turned intellectual property (IP) provider Advent Solar, has released details of multi-crystalline, mono-crystalline and UMG solar cell conversion efficiencies, using its Emitter-Wrap Through (EWT) back-contact developed technology, which is part of the Ventura solar architecture. The results were said to have been validated via round robin tests at Fraunhofer, NREL and Sandia Labs.

Advent Solar claims its has reached 18.2% efficiencies on mainstream 156mm mono-silicon wafers; 17.2% on 156mm multi-crystalline wafers; and 16.56% on 156mm UMG wafers.

Solar-cell start-up and Intel spinoff SpectraWatt moves operations from Oregon to New York

Oregon's loss is New York's gain, as crystalline-silicon solar cell manufacturing start-up SpectraWatt said that it will build its first factory in IBM territory in Hopewell Junction, NY. The venture-backed Intel spinoff originally chose Hillsboro, OR, as its base of operations, but suspended construction there earlier this year while it searched for another site.

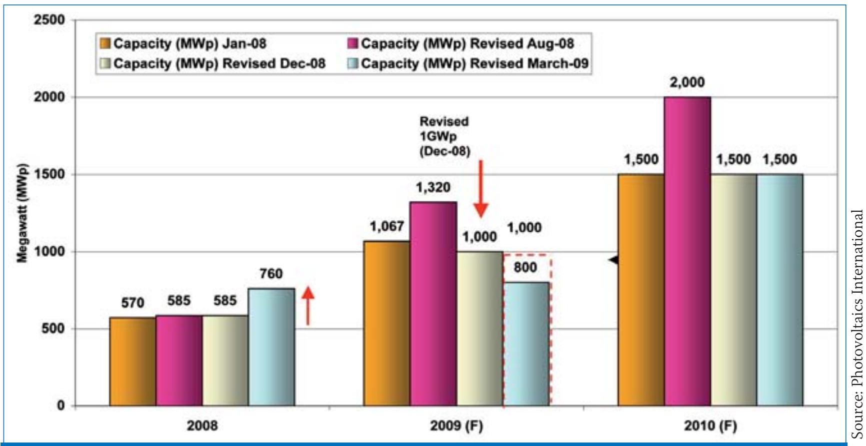
The cellmaker will build its initial advanced 60MW fab in the Hudson Valley Research Park, which is scheduled to be in production by early 2010. Additional lines are being planned, and the site's manufacturing capacity expected to reach 120MW within two years. The move should also result in 100 new jobs in the region within its first year of operation.

Investors in SpectraWatt's US$50 million funding round in mid-2008 included Intel Capital, Cogentrix Energy, PCG Clean Energy and Technology Fund, and Solon SE. The company initially planned to begin product deliveries by mid-2009, but pushed back its production timeline when the decision was made to find another location to construct its research and manufacturing facilities.

PV cell production at Q-Cells grew 48% in 2008; flexible production strategy planned for 2009

Q-Cells SE posted record sales and cell production for its full year 2008 financial results, retaining its position as the largest solar cell manufacturer. The company reached production volume in its core crystalline business of 570.4 MWp, slightly lower than the previous guidance of 580MWp but a 48% increase over 2007 levels. Sales grew by 46% to €1,251.3 million, compared to €858.9 million in 2007. Q-Cells expects to ramp both c-Si and thin-film capacity in 2009 to between 1.3GW – 1.4GW and 200MW – 250MW levels, respectively. Capital spending for 2009 will be within the range of €400 million to €500 million, dependent on market demand, the company said.

However, the core of the planned expansions come from existing investments made in 2008 in new plants in Malaysia for c-Si cell production and the initial plant ramps at thin film-subsidiaries, primarily at Solibro, Sontor and Calyxo.



Q-Cells revised capacity forecast.

Phase I of the new fab in Malaysia is now completed and expected to start ramping in the second quarter of 2008. However, Q-Cells executives noted in a conference call with financial analysts that Phase II ramp would be pushed out and ramp would be governed by market demand.

Q-Cells has cell supply contracts for 2009 of between 850MW and 970MW that includes 'delivery risk' and options +/-10%. Production targets for c-Si cells were projected to be in the range of 800MW and 1GW in 2009, roughly in line with guidance previously given.

REC Solar to slash 2Q09 PV cell, module production by nearly 50%

In response to what it calls "the challenging market environment for the solar industry" and subsequent buildup in its inventories in the 1Q, REC Solar has decided to slash its 2Q production of solar PV cells and modules by nearly 50%.

As a result of the move, the company said that approximately 180 employees will be affected through terminations of temporary employment contracts, temporary lay-offs of permanent employees, and rescheduled vacations. As long as there is "good contract coverage," REC also said it does not expect changes to the production of cells and modules in the 3Q and 4Q.

iTi Solar receives order for inkjet printing technology for roll-to-roll production line

Industrial inkjet technology company iTi Solar has announced that it has received an order for one of its digital inkjet systems from Solarcoating Machinery GmbH (ScM) of Germany, a supplier of turnkey production line solutions for flexible solar cell fabrication. ScM will use the system for its integrated roll-to-roll solar cell manufacturing production line.

Incorporating iTi Solar's inkjet system as an optional module for its Click&Coat coating system, ScM will allow cell manufacturers to print on solar cells, an alternative to traditional analog deposition technologies.

NREL installs iTi Solar inkjet, spray deposition tools for advanced solar cell research

The U.S. Department of Energy's National Renewable Energy Laboratory has installed iTi Solar inkjet and spray workstations in the lab's advanced atmospheric processing platform (APP), which is located in the Process Development and Integration Laboratory at the National Center for Photovoltaics in Colorado. NREL will use the iTi Solar workstations to develop low-cost nonvacuum processing methods and materials for use in advanced solar PV manufacturing.

"Inkjet printing is an attractive, viable alternative to many existing deposition approaches and has the potential to produce high-quality solar cells at reduced cost," said NREL scientist Maikel van Hest. "After a global competition, we seleacted iTi Solar's inkjet and sprayer systems."

Despatch Industries' metallization furnaces in high demand in China

Process technology company Despatch Industries has received multiple orders for its metallization firing furnaces from three new China-based customers. The furnaces in question have accounted for 8GW of production capacity worldwide, according to the company, and remain popular among Chinese solar manufacturing companies despite the economic downturn.

Amtech receives further US$3 million in orders from two Asia-based customers

Tempress Systems, Inc., subsidiary of Amtech Systems, Inc. has revealed that it has received approximately US$3 million in orders for its diffusion processing systems. The follow-on orders were placed by two unnamed Asia-based customers, and mark the second such order for Tempress since the start of the year.

OTB Solar orders solar-cell crack detection tool from RUV Systems

An RUV 2.2 QC Automation offline fully automated crack detection tool will be shipped soon to OTB, where it will be deployed to analyze and demonstrate the performance of its production lines, specifically the issue of crack initiation, the companies said.

The next step is inline crack detection. The Dutch companies have begun a cooperative development project to integrate RUV crack detection into OTB's Linex production lines.

Leading solar turnkey equipment manufacturer to buy SiXtron SunBox silane-free delivery systems

The Sixtron SunBox operates alongside the PECVD system on a solar-cell manufacturing line to safely and effectively deposit nonreactive, silane-free SiCN antireflective coatings (ARCs) and backside passivation layers on c-Si PV cells, ensuring maximum sunlight absorption and conversion efficiency.

Until now, the ARCs and backside passivation layers of cells have been deposited using silane, a volatile and pyrophoric gas that requires costly safety and handling procedures while multiplying manufacturers' financial and operational risks.

Roth & Rau to establish solar cell production line at UNSW

Roth & Rau AG, a leading international supplier for the solar power industry based in Germany, plans to construct a state-of-the-art silicon solar cell production line at the University of New South Wales, Australia. The growth of silicon solar cell technologies from laboratory processes to factory-ready industrial processes will be done at the Solar Industrial Research Facility (SIRF), an industrial grade manufacturing facility that will be one of the first solar research and development facilities in the Asia-Pacific region.

This marks Roth & Rau's first operational presence in the Asia-Pacific region. The SIRF will display advanced solar cell manufacturing technology to prospective buyers and will also train the company's staff in advanced equipment and processes. It should also attract more research students to UNSW.

Precision Process ships two roll-to-roll electroplating tools to unnamed manufacturers

Wet processing and electroplating systems provider Precision Process Equipment, Inc. has announced that it has received two new orders from two unnamed, independent solar manufacturing companies for two separate roll-to-roll plating system lines from its Excellite FSP system line.

Hongchen places follow-on PV1200 metallization line order with DEK

China-based PV manufacturer Zhejiang Hongchen has placed a follow-on order with DEK for a second PV1200 photovoltaic metallization line. Zhejiang Hongchen cited the zero wafer breakage and high throughput of the system as well as short delivery times as key reasons for the purchase of another system.

"After purchasing the first platform, we discovered that the breakage rate was incredibly low," said Xiang Xiao Long, General Manager of Zhejiang Hongchen. "Plus, while consistently high print quality means that our cell efficiencies are extremely high, a compact footprint enables us to optimise factory floor space."

DEK's PV1200 photovoltaic metallization line has a claimed 1200 cells-per-hour throughput, six-sigma process rating, 12.5 micron resolution and advanced handling capabilities.

Singapore's SERIS to install multiple Synopsys Sentaurus TCAD systems

Synopsys, Inc. has received a multiple tool order from the Solar Energy Research Institute of Singapore (SERIS) for its Sentaurus TCAD system to aid in the solar research company's development programs. SERIS is Singapore's national institute for applied solar energy research, jointly sponsored by the Singapore Economic Development Board (EDB) and the National University of Singapore (NUS).

The Sentaurus TCAD tools simulate the fabrication steps and photovoltaic performance of solar cells, leading to developments in cell designs and ultimately increased cell efficiency at lower costs. SERIS's research focuses mainly on the development of materials, components, processes and systems for the generation of solar power.

Product Briefings

Carbone of America

Carbone of America's Ultra Carbon Division offers new 'SolarMaxx 7000' SiC coatings

Product Briefing Outline: Carbone of America's Ultra Carbon Division (UCD) has announced the commissioning of its state-of-the art facility for advanced silicon carbide and pyrolytic carbon coatings. This new facility combines precision-controlled coating equipment to produce proprietary silicon carbide 'SiC' coatings. 'SolarMaxx 7000' is one its newest of SiC coatings for photovoltaic silicon wafer processing applications.

Problem: Silicon carbide has a number of properties that make it attractive when a hard coating that has excellent resistance to friction, wear and high-temperature corrosion is required. Its ability to withstand constant and intensive use has made the material desirable for demand applications such as CVD processes.

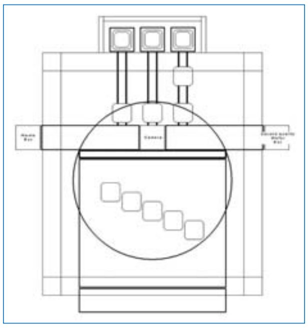
Solution: This coating is specially engineered for plasma enhanced/assisted chemical vapour depositions or PECVD/PACVD-type reactions. UDC is capable of providing these types of coatings with controlled deposition uniformity on complex shapes with micron layer precision.

Applications: Silicon Wafer Processing.

Platform: UCD's ultra-high purity graphite components are made from isomolded graphite. These unique and conformal coatings can significantly increase the lifetimes of graphite components versus non-coated components, saving downtime and money.

Availability: Currently available.

AMB Apparate+Maschinenbau GmbH



AMB's new wafer handling system handles high throughput wet benches

Product Briefing Outline: AMB Apparate+Maschinenbau GmbH is launching a new high-efficiency, smooth wafer handling system, which is claimed to be easy to operate and maintain. The new wafer handling system named 'BASIC LINE,' loads and unloads inline wet benches with a high level of reliability.

Problem: The system faces the need for cost-efficient, automated loading and unloading functions for a more efficient production.

Solution: The insert core of the BASIC LINE is the new high-speed four-arm robot system combined with a new type of gripper, which enables a high throughput with a smooth wafer handling process. The wafers are loaded to the system either in cassettes or stack magazine boxes, from which point the wafers are transported to the pick-up position of the robot. The robot transfers the wafers to the loading belt for the wet bench while a camera system checks each wafer on the fly; in case of defects, wafers are discharged automatically. For unloading,, the system takes over the wafers from the wet bench on an unloading belt where the wafers' position is detected by a camera. The robot then picks up each wafer, while another camera system checks each wafer for defects.

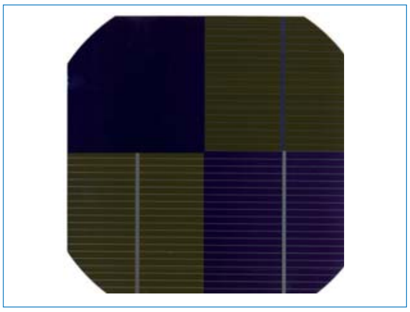
Applications: square and pseudo-square multi- and monocrystalline silicon wafers of 130–300µm thickness.

Platform: All components of the BASIC LINE are mounted on a heavy-duty welded steel frame.

Availability: June 2009 onwards.

Product Briefings

MacDermid Photovoltaics/iTi Solar



MacDermid Photovoltaics and iTi Solar offer free Si cells using off-contact patterning

Product Briefing Outline: MacDermid Photovoltaics and iTi Solar have offered to build free samples of Si cells formed with off-contact patterning and wet chemical conductor formation. Digital off-contact patterning and wet chemical metallization of silicon wafers provides superior conductors and the best contact between silicon and soldered conductors. The processing follows the layout and design of conventional PV cells, but eliminates screened paste, while reducing shadowing by up to 60%.

Problem: As the industry reaches toward grid parity, wet chemicals will deliver the required cost, processing and efficiency advantages. Conventional Si cells rely on screen-printed silver paste, which is expensive, provides marginal contact, suffers from poor bulk conductivity, and relies on mechanical printing which can damage the wafers.

Solution: Next-generation silicon cells are being produced by leading PV manufacturers using metal conductors formed with wet process chemicals. The chemical-formed conductors boast the best conductivity available, and form strong, intimate contact to the silicon. With improved electrical and mechanical performance, cell fingers can now be produced at 50-micron finished widths, dramatically reducing shadowing. With more light, lower resistance, and improved predictability, efficiencies can increase by over 1% absolute.

Applications: Replacement of silver paste for patterning and conductor formation of silicon cells.

Platform: Patterning is accomplished using high-definition etch resist that has been UV-cured. Demo cells are made at iTi Solar, where custom scale-up to 2,500 cells/hr per line is easily achieved. Chemical etch/strip, seed metal sinter, and build-up is conducted at MacDermid Photovoltaics. Turnkey in-line or vertical equipment/chemistry specifications are available for a variety of build-up options.

Availability: Summer of 2009.

RENA GmbH

CupCellPlate system from RENA enables fine line printing for higher efficiencies

Product Briefing Outline: RENA GmbH has launched the CupCellPlate system, which enables a reduction in paste width and thickness to boost conversion efficiencies. During the plating operation each solar cell is positioned on top of a separate cup. The cell lies on contact pins above the cup and electrolyte or rinsing water flows against the cell. Due to this configuration, it is possible to optimize the flow and thus the plating homogeneity.

Problem: In today's back-end process of solar cell production, the contacts that transport the current out of the cell are printed with metal paste onto the cell. After a thermal treatment, there remains a porous structure that has only a fraction of the conductivity of pure metal. Due to the reduced conductivity, the maximum efficiency of the solar cell cannot be achieved.

Solution: The idea behind the CupCellPlate system is the reduction of the paste width and thickness and use of the printed contact as seed/start layer for the following conductivity-enhancement with high conductive electroplated metal layers. The efficiency of the solar cell is increased as more current is flowing. In addition the CupCellPlate allows the integration of low-cost and innovative metal sequences like nickel/copper/tin instead of silver into production. A line width reduction such as the novel fine line screens developed by RENA in cooperation with NBTechnologies and Frintrup reduces the shadowing of the effective area, allowing the printing of 60µm structures, compared to 100-120µm previously using classic paste printing, leading to a claimed 0.5% efficiency increase.

Applications: Solar cell electroplating of Ni, Cu, Sn and Ag.

Platform: The automatic process control guarantees 24-hour operation with a throughput of 2400 wafers per hour. The transport of the solar cells from one process step to the next is performed with a special handling unit which transfers a complete row in parallel.

Availability: Currently available.

Schmid GmbH + Co.

Schmid's new DoD2000 ink-jet printer increases throughput

Product Briefing Outline: Schmid GmbH + Co. is launching a high-throughput inkjet printer to apply the metallic contact patterns on the emitter side of silicon wafers without touching the substrate. The DoD2000 – with a throughput of 2,000 wafers per hour – is a drop-in replacement for Schmid's slower and less accurate DoD1500 machine. The leap in production capacity is the result of improvements in mechanical design, handling cycles and printing routines.

Problem: Inkjet printing, once considered the most promising candidate to replace conventional screen-printing due to its non-contact advantages, has faced operational problems such as ink clogging in the nozzles and non-availability of suitable ink compositions for the process.

Solution: By using special cleaning procedures and hot-melt types of inks, Schmid's DoD2000 ink-jet printer has less than 5% downtime. The DoD2000 printer applies the contact in a batch sequence of 25 wafers as thin as 100µm. After loading, each wafer is individually positioned by a high-accuracy auto-alignment system. The loaded batch is then printed in one go with five print heads, followed by unloading. The entire cycle takes 45 seconds. As the tool uses hot-melt ink, dryers are not necessary in the process. The DoD2000's minimum line thickness is 40µm, which reduces the shadowing effect. However, the deposited front contacts alone might not be sufficient. The DoD2000's print can act as a seed layer that needs to be thickened by a plating process in a later step.

Applications: Inkjet printing of metallic contact patterns on the emitter side of silicon solar wafers.

Platform: The DoD2000 printer is fully equipped with five print heads and auto wafer alignment.

Availability: Currently available.

DALSA Corporation

DALSA offers low-cost high-performance solar cell inspection

Product Briefing Outline: DALSA Corporation has announced its entrance into the solar cell inspection market with a solar cell inspection kit designed for low-cost high-volume production applications. High-performance image sensor technology, coupled with DALSA's TDI (time delay integration) technology, is claimed to provide fast and precise image capture.

Problem: Success factors for solar cell inspection include: image capture speeds, image resolution, and embedded processing capability. DALSA's cameras and hardware are used in the initial part of the quality inspection process to verify patterns and edges, inspect coatings, and to check for micro-cracks. The precision of DALSA's image capture and processing technology contributes to the immediate and accurate detection of defects in this critical stage of the manufacturing process.

Solution: Advantages of DALSA's new capabilities in line scan, area scan, and embedded processing include DALSA's TDI (time-delay integration) technology, which is accurate in identifying defects, and efficient in delivering the fastest image capture speeds claimed in the industry (110 KHz), resulting in improved yields and reduced costs, according to the company. DALSA's patented CMOS sensor technology is used, which enables 62 frames per second with 4 megapixel resolution, for greater system throughput. DALSA's new Pantera 22M camera allows image capture of a solar cell down to 40µm with one shot by utilizing its 22 megapixels, with low dark current, low noise and higher dynamic range.

Applications: 100% inline inspections, enabling real-time embedded acquisition, processing, defect analysis, data reduction, data filtering and defect classification

Platform: These capabilities are delivered via the following products by DALSA: Piranha HS 4K (the company's fastest TDI camera), Falcon 4M60, Pantera 22M, Piranha3 8K and the Anaconda.

Availability: Currently available.

Keithley Instruments

Keithley updates solar cell tester to support Drive-Level Capacitance Profiling

Product Briefing Outline: Keithley Instruments has made a variety of enhancements to its Model 4200-SCS Semiconductor Characterization System. The Keithley Test Environment Interactive (KTEI) V7.2 upgrade includes nine new solar cell test libraries, an expanded frequency range for the system's Capacitance-Voltage (C-V) measurement capability, and support for the company's new nine-slot Model 4200-SCS instrument chassis.

Problem: The new test libraries included in KTEI V7.2 expand the Model 4200-SCS's capabilities for solar cell I-V, C-V, and resistivity testing applications, which are increasingly important, given the growing interest in and governmental support for alternative energy technologies. The software upgrade also supports Drive-Level Capacitance Profiling (DLCP).

Solution: The continuing growth in I-V, pulse, and C-V characterization applications has meant that Model 4200-SCS users who need exceptional testing flexibility and capabilities have been finding their mainframes somewhat crowded. To address this need, the V7.2 upgrade provides support for a nine-slot instrument chassis. Previously, the Model 4200-SCS had just eight slots to hold a growing array of source-measure units (SMUs), pulse generation and scope cards, and capacitance-voltage cards. Existing Model 4200-SCS systems can be upgraded to support nine slots.

Applications: Solar cell testing.

Platform: In support of the V7.2 upgrade, Keithley has also introduced a new high performance triaxial cable kit (eliminating the need for recabling) for connecting the Model 4200-SCS to a prober, designed to simplify the process of switching between DC I-V, C-V, and pulse testing configurations.

Availability: Version 7.2 of KTEI is available at no cost to existing Model 4200-SCS users. However, there is a charge to calibrate the upgraded 4210-CVU and to upgrade existing Model 4200-SCS systems to support nine instruments.

ACI-ecotec GmbH/Fraunhofer IPA

ACI-ecotec's new wet wafer separator automates step for higher throughput and reduced breakage

Product Briefing Outline: Together with the Fraunhofer IPA in Stuttgart, ACI-ecotec GmbH & Co. KG developed the ecoSplit, the first wet wafer separator, and has recently introduced the system's 3rd revision. The system is claimed to be an economical, fast and reliable solution for separating pre-cleaned, raw wet solar wafers from the wire saw for inline or batch processing.

Problem: Solar wafers from pre-cleaned wet wafer stacks direct from the wire saw need to be separated from the sawn stack for the subsequent cleaning process. The wafers are held together by fluid retention of wire saw coolant and waste silicon carbide, rendering them difficult to separate manually without a compromise of speed against breakage. The market cost per wafer is dropping; additionally, wafer thicknesses are getting smaller and breakages are increasing through manual wafer handling.

Solution: The ecoSplit is a separation system that offers a very short ROI and a low COO by providing a totally safe, proven, and fast mechanical method of separating wafers into process carriers for batch processing, or into 5-6 output lanes for inline processing. The patented singulator module offers a solution for both mono- and multicrystalline wafers and is user-configured for 125, 156 and 210mm wafers over a very short changeover time. A spraying system ensures wafers are kept wet throughout separation and during transportation through the system. There is also an automatic rejection lane for wafers that are out of the thickness tolerance, which enables continuous operation.

Applications: Raw wet wafer separation of pre-cleaned sawn wafer stacks.

Platform: The ecoSplit-C system uses a single modular singulator lane to directly load the ACI-ecotec ecoCarrier, or two singulator lanes to load 5-6 output tracks for the ecoSplit-I inline version.

Availability: Currently available on a 16 – 24 week lead-time from receipt of purchase order.

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Critical components and subsystems for the PV manufacturing industry

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ABSTRACT

Explosive growth in sales of critical subsystems and components for use in photovoltaic manufacturing equipment provided one of the few bright spots in an otherwise depressed market during 2008. The outlook for sales into the PV industry in 2009 is for demand to be relatively flat, but strong underlying demand for PV cells should lead to a recovery in 2010 and a return to double-digit growth rates, as outlined in this paper.

The critical subsystem market

Suppliers of critical subsystems and components to the semiconductor and related manufacturing industries have experienced a real rollercoaster ride in recent times. Growth of around 30% in 2006, followed by a flat year in 2007, then a drop of 22% in 2008 has got the industry right back to where it started in 2005 at a value of US$5.5 billion.

Considering that the market peaked at US$7.3 billion back in 2000, and sales will struggle to beat US$3.1 billion in 2009, this decade looks drastic in terms of market growth. However, behind the appalling numbers, there has been one area that has delivered consistently high growth rates to become one of the major market sectors. The photovoltaic cell manufacturing industry has emerged from its status as a niche market and has claimed its place in mainstream manufacturing.

The PV industry now accounts for over 11% of the total market for critical subsystems and components. With the PV industry set to outgrow the semiconductor and flat panel display industries over the next five years, the market for critical subsystems used in PV manufacturing equipment is expected to represent about 25% of the total market by 2014.

PV manufacturing equipment contains numerous parts, many of which are generic and can be used in a wide range of industries. Critical subsystems and components, however, are products that have been specifically designed to address applications within the semiconductor and related manufacturing industries, and to actively affect the processing and handling of substrates.

A well-defined group of companies has emerged to serve this market with products such as vacuum pumps, process power supplies, robots, fluid delivery systems, integrated process diagnostics and thermal control subsystems. One of the defining features of the critical subsystems industry is the level of dependency that equipment companies have on this group of suppliers to provide the products and technology that enable them to develop the next generation of process tools.

> "The PV industry now accounts for over 11% of the total market for critical subsystems and components."

The critical subsystem market for photovoltaic applications

In 2000, the photovoltaic industry was just one of many small and diverse markets being served by critical subsystems and components suppliers. At that time, the main industry sectors of semiconductor, flat panel display and data storage accounted for virtually all the demand for high-value, high-technology products. However, since then, the photovoltaic industry has come out of the background and sales of critical subsystems for PV applications, which totalled less than US$10 million in 2000, have grown to reach a value of almost US$600 million in 2008. These figures represent a compound annual growth rate of 66% and the expectation is that it will continue growing at double-digit growth rates after the 2009 hiatus.

Clearly, the photovoltaic industry is now on the radar screens of all suppliers eager to capture a piece of the action. Interestingly, the main beneficiaries to date are those companies that took decisive action during the last downturn in 2001 to 2002 to insulate themselves from the volatility that goes hand-in-hand with the semiconductor industry. The key players actively took steps to diversify into other industries, broaden their product portfolios, extend their global service and support networks and cut costs by manufacturing in low cost regions of the world.

This is proving to be a winning strategy as the companies that followed this path have been ideally placed to provide the photovoltaic industry with the products, technology and support while being able to handle rapidly-growing order volumes. Clear leaders in the field are Advanced Energy, Edwards and MKS Instruments, although they are finding increased competition from various quarters as late entrants fight for a piece of the market.

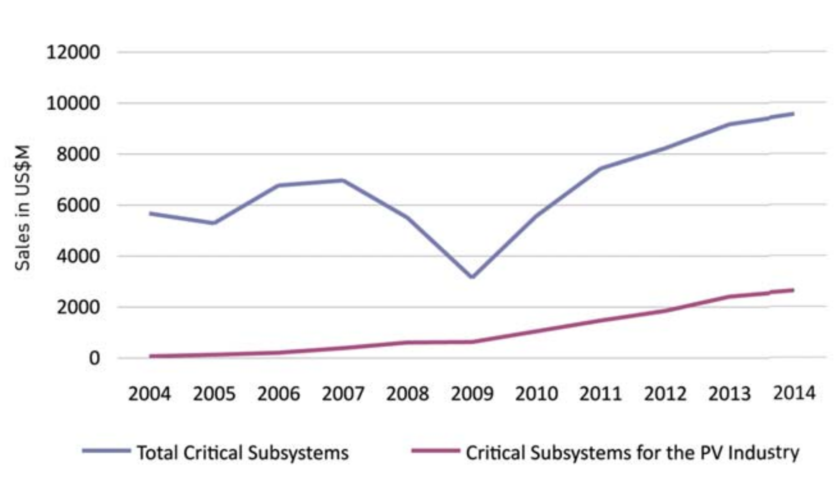

Figure 1. The critical subsystems market (photovoltaic) – projection to 2014.

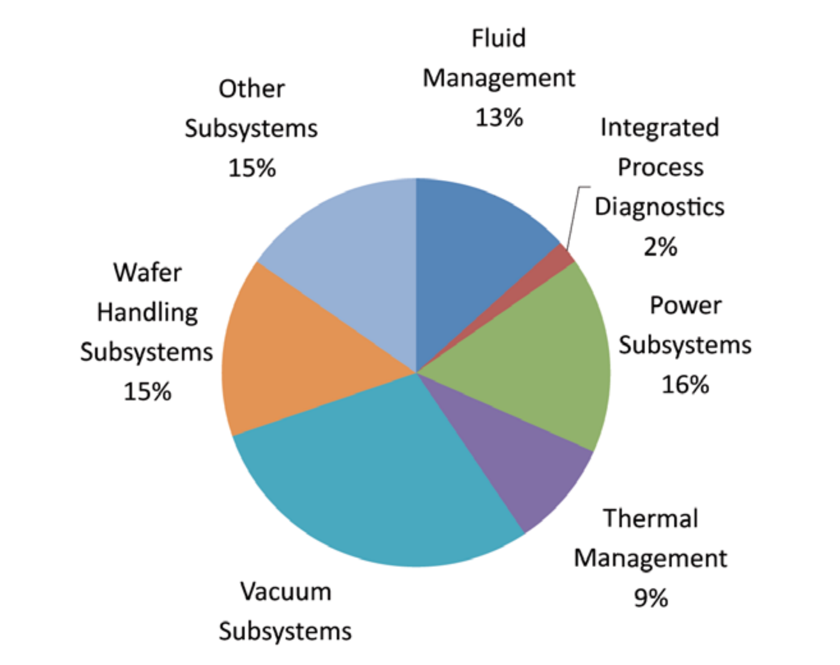

Figure 2. The critical subsystems market by subsystems technology (PV) in 2008.

The market for critical subsystems – breakdown by technology type

The main subsystems technologies used in PV cell manufacturing equipment are fluid management, integrated process diagnostics, process power, thermal management, vacuum subsystems, wafer handling and other subsystem technologies. Demand for critical subsystems used for PV applications grew 60% in 2008 to reach a value of just under US$600 million.

The largest segment is for vacuum subsystems, which includes vacuum pumps, pressure gauges, and abatement subsystems and represents 30% of the total for 2008 with a value of US$175 million. The next largest segment was for process power subsystems, including RF, DC and microwave power supplies, matching networks and fluorine gas generators, representing 16% of the market at US$97 million. Both these subsystems technologies have key roles to play in vacuum deposition tools, particularly for PV cells based on thin-film technology.

> "Demand for critical subsystems used for PV applications grew 60% in 2008 to reach a value of just under US$600 million."

As current forecasts indicate that demand for equipment used for silicon thin-film-on-glass cell technology will outgrow the market for other cell technologies, then the 46% combined share of the market held by vacuum and power subsystems today is expected to account for over half the subsystems market by 2014.

The PV equipment market

The first real challenge to the photovoltaic equipment industry is happening right now. Following several years of strong growth, a relatively flat year for suppliers of equipment to the PV solar industry in 2009 is starting to spell trouble for the

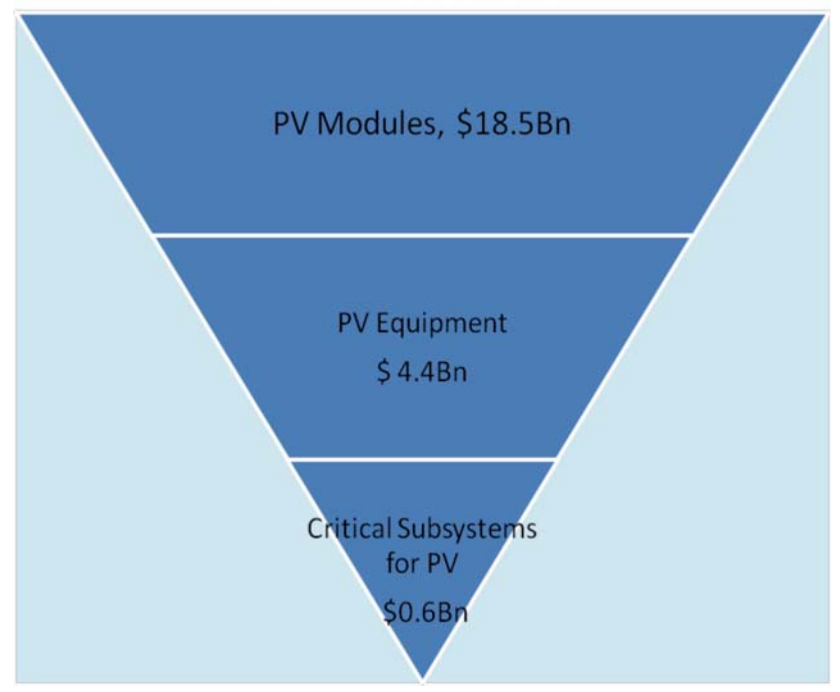

Figure 3. PV industry supply chain 2008.

smaller, less well-resourced equipment companies. In the current business climate, most companies would be delighted with flat sales, but, for an industry that has experienced such rapid growth in recent years, it is a serious problem. Those equipment suppliers basing their expansion plans on double-digit growth for 2009 have overshot the market and are now having to go through the painful process of resizing their businesses.

"Those equipment suppliers basing their expansion plans on double-digit growth for 2009 have overshot the market and are now having to go through the painful process of resizing their businesses."

This could be too much for some and, with over 250 equipment companies actively engaged in the market, we expect some fallout and consolidation. It is a telling fact that the publicly listed PV equipment companies delayed their earnings releases for the fourth quarter of 2008 and have been reluctant to give clear guidance for 2009. Order visibility has undoubtedly decreased, but a look at what is happening to the suppliers of critical subsystems and components used in PV equipment provides an insight into the size of the problem.

A recent survey of these companies revealed that subsystems and components orders for the PV industry for the first quarter of 2009 are likely to be down around 25% on the previous quarter. A significant portion of this decline can be attributed to the depletion of the supply chain through inventory consumption, but continued weakness in orders points to a negative quarter for equipment sales in Q2, and maybe also for Q3. Once cell demand starts to catch up with the installed production capacity, which should be in the second half of the year, we will start to see equipment sales recover.

Overall, equipment sales revenues are expected to grow around 6.7% in 2009, but these numbers are slightly skewed by the fact that long customer acceptance times mean a sizeable portion of revenues in 2009 will be for tools that were actually shipped in 2008. Although the number of PV manufacturing systems shipped in 2009 is expected to decline, sales of critical subsystems are still forecast to grow, albeit at a lower rate of 3.4%. This is due to the fact that supply chains will need to be replenished by the end of 2009 if the equipment suppliers are to fulfil their equipment orders at the beginning of 2010.

While the overall equipment market is flat, the picture on a company-by-company basis is different. Some of the larger companies are still expecting to outgrow the market at the expense of the smaller companies, and the longer this situation continues the greater the possibility that some of those smaller equipment companies will be shaken out of the industry. Unfortunately, it is the smaller equipment companies that are the ones most likely to be using smaller locally available critical subsystems suppliers that are trying to establish a position in the market.

Nevertheless, it is not all bad news for the smaller critical subsystems supplier as the current market adjustment that is currently underway is forcing the larger equipment suppliers to reassess their costs and look to lower cost alternatives. In particular, many are questioning whether they actually need such highly specified subsystems on PV cell manufacturing equipment.

The majority of critical subsystems are used in vacuum-based thin-film deposition equipment and etching and cleaning equipment. Most of this technology has its origins in the semiconductor industry and it is not surprising that many of the equipment suppliers are also from the semiconductor industry. For many suppliers, the equipment used in PV cell manufacture is actually based on the same platforms as that used for semiconductor or flat panel display manufacture; tools are often made to a similar specification with the same parts.

"Sales of equipment and subsystems are expected to pick up in the second half of 2009 as the financial markets start to free up."

While the PV industry has been growing so quickly, the focus has been on delivery and performance rather than the cost of subsystems. Now that demand has fallen away, the attention is firmly back on cost. In reviewing areas where costs can be reduced, it is clear that for some applications highly specified parts are not warranted and there is some scope for change. This opens the door for some of the smaller subsystems suppliers or suppliers with lower technology products to enter the market with lower value products that are no longer deemed to be critical to the process. The dilemma for equipment manufacturers, however, is that in taking this approach, it may be possible to reduce the purchase price of the tool, but the risk is that it may have a negative impact on the total cost of ownership of the tool.

For example, if the subsystem is less reliable, needs more frequent maintenance, or its use results in lower yields, then the initial cost savings could be counter-productive. The major critical subsystems vendors recognise this and are mounting a strong case for continued use of highly specified products on the grounds of cost of ownership. However, equipment companies are seriously considering this option, thereby presenting an opportunity for latecomers and new entrants to establish themselves in the market.

Conclusion

The photovoltaic equipment industry has undergone explosive growth in recent years to become a significant market that reached a value of US$4.4 billion in 2008. Suppliers of subsystems and components have been major beneficiaries as it has resulted in sales of almost US$600 million and helped to offset their reliance on the semiconductor and flat panel display industries.

Uncertainty in the financial markets is currently tempering the growth in all PV markets. End demand for PV cells has weakened, and reduced access to finance has caused PV cell and module manufacturers to pull back on their original expansion plans. This, in turn, is having an impact on the suppliers of critical subsystems and components, not just in terms of sales, but also from their customers looking to cut their material costs. This situation is expected to be temporary, as the underlying demand for PV cells, which is driven by continued government subsidy and the long-term need to reduce the reliance on fossil fuels, remains strong. Sales of equipment and subsystems are expected to pick up in the second half of 2009 as the financial markets start to free up.

One of the main difficulties in forecasting the demand for PV cells, and hence equipment and subsystems, is because actual sales still depend heavily on subsidies and will continue to do so at least until the industry is able to supply PV cells that can compete directly with other sources of electricity. Predicting the level of subsidy or the point at which parity between solar and grid electricity are reached with a high level of confidence is not possible. But based on current government commitments to transition more of their electricity supply to renewable sources, the PV equipment and subsystems industries are likely to grow at a compound annual growth rate in the region of 30% over the next five years.

While this is a very attractive market, it should be remembered that virtually all of the demand is for additional capacity and there are very few purchases that are being made to replace obsolete equipment. This means that, unless there is a major step change in manufacturing technology, the equipment that is being installed today is still likely to be producing PV cells long into the future. The implication of this is that at some point, currently beyond our forecast horizon, the market will eventually mature and turn into a replacement market. Also, if there are limited developments in manufacturing technology then there will be reduced scope for the development of new subsystems, which may result in the commoditisation of subsystems where cost rather than technology becomes the focus. This contrasts to the semiconductor industry, where continued technology transitions ensure that whole swathes of equipment become obsolete and are retired each year and that new subsystems have to be continually developed to enable the new manufacturing technologies.

For now, at least, the PV industry is proving to be a major driver of new business for critical subsystems and components suppliers and, for many ,is proving to be a real lifesaver during difficult times.

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Challenges in producing photovoltaic modules on thin wafers

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ABSTRACT

The principal paths to cost reduction for the photovoltaics industry are increasing the efficiency of solar cells and the power density of modules, together with the reduction of the specific consumption of silicon. Following the slowdown in the ever-increasing growth of the PV market earlier this year, and the reduction in the market cost of polysilicon, wafer producers and most cell producers moved back to the 180µm generation substrates. It may take some time for manufacturers to tackle the technological issues that need to be addressed in order to successfully decrease wafer thickness further. In this article, some of the issues related to the production of thinner and thinner cells are outlined and discussed.

Cell and module efficiency directly impact the overall €/Wp cost of a PV module and have historically been a major focus for technological development. Commercial module efficiency values (defining efficiency on the basis of the total outer dimensions) are in the range of 12-14% for screen-printed cells and 15-17.5% for the best-performing cells. Device designs capable of achieving module efficiencies of over 18% for multicrystalline silicon, and over 20% for monocrystalline silicon, are expected at a production scale in the short to medium term. Calculated efficiency limits as a function of substrate thickness indicate an optimum in the 40-100µm range on both n- and p-type wafers for resistivities >1Ωcm [1,2].

Purified silicon (polysilicon) is the basic ingredient of crystalline silicon modules and also forms an important part of the overall module cost. For the past few years, the availability of polysilicon feedstock has been a critical issue for the rapidly growing PV industry. The tight supply has caused very high polysilicon spot market prices and has limited production expansion for part of the industry. On the other hand, it has triggered rapid innovation in wafer production and cell manufacturing with a reduction of cell thickness of 45-52% from 330µm down to 160µm over a period of five years, despite increasing handling and processing problems. During the same timeframe, the typical wafer area grew by 140%. As a result, the silicon consumption per Wp of module power produced is significantly reduced. Silicon usage is currently 8-9g/Wp; a figure that was typically 13g/Wp just a few years ago. Given a feedstock cost in the range of 30-50 €/kg, this corresponds to 24-50€c/Wp – roughly half the often-cited target cost of ~1€/Wp.

As some lead cell manufacturers moved down in thickness to 160µm x 156mm x 156mm, the reduced amount of silicon used was offset by the losses in yield – both during the cell as well as the module manufacturing. Wafer producers and most cell producers moved back to the 180µm generation substrates in response to this.

Processing large-area thin cells

Achieving thinner wafers

The ratio of the amount of high quality silicon required to make a module versus its nominal power (g/Wp) is the direct related economical parameter affected by processing thinner wafers. While using advanced, highly automated wire-saw-related processing techniques should allow production of very thin wafers with high yield, it is near impossible to limit the total amount of silicon consumption to values below 100µm.

> "While in R&D environments very thin wafers (80-120µm) have been produced, the minimum thickness in the established industrial ribbon technologies is not less than 150µm."

The additional silicon loss linked to the kerf made by the wire and slurry can be avoided if the wafers are casted to thickness as is done in ribbon technologies such as Edge-defined Film Growth (EFG, Wacker-Schott); Crystallisation on Dipped Susbstrate (CDS, Sharp); String Ribbon (SR, Evergreen); Ribbon Growth on Substrate (RGS, ECN); or Ribbon on Sacrificial Template (RST, Solarforce). Such wafers are multicrystalline but can be of good quality as demonstrated by the high efficiencies reached on large areas using industrial processes by, for example, Sharp (14.8% on CDS [3]) and IMEC (16.0% on EFG [4]).

Furthermore, these technologies have a very high throughput potential, although this is mostly leveraged by losses in material quality. While in R&D environments very thin wafers (80-120µm) have been produced, the minimum thickness in the established industrial ribbon technologies is not less than 150µm.

Layer-transfer approaches form an alternate class of technologies to achieve very thin wafers. The cost of ownership of processes based on growing a thick epitaxial layer of silicon on top of a 'weakened' intermediate layer followed by detaching such as the PSI-process [5] or creating voids [6] is threatened by the additional cost linked to preparing the weak layer and the epitaxy process. Alternatives such as the PolyMax technology developed by Silicon Genesis, or the Stress-induced LIft-off Method (SLIM-Cut) developed at IMEC [7] (see Figure 1) aim at repeatedly releasing a very thin layer of silicon from a carrier with minimal losses. This is performed either by creating a sub-surface weak layer by implantation or by inducing stresses beyond the shear stress of silicon, exploiting the difference in thermal expansion between the carrier wafer and a deposited stress-inducing layer.

The most decisive advantage of the latter technique is that the crack depth (and therefore the final thickness of the silicon film) is governed by the mechanical properties of the materials used and does not rely on pre-processing of a weak layer. Another advantage of this method is that it was developed using only industrial tools (screen-printers, belt furnaces). The potential for low cost is therefore present from the beginning of the development. In addition, the first results obtained (10cm^2 free-standing films; cell efficiency of 10% obtained on a 1cm^2 cell) are extremely promising given that no tool was designed to tackle the specific issues related to the method. An advantage inherent to the layer transfer approaches is that the thin silicon films can be monocrystalline as well as multicrystalline, allowing for higher efficiencies on higher quality samples.

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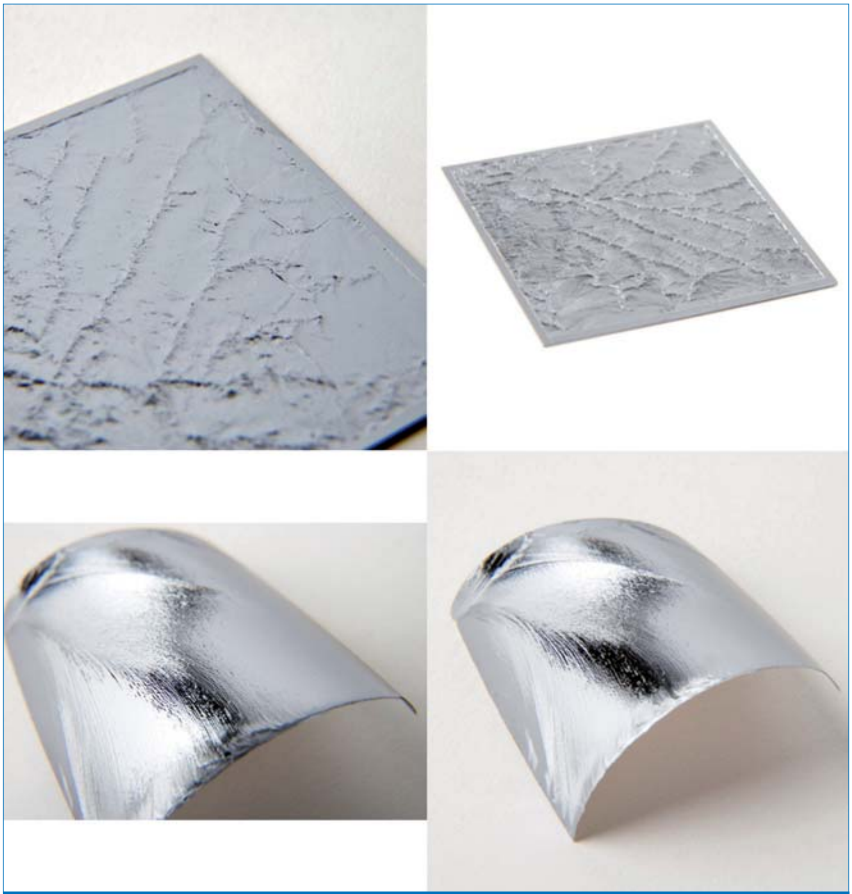

Figure 1. 'Stress-induced lift-off method' (SLIM-Cut) process. A high thermal stress is induced by a metallization layer, resulting in the release of a 50µm Si foil. The top row shows the remaining substrate and the bottom row, the thin lifted-off silicon layer.

Reaching high efficiencies

The thinner the substrates are manufactured, the higher the relevance of the recombination at the rear surface and optical enhancement on the performance of the solar cell. Whereas the bending of thin substrates under the influence of a traditional full aluminium back surface field (BSF) could be remedied by a dedicated cooling treatment after firing, the limited electrical surface passivation offered by such alloyed BSF will require giving up this established technology and a move to a dielectric passivated and locally-contacted rear surface, as was introduced in the Passivated Emitter and Rear Cell (PERC) structure. Usually, such dielectric passivation of the rear of the cell can be offered through deposition of commonly used dielectrics in photovoltaics such as SiN_x or SiO_x, or combinations of these.

Alternatively, technologies new to the photovoltaic industry such as Atomic Layer Deposition (ALD) of negatively charged dielectrics (e.g. AlO_x) are being explored. The local contacting can be done either by first locally opening the dielectric, depositing the base contact (typically aluminium) on the rear and firing (iPERC, IMEC [4]), or by depositing the base contact on the dielectric and locally firing it through by means of laser (Laser-Fired Contacts, LFC, FhG-ISE, [8]).

Using the iPERC technology, large-area cell efficiencies of 17.6% were demonstrated on 130µm-thin monocrystalline substrates and 16.8% on 120µm-thin multicrystalline. An additional benefit of such dielectric passivation is the excellent mirror extending over the vast majority of the rear surface increasing the light-trapping properties within the solar cells.

As the iPERC and LFC processes are finding their way to the market, R&D efforts are shifting to the next generation in order to further push up the efficiencies. The structural difference between a PERC cell with self-aligned but high recombinative rear contacts and a Local Back Surface Field (LBSF) or Passivated Emitter and Rear Locally diffused (PERL) cell is marginal. However, achieving the reduced recombination at the rear contacts due to a diffused high-low junction beneath the contacts requires significant process changes. With such PERL structures, the 20% barrier for thin large-area industrial cells will be overcome.

Although major efforts are ongoing in reducing the metallization coverage for double-side-contacted cells, part of the surface will be covered by fingers while ~2% of the surface will be covered by the cupper ribbon that provides the series interconnection with the neighbouring cell. Part of this loss can be avoided by having the solder pads to the contact grids of both polarities available at the rear surface [9]. This potential for performance increase has triggered the early developments of back-contacted cells. On the other hand, the drawback of the technology is that an adapted module manufacturing is required. To date, the most successful market penetration of back-contact cell technologies is by companies that sell the integrated product (cell & module).

In such very thin double-side- as well as single-side-contacted cells, the other challenge is to maintain strong absorption of IR photons. This requires ever-better light-trapping schemes. The prevailing approaches based on front-side texturing in combination with some sort of highly reflective back surface may be extended to reach efficiencies over 20%, but eventually more complex concepts such as multilayer interferometric reflectors, or the embedding of metal particles to introduce plasmonic effects, may be necessary.

Maintaining process yield

Added to this problem of fragility, thin wafers also become increasingly flexible. As a result, the combination of thin, large-area and square wafers is posing processing problems in terms of handling, batch-type wet chemical processing, and processing at elevated temperatures. The thin wafers are delicate and notoriously difficult to handle without inducing damage in the form of chipping and cracking. Handling issues begin when the wafers need to be separated at the entrance of the production line. Once wafers start moving through the production process, the emphasis is on transporting them smoothly with no jarring or shaking.

The high production volumes in photovoltaic manufacturing demand gripping methods for wafers that can keep hold of wafers through the high rates of acceleration and deceleration. In batch-type wet chemical processing, the wafers stick to each other in the cassette and can rarely be released without yield losses. As such, the use of in-line wet processing tools or switching to dry processing is recommended.

These methods provide further benefits via their property of addressing only a single surface of the cell, thus allowing easier decoupling of surface treatments between the front and rear surface. In processes where wafers are (even moderately) heated, such as diffusion, Chemical Vapour Deposition (CVD) processes or Physical Vapour Deposition (PVD), the wafers curl from the corners up under the influence of the thermal gradients induced by shape. As a result, an increased level of automation will be required.

This increased automation will also be required in R&D environments where

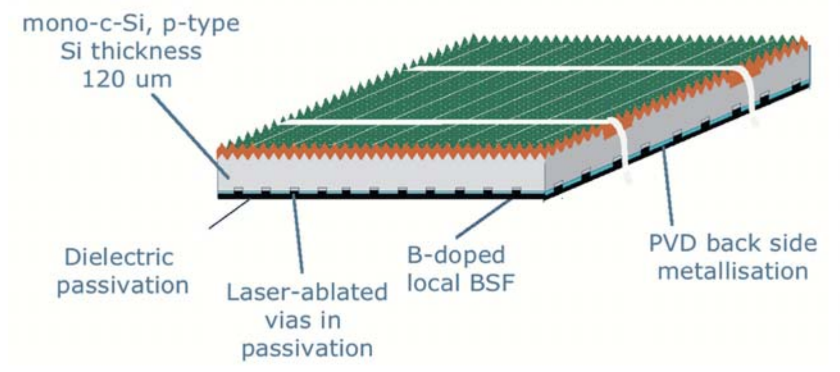

Figure 2. PERL cell with back-side passivation improved by a B-doped Back Surface Field.

handling has often been performed manually. This will significantly increase the cost of R&D operations. Additionally, the importance of in-line processing, supporting the wafers over one of the surfaces and incorporating soft clamping mechanisms near the edges is expected to grow.

Module manufacturing

Pursuant to cell production in the value chain is the manufacturing of the laminate or module, which will be sold under a 20-25 year warranty liability that tends to freeze any developments. The enthusiasm on the part of module manufacturers to change to the proven technology of interconnecting the cells by soldering and handling of full strings or even cell meshes in building up the laminate is low and major changes are not expected as long as they are not needed.

The acceptance of future thin cell offerings by module producers will need to go hand-in-hand with significant cost savings to offset the increased risk in introducing new technologies. These cells are expected to be very thin and fragile, highly efficient and capable of delivering high currents, dictating the use of higher cross-sections of the applied interconnectors. The cell thickness will eventually be less than the thickness of the cupper ribbons soldered to the front and the rear of the device, which will induce tremendous stresses in the interconnected cells.

As for cell processing, high levels of automation with minimal impact on the wafers will be required. Additionally, reducing the effective overall soldering temperature by using advanced soldering methods such as local laser soldering, low temperature solders, or eventually using conductive adhesives will become more common. Another alternative to soldering front to rear is the use of back-contacted cells where, through well-considered co-development of cell and module technologies, much wider and thus thinner interconnects could be used, helping in reducing the mechanical stress induced by the interconnection process.

Conclusions

The speedy reduction of wafer and cell thickness has currently been slowed down by a combination of reduced need as the silicon feedstock became cheaper as a result of increasing processing issues. The need to further significantly reduce the cost of photovoltaic modules in order to achieve grid parity, combined with the potential for higher efficiencies in thinner cells, will eventually lead to further reduction of the cell thickness.

The present calm on the market offers wafer, cell and module producers the time to address the upcoming technical challenges in producing thin wafers and achieving high cell efficiencies on these wafers while maintaining production yield in processing both the cells and the modules, which will give them a strategic lead to tackle the pressure on price. In order to exploit the full potential of the introduction of thin and eventually back-contacted cells, integrated companies or strategic partnerships (cell & module) where concerns from both parties can openly be discussed will have a definitive advantage.

References

[1] Kerr, M. J. et al 2002, 'Lifetime and Efficiency Limits Of Crystalline Silicon Solar Cells', *Proc. 29th IEEE PVSC*, New Orleans, USA.

[2] Hayashi, Y. et al 1987, 'Experimental fabrication of thin film single crystalline Solar Cells', *Bulletin of the Electrotechnical Laboratory*, Vol. 51, No. 5&6, pp. 38-40 (Japanese text).

[3] Takakura, T. et al 2008, 'Effect of Rapid Thermal Process for CDS Silicon Solar Cell', *Proc. 23rd EUPVSEC*, Valencia, Spain.

[4] Choulat, P. et al 2008, 'High Efficiency Industrial Type PERC Solar Cell on Very Thin EFG Substrates', *Proc. 23rd EUPVSEC*, Valencia, Spain.

[5] Brendel, R. 2004, 'Thin-Film Crystalline Silicon Mini-Modules Using Porous Si for Layer Transfer', *Solar Energy*, Volume 77, Issue 6, pp. 969-982.

[6] Depauw, V. et al 2007, 'Anodisation of Branched and Columnar macropores in n-type silicon under front side Illumination', *Phys. Sta. Sol.* (c), Vol. 4, Issue 6, pp. 1928-1932.

[7] Dross, F. et al 2008, 'SLIM-Cut: A Kerf-Loss-Free Method for Wafering 50-μm-Thick Crystalline Wafers Based On Stress-Induced Lift-Off', *Proc. 23rd EUPVSEC*, Valencia, Spain.

[8] Schneiderlöchner, E. et al 2002, 'Laser-fired Rear Contacts for Crystalline Silicon Solar Cells', *Progress in Photovoltaics: Research and Applications*, Vol. 10, Issue 1, pp. 29-34.

[9] Van Kerschaver, E. et al 2006, 'Back-contact Solar Cells: A Review', *Progress in Photovoltaics: Research And Applications*, Vol. 14, pp. 107-123.

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PECVD a-Si layers for industrial high-efficiency solar cell processing

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ABSTRACT

Amorphous silicon is one of the most effective materials in passivating silicon interfaces. At Fraunhofer ISE, highly passivating amorphous silicon coatings were developed by an industrially applicable Plasma-Enhanced Chemical Vapour Deposition (PECVD) process. Thin-film stacks of amorphous silicon and SiO_x display excellent passivation quality, indicated by effective charge carrier lifetimes ranging from 900 to 1600µs and resulting surface recombination velocities between 9 and 3cm/s^{-1}. The demonstrated temperature stability opens up new application opportunities also for amorphous silicon films in the industrial production of highly efficient solar cell structures, which will be further discussed in this paper.

Introduction

All cell structures that have shown efficiencies greater than 20% feature an efficient surface passivation with thin, mostly dielectric layers. However, the present state-of-the-art rear surface structure of industrial silicon solar cells is a screen-printed and thermally-fired Al back surface field (Al-BSF), which has two major restrictions: (i) the wafer bow due to mechanical stress, and (ii) the lower electrical and optical properties. A common measure for the quality of a surface is represented by the so-called 'surface recombination velocity' (SRV). The term 'surface recombination' describes the recombination processes taking place at the semiconductor surface. Here, the crystal lattice is abruptly disconnected, leading to a large amount of dangling bonds. These disturbances of the lattice create energy levels that are partly located within the band gap in between the conduction and the valence band (see Figure 1). The surface recombination velocity (SRV) S is defined as:

$$S = \frac{U_s}{\Delta n},$$

with U_s as surface recombination rate and Δn as excess carrier density. The larger the SRV, the quicker the charge carriers recombine at the surface.

When a dielectric layer is deposited on top of the surface, additional so-called 'band bending' typically occurs. The band bending is due to the difference in the Fermi level in the substrate and the layer as well as the fixed charges within that layer. The effective SRV S_{eff} accounts for the band bending effect by virtually shifting the surface into the wafer bulk to the location where the band bending starts, as outlined below:

$$S_{eff} = \frac{U_s}{\Delta n(x = d)}$$

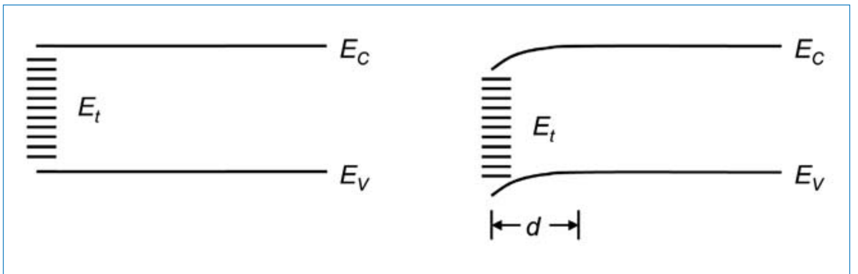

Figure 1. Defect (trap) energy levels within the band gap at the wafer surface (left picture: without band bending; right picture: with band bending).

There are two different mechanisms that lead to good surface passivation [1]: (i) the reduction of interface states D_{it}, and (ii) field effect passivation – that is, the strong reduction of one carrier type by incorporation of fixed charges Q_f in the passivation layer. Although these mechanisms or the combination of both lead to low surface recombination velocities, the resulting $S_{eff}(\Delta n)$ curve shows different characteristics. The reduction of interface states is more effectively reached for thermally grown SiO_2 layers, while the field-effect passivation together with a moderate reduction of D_{it} is more

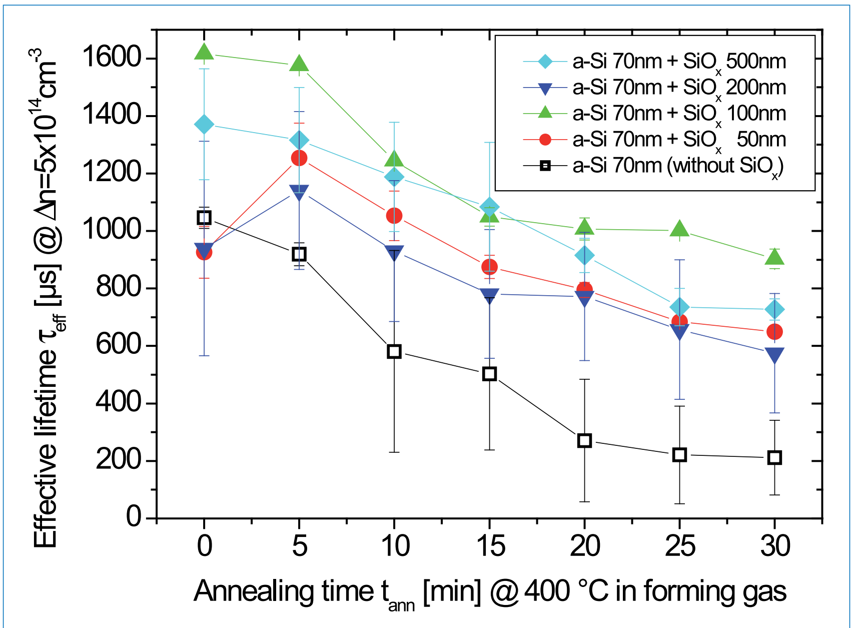

Figure 2. Carrier lifetimes of symmetric (SiO_x/) a-Si/c-Si/a-Si (/SiO_x) samples after stepwise annealing. a-Si + SiO_x systems show best stability [16].

typical for PECVD deposited layers like SiN_x. Typical values for SiO_2 are Δ_{it} = $10^{10}cm^{-2}eV^{-1}$ and $Q_f = 10^{10}cm^{-2}$, while for SiN_x, values are D_{it} = $10^{11}cm^{-2}eV^{-1}$ and Q_f = $10^{11}cm^{-2}$.

> "Since the inversion layer is a crucial part of the surface passivation mechanism of SiN_x layers, the apparent quality of SiN_x layers on lifetime test wafers 'vanishes' when applied to real cells."

Although it seems possible to design a perfect layer or layer system simply by performing lifetime and optical measurements, a final decision has to be made by applying these layers to solar cells. SiN_x passivation is an example of how good surface passivation quality is only a necessary but not a sufficient condition. Although single SiN_x layers show the very best surface passivation quality on lifetime test wafers – even better than thermal oxidation – none has so far managed to fabricate a cell with efficiencies attainable by those featuring the 'classical' thermal oxidation. In particular, the short-circuit current is significantly lower. This reduction was explained by Dauwe et al [2] via the short-circuiting of the inversion layer induced by the fixed charges in the SiN_x layer at the rear contact points. Since the inversion layer is a crucial part of the surface passivation mechanism of SiN_x layers, the apparent quality of SiN_x layers on lifetime test wafers 'vanishes' when applied to real cells. This problem can be solved in two ways:

- the application of a dielectric stack system consisting of a thin silicon oxide below the SiN_x layer. This oxide layer can even be deposited by PECVD (excellent surface passivation quality has been reported [3-6]).
- by the application of amorphous silicon as a passivation layer. For the HIT cell structure, it was a natural choice to use amorphous silicon as the rear surface passivation since the emitter is also formed by this layer type. This type of passivation is also applied on standard

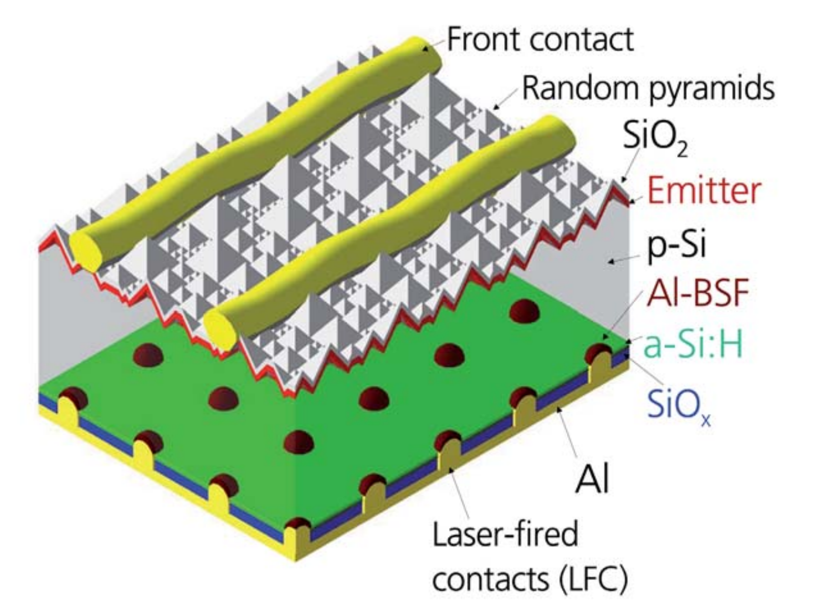

Figure 3. Schematic of fabricated solar cells. The rear surface passivation was created using a stack of PECVD a-Si:H and PECVD a-SiO_x:H.

silicon solar cells achieving excellent cell results [7] reaching efficiencies up to 21.7% (V_{oc} = 677mV) [8].

The following section will focus on explaining the latter approach in particular in more detail.

Amorphous silicon

Lifetime investigation

Hydrogenated amorphous silicon (a-Si:H) layers have been in use for many years within the photovoltaic community. Thin-film solar cells deposited on glass substrates or deposited amorphous emitters on crystalline silicon wafers as found in the HIT (heterojunction with intrinsic thin layer) structure [9] can be found in industrial production. For passivation of crystalline silicon wafer surfaces, it has been shown that a Si:H layers can provide an extremely effective means to enhance the minority carrier lifetime [10-13]. However, one typical characteristic of a Si:H layers is their relatively low thermal stability, which limits the applicability of a Si:H passivation in industrial production lines. The incorporation of an additional PECVD a SiO_x:H layer on top of the a Si:H leads to an improved thermal stability of the passivation quality of a Si:H at a c Si surface. Initially (as-deposited), all samples (Float Zone silicon wafers of 1Ωcm, p-type (Boron-doped), 250µm-thick, shiny etched surfaces, both sides covered with a Si:H) showed an excellent surface passivation with lifetimes in the range of 900µs to 1600µs. As the maximum bulk lifetime of these samples can be calculated to 2300µs when only Auger recombination is assumed (using the Auger model by Glunz and Rein [14]), the surfaces must be at a very well passivated state. Surface recombination velocities in the

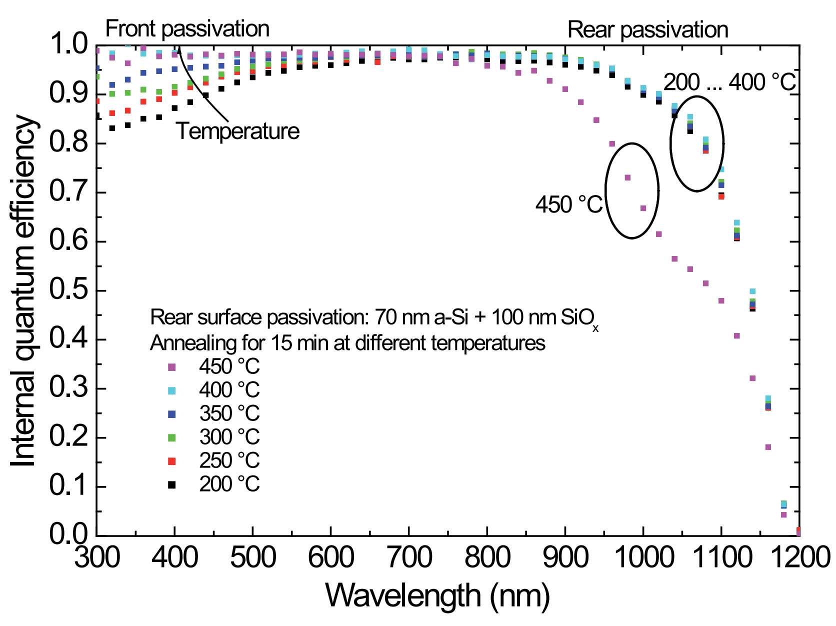

Figure 4. Internal quantum efficiency of solar cells annealed at different temperatures vs. the wavelength of light. An increase in front passivation (thermally-grown SiO_2) at short wavelengths with annealing temperature was found. The rear passivation (a-Si + SiO_x) is stable until 400°C but decreases strongly at 450°C [8].

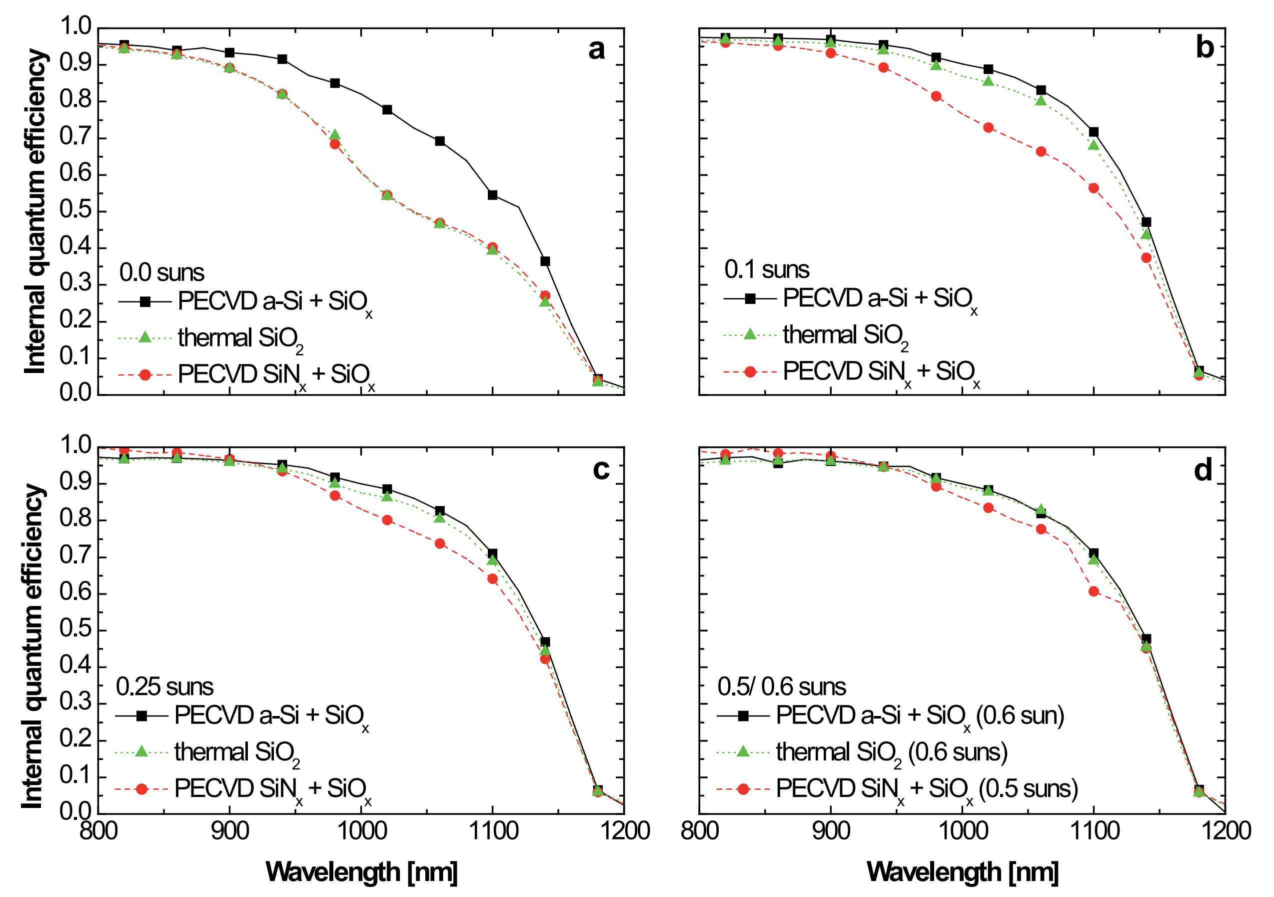

Figure 5. Comparison of bias light-dependent IQE measurements in the long wavelength regime of solar cells with (i) a-Si:H + a-SiO_x:H passivation, (ii) thermally-grown SiO_2 passivation, and (iii) a-SiN_x:H + a-SiO_x:H passivation on the rear [16].

range of 9cm/s to 3cm/s can be calculated using the equation of Nagel et al [15]. No significant difference between the single-layer a-Si and the double-layer a-Si + SiO_x was observed. After annealing for 5 minutes in forming gas at 400°C, most lifetime results were quite stable. (One exception: the samples with lifetimes of approx. 900µs in the as-deposited state (samples with SiO_x thickness of 50nm and 200nm) improved significantly to between 1100µs and 1300µs. The samples with single-layer a-Si passivation degraded slightly to approx. 900µs.)

All lifetime values degraded with increasing annealing time. A stronger degradation could be found for the single layer a-Si passivated sample. After 30 minutes, an approximate lifetime of 200µs could be measured. The stack layer samples (a-Si + SiO_x) generally showed a better thermal stability compared to the single layer (a-Si) samples. No clear dependence could be found for the thickness of the SiO_x layer in the investigated thickness range.

Solar cell application

In order to show the capability of a-Si layers as a rear surface passivation layer, high-efficiency solar cells were fabricated. The cells exhibit evaporated TiPdAg front contacts, a thermally oxidised anti-reflection coating that also serves as the front passivation layer, a 120Ω/sq n-type emitter, a 0.5W/cm p-type bulk, PECVD-a-Si and -SiO_x, an evaporated Al layer at the back and laser-fired contacts that led to a local Al-BSF underneath the point contacts (see Figure 3).

> "The stack layer samples (a-Si + SiO_x) generally showed a better thermal stability compared to the single layer (a-Si) samples."

The a-Si (~70nm) and SiO_x (~100nm) layers used are the same as were investigated in the lifetime experiment. After finishing the cells, the I-V characteristics were measured. Subsequently, the cells were annealed at different temperatures in forming gas for 15 minutes (excluding 10 minutes of ramping up the temperature) to find the optimum annealing temperature for front and rear passivation and for the local laser-fired rear contacts. The challenge was to find a temperature that would increase the front passivation and the rear contacts without harming the rear passivation. The I-V-characteristics of the cells were then re-measured.

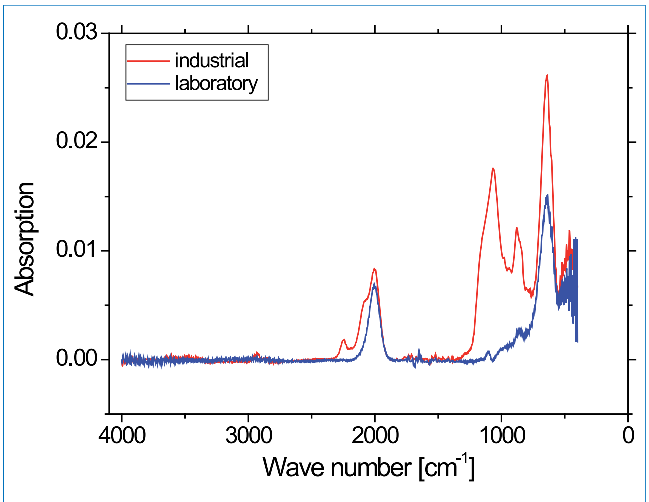

Figure 6. FTIR spectra of amorphous silicon layers deposited in a laboratory-type (blue) and an industrial-type PECVD (red) reactor [16].

Cell Processing

The solar cell parameters show a strong dependence on the annealing temperature; efficiency increases steadily for annealing temperatures from 200°C to 400°C with values of 20.0% to 21.7% with a strong decrease at temperatures above 450°C.

The question that arises here is: which physical effect drives the efficiency to these values? Internal quantum efficiency (IQE) measurements give insight into the answer to this question and are depicted in Figure 4. The cells were annealed at temperatures between 200°C and 450°C in steps of 50°C. A short wavelength regime was found in the range of 300nm to around 550nm affecting the solar cell's front surfac. The observed increase in quantum efficiency with higher annealing temperatures to about the same results at temperatures of 400°C and 450°C is attributed to the annealing of the front surface passivation, performed by thermal oxidation. Thus, the well-known oxide annealing effect has been described. The quality of the solar cell's bulk and rear surface can be derived from the IQE at long wavelengths around 900nm to 1200nm, where very high values can be found. Hence, the quality of the bulk and the rear surface seems very satisfactory.

For annealing temperatures of 200°C to 400°C the passivation properties of the rear surface is almost stable, with only the possibility of a slight improvement with higher applied temperatures. When the temperature is increased further to 450°C, the performance of the solar cell's back deteriorates compared to that recorded using lower temperatures. This effect fits in the observation of an overall decreased cell performance of the 450°C annealed cells at the I-V measurements. We attribute this effect to the de-passivation of the solar cell's back.

Hydrogenated amorphous silicon is known for its relatively low thermal stability. The observed de-passivation is most likely due to the cracking of hydrogen bonds at the c-Si a-Si interface, which are suspected to be important for the passivation effect. This leaves silicon dangling bonds and Shockley-Read-Hall (SRH) active recombination centres at the interface.

We found that the quantum efficiency behaviour of cells with a Si:H rear passivation did not change for bias light intensities of 0.1 to 0.6 suns. Therefore, a very stable rear passivation has been achieved that also provides excellent passivation at low light intensities. At 0.0 suns bias intensity the cell's rear showed slightly lower IQE values in the long wavelength regime. Hence, the rear passivation is significantly lower but still on a decent level. When the bias light dependence is compared to thermal SiO_2 or PECVD a SiN_x:H (very Si-rich), we found that the a-Si:H passivation is the most stable (see Figure 5).

Transfer to industrial deposition equipment

The deposition of high-quality passivating amorphous silicon in a small laboratory-type direct plasma PECVD reactor has been proved by Hofmann et al in 2004. For implementation of the a-Si passivation process, it is necessary to transfer the deposition process to high-throughput equipment. In our investigation, an SiNA machine from Roth&Rau was used, a PECVD tool that exhibits plasma excitation by microwaves that are introduced into the reactor by linear antennas.

> "The minority carrier lifetimes were measured with the QSSPC technique leading to lifetimes up to >1ms (S_{eff} < 10cm/s)."

Usually, the topic that generates most interest in this regard is the surface passivation quality of a-Si layers deposited with the industrial PECVD tool. High-quality silicon wafers with the following characteristics were used: float zone, p-type, boron-doped, 1Ωcm, 250µm-thick, shiny etched surfaces. After cleaning the surfaces in a wet chemical RCA bath sequence, amorphous silicon was deposited sequentially on both surfaces. Next, the minority carrier lifetimes were measured with the QSSPC technique leading to lifetimes up to >1ms (S_{eff} < 10cm/s).

Fourier transformed infrared spectroscopy (FTIR) offers a means to characterise the composition of thin layers. In this case, a comparison between an a-Si layer deposited in our laboratory-type and our industrial-type PECVD reactor was performed, the results of which are shown in the graph in Figure 6.

The thickness of the layers is approximately the same (lab: 70nm, industrial: 85nm), which means that the peak heights can be directly compared. The absorption peaks at 2000cm^{-1} are attributed to Si-H bonds. Hence, the Si-H bond density in both layers is approximately in the same order of magnitude.

In the wave number range of 1000cm^{-1} the absorption peaks correspond to Si-O and Si-N bonds. It seems clear that the a-Si layer deposited in the industrial-type PECVD reactor is contaminated with nitrogen and oxygen in a stronger way than the reference a-Si layer. Nevertheless, this does not lower the surface passivation properties significantly.

Conclusion

Stacks of amorphous silicon and silicon oxide – both deposited applying a PECVD system – are successfully used for passivating crystalline silicon wafers, leading to surface recombination velocities below 6cm/s. These stacks were used to passivate crystalline silicon solar cells' rear surfaces and led to a maximum cell efficiency of 21.7% on p-type (Boron-doped) float zone silicon substrates with a thickness of 250µm.

I-V and IQE measurements lead us to the conclusion that the rear surface passivation (a-Si + SiO_x) was stable until a temperature of 400°C was reached. Bias light-sensitive IQE measurements showed very stable passivation properties of the a-Si:H/ a SiO_x:H stack at low injection levels. Excellent surface passivation could be reported for a-Si layers deposited in an industrial-type inline PECVD reactor. These a-Si layers exhibit an increased absorption in FTIR measurements, which can be attributed to N and O contamination.

References

[1] Aberle, A.G. 1999, 'Crystalline silicon solar cells: advanced surface passivation and analysis of crystalline silicon solar cells,' Sydney, Australia.

[2] Dauwe, S., Mittelstädt, L., Metz, A. & Hezel, R. 2002, *Progress in Photovoltaics: Research and Applications*, Vol. 10, p. 271.

[3] Agostinelli, G., Choulat, P., Dekkers, H.F.W., Vermariën, E. & Beaucarne, G. 2006, *Proceedings of the 4th World Conference on Photovoltaic Energy Conversion*, Waikoloa, Hawaii, USA, p. 1004.

[4] Hoex, B., Peeters, F.J.J., Creatore, M., Blauw, M.A., Kessels, W.M.M. & van de Sanden, M.C.M. 2006, *Journal of Vacuum Science and Technology*, A 24, p. 1823.

[5] Hofmann, M., Kambor, S., Schmidt, C., Grambole, D., Rentsch, J., Glunz, S.W. & Preu, R. 2007, *Proceedings of the 22nd European Photovoltaic Solar Energy Conference*, Milan, Italy, p. 1030.

[6] Seiffe, J., Weiss, L., Hofmann, M., Gautero, L. & Rentsch, J. 2008, *Proceedings of the 23rd European Photovoltaic Solar Energy Conference and Exhibition*, Valencia, Spain, p. 1700.

[7] Dauwe, S., Mittelstädt, L., Metz, A., Schmidt, J. & Hezel, R. 2003, Proceedings of the 3rd *World Conference on Photovoltaic Energy Conversion*, Osaka, Japan, p. 1395.

[8] Hofmann, M., Glunz, S., Preu, R. & Willeke, G. 2006, *Proceedings of the 21st European Photovoltaic Solar Energy Conference*, Dresden, Germany, p. 609.

[9] Tsunomura, Y., Yoshimine, Y., Taguchi, M., Baba, T., Kinoshita, T., Kanno, H., Sakata, H., Maruyama, E. & Tanaka, M. 2009, *Solar Energy Materials and Solar Cells*, Vol. 93, p. 670.

[10] Schaper, M., Schmidt, J., Plagwitz, H. & Brendel, R. 2005, *Progress in Photovoltaics: Research and Applications*, Vol. 13, p. 381.

[11] Dauwe, S. 2004, Ph.D. thesis, University of Hannover, Hannover.

[12] de Wolf, S. 2005, Ph.D. thesis, Catholic University of Leuven, Leuven, Belgium.

[13] Gatz, S., Plagwitz, H., Altermatt, P., Terheiden, B. & Brendel, R. 2008, *Applied Physics Letters*, Vol. 98, p. 173502.

[14] Glunz, S.W., Biro, D., Rein, S. & Warta, W. 1999, *Journal of Applied Physics*, Vol. 86, p. 683.

[15] Nagel, H., Berge, C. & Aberle, A.G. 1999, *Journal of Applied Physics*, Vol. 86, p. 6218.

[16] Hofmann, M. 2008, Ph.D. thesis, University of Konstanz, Konstanz.

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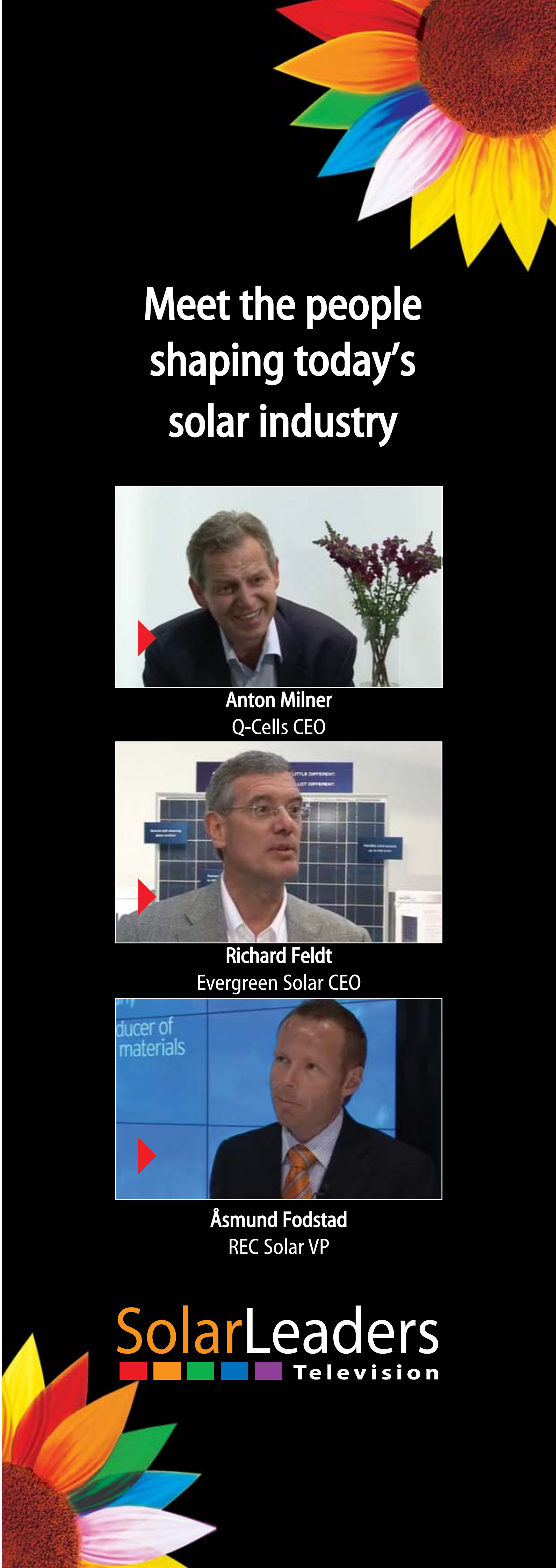
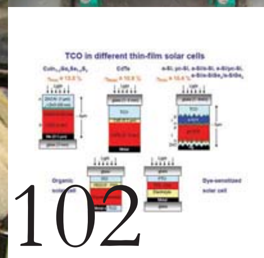


Thin Film



News

Applied Materials sees US$1.9 billion SunFab thin-film PV turnkey deal shrink to US$250 million

Applied Materials has filed a document with the U.S. Securities and Exchange Commission that acknowledges a US$1.9 billion sales agreement signed in March 2008 to supply its SunFab tandem-junction amorphous-silicon thin-film PV turnkey production lines to an unnamed customer has shrunk to US$250 million. The capital equipment company blamed "subsequent deterioration in global economic and financial market conditions" for the writedown.

The SEC 8-K filing says that "the parties recently entered into an amendment of the original agrement that, among other things and subject to the satisfaction of certain conditions, reduces the production capacity to be supplied by Applied and reduces the aggregate purchase price" by US$1.65 billion.

The amended deal holds that "the rights and obligations of each of Applied and Buyer under the original agreements with respect to the purchase and sale of the remaining solar production equipment and related services shall terminate, except for certain rights and obligations specified in the amended agreement."

Applied says that it "has not recognized any orders in connection with the original agreements or the amended agreement" and that the two parties will still "explore additional business opportunities."

Thin-Film Production News

Weak demand forces Uni-Solar to implement temporary plant shutdowns

United Solar Ovonic (Uni-Solar), a whollyowned subsidiary of Energy Conversion Devices and one of the largest manufacturers of flexible solar laminate products, has been forced to temporarily shut down its Michigan production operations in Auburn Hills and Greenville, while also delaying the planned ramp at its second facility in Greenville. The s-Si thin-film specialist cited the economic conditions and weak demand for the shutdowns, which will last 4 weeks at Greenville through to June 17 and 3 weeks at Auburn Hills, which will reopen June 7.

Sunfilm first with 8% efficiency tandem junction cells from a SunFab thin film line

Sunfilm AG has become the first Applied Materials SunFab thin film customer to qualify tandem junction cells for volume production. Factory acceptance was said to have taken place on April 14, 2009, with module efficiencies of up to 8%. Sunfilm AG was established at the end of 2006 by Good Energies and NorSun and is located in Grossroehrsdorf, Germany.

"This is excellent news for our existing and future customers," said Dr. Sicco W.T. Westra, Chief Business Development Officer of Sunfilm. "We can now begin delivery of our products in larger quantities. With a total annualized capacity of over 120MWp between this first production line and our second production line that we plan to start up later this year, we are in a strong position to fulfill market demand."

"This is an outstanding accomplishment for both Sunfilm and Applied. It demonstrates technical excellence and our ability to collaborate and execute to enable our customer's success," said Dr. Randhir Thakur, senior vice president, general manager SunFab Thin Film Solar and Display Business Group. "Rapidly driving leading edge technology into manufacturing is a core capability of Applied and this milestone is another demonstration of our ability to quickly move tandem junction technology from the lab to commercial production."

Although the thin film panels are 5.7m^2, Sunfilm like Signet Solar is making available modules of various sizes. With tandem junction cells, Sunfilm said that its 1.4m^2 module generates up to 115Wp, while a full-size 5.7m^2 panel will deliver about 450Wp.

Sunfilm's Grossroehrsdorf, Germany 'SunFab' facility.

ENN Solar ramps on time with SunFab tandem junction thin film technology

ENN Solar Energy Co., Ltd. has produced its first tandem junction thin film modules at its 60MW 'SunFab' line, claiming the first Chinese based thin film manufacturer to produce tandem junction cells on a production line. ENN Solar has previously planned production to start in the first quarter of 2009.

The companies claim that the new milestone was achieved five months after equipment installation at EEN Solar's facility in Langfang, China. EEN Solar has aggressive plans to ramp capacity, claiming a target of 500MW by 2011.

ECD updates guidance: Thin-film solar PV company slows production, expansion plans

Thin-film solar PV manufacturer Energy Conversion Devices announced that it will slow down the pace of its "demand-driven" manufacturing and expansion plans, because of the what it calls the "impact of credit availability on project flow in the global pipeline for photovoltaics." The company – known for its Uni-Solar brand flexible TFPV laminates – will enact a series of cost-cutting measures, such as temporary shutdowns and factory and workforce consolidations, including layoffs.

The Michigan-based company said it will implement a two-week production hiatus, effective March 22. It will also postpone equipment orders and new hiring until demand improves, while it completes basic construction at its new Battle Creek 120MW a-Si module facility, which was originally scheduled to go online by the end of 2009.

The company plans to relocate about 130 employees from its Auburn Hills 1 facility to its newer Auburn Hills 2 site, as part of efforts to consolidate production and cut overall costs and enhance manufacturing efficiencies.

The move will lead to a permanent reduction of approximately 70 positions

at Auburn Hills 1. The affected individuals will receive severance and outplacement services, but will have the opportunity to apply for future jobs at ECD facilities.

The lack of visibility caused by the stormy economic conditions also led ECD to back off its previously stated third-quarter and full fiscal-year 2009 financial guidance. The company said that its previously stated financial guidance numbers for those periods no longer apply.

The company believes that solar product revenue for the fiscal third quarter will approximate the results from the same period a year ago; ECD's 3Q08 revenues were US$70 million, mostly coming from the solar lines, with net income of US$7 million.

XsunX scales back thin-film solar PV module manufacturing plans

Citing what it calls "the limitations presented by the unanticipated volatility within the financial markets," XsunX said it plans to reduce its budgeted manufacturing requirements by two-thirds at its Oregon facility, while continuing to work to service existing sales agreements for its amorphous-silicon thin-film PV modules. The company is also reviewing the implications of the recently enacted renewable energy investment credits included in the federal stimulus package.

XsunX CEO Tom Djokovich provided the following statement. "In January the company began preparing modifications to its manufacturing plans that would require fewer manufacturing components and significantly less capital expenditures with the objective of providing sufficient manufacturing capacities of approximately 10 to 13MW necessary to service our existing sales contracts. Our plans include reducing budget requirements to approximately US$13 million, which is roughly one-third our current budget.

The company said it is reviewing the renewable energy manufacturing investment credit provisions of the American Recovery and Reinvestment Act of 2009, which provides up to US$2.3 billion to fund a 30% investment tax credit (ITC) for manufacturing assets used to produce alternative energy products.

These credits and grants apply to projects creating or retooling manufacturing facilities to make components used to generate renewable energy – areas in which XsunX is already carrying out activities.

Taiwan's Kenmec plans thin-film PV module turnkey production line

Taiwan-based EMS provider and automation equipment manufacturer Kenmec Mechanical Engineering looks set to roll out its first turnkey production line for amorphous silicon (a-Si) thin-film PV modules in May of this year, according to a report in Digitimes. The annual capacity of the line has yet to be reveealed.

Kenmec, who will supply the automation equipment for the production lines, will tap other international suppliers for such key equipment as PECVD systems and others, based on clients' individual requirements. The report claimed that Kenmec's turnkey production line would produce modules capable of 7-8% conversion rates.

The company is also anticipating that it will be ready to offer CIGS thin-film turnkey production equipment to the market in 2010.

Genesis Energy close to funding deal for first 'SunFab' thin film line

One of the earliest of potential customers of Applied Materials 'SunFab' thin film production lines, looks close to securing the necessary funding that would see it establish the first of three planned production facilities. Genesis Solar, a subsidiary of Genesis Energy Investment Plc has recently announced that it has a Letter of Intent from an unidentified U.S. investor to inject US$42 million into its Spanish subsidiary, Genesis Solar España S.L., which has a partially completed production facility designed to house Applied's 'SunFab' thin film line in El Puerto de Santa Maria, Cadiz, Spain.

The US$42 million investment is contingent on an approved equity swap, whereby Genesis Energy Investment PLC acquires a stake in the US company in return for 100% of its Spanish subsidiary. A board meeting will discuss the arrangements in April, 2009.

The XsunX facility in Oregon, USA.

Genesis Solar had previously secured regional subsidies in Spain and Hungary to build and operate thin film PV production facilities and had future plans to establish manufacturing in Singapore.

However, the thin film start-up said it had been caught-up in the financial crisis due to certain assets of a significant value it held, that proved difficult to obtain release from third parties, causing delays to the production plans.

Energosolar teams with Parity Solar on 24MW thin-film module line in Jiangsu, China

A new thin-film module manufacturing line has been commissioned in Jiangsu province, China that will see an initial 24MW – and a potential increase to 96MW by 2011 – of a-Si modules hit the market. The agreement states that EnergoSolar Hungary Equipment Manufacturing Ltd. provide the turnkey end-to-end module production line for Parity Solar Ltd., with the first phase of installation commencing in 3Q09.

EnergoSolar has received a down-payment for its services, that will include supply and installation of key equipment including PECVD tools, sputtering machines, front- and back-end equipment, as well as the training of the staff of Parity.

The planned 24MW output will generate approximately 470,000m^2 of high-quality thin-film PV modules per annum. Parity Solar is nearing completion of the preparation of the facility building in Zhenjiang, with utility installation commencing this month. Equipment delivery is scheduled to take place in the next six months.

Konarka plans plastic on glass BIPV product collaboration

Konarka Technologies has teamed with Arch Aluminum & Glass to develop building integrated photovoltaics (BIPV) products using its polymer-based, organic photovoltaic (OPV) technology on glass. Arch Aluminum specializes in artistic and architectural glass products.

"Until today, aesthetic and performance concerns limited the ability of architects to use BIPV technology in their designs," commented Arch CEO Leon Silverstein. "This product development investigation is about the creation of a new product category, one that had been unavailable until today. It is energy-efficient and transparent with superior vertical performance and a subtle red, blue or green aesthetic."

According to a recent Lux Research report, the BIPV market is currently worth US$1.7 billion. Near-term growth would be limited due to lack of standardization and competition from the conventional building-applied photovoltaics (BAPV) approach. Many of the flexible and a-Si thin-film manufacturers are expecting to compete in the BIPV market.

News

Tool Order News Focus

Solar Thin Films ships equipment to Grupo Unisolar

Solar Thin Films has said that the majority of tools required for customer Grupo Unisolar's 6MW a-Si thin-film PV plant have been shipped. Its subsidiary, KRAFT Elektronikai Zrt. of Budapest, Hungary was responsible for the turnkey project. The contract is worth US$10.29 million, although it had originally been reported by the company as a US$12.3 million contract.

"We are delighted that this project is on track to date and we look forward to completing our equipment shipments and commencing installation in the coming months," noted Peter Lewis, Group Vice President, Equipment and Thin Films Division. "This project is particularly important to KRAFT and to Solar Thin Films as it represents another step in our effort to transition KRAFT from an equipment supplier to a 'turnkey' systems supplier and because the equipment shipped includes improvements to the system as a result of the recently signed Cooperation Agreement between KRAFT and our new merger partner BudaSolar."

Solar Thin Films acquired BudaSolar Technologies Co. Ltd. of Budapest, Hungary in April, 2009.

Jenoptik to supply laser line for Asia-based thin-film manufacturer

An Asia based thin film solar manufacturer has placed an order with Jenoptik Automatisierungstechnik in the laser processing systems business unit for a complete automated 'Jenoptik-Votan Solas' system, used for laser structuring and ablation processes. The use of lasers will allow for structuring with widths ranging from 30 to 60 micrometers. Delivery of the production line is planned for mid-2009.

Jenoptik said that its lasers and material processing division expected to receive more orders for its laser system in Asia.

Veeco to supply CIGS thin-film PV production tools to Daiyang Metal

Veeco Instruments and Daiyang Metal have entered into a strategic partnership in which the equipment supplier will provide the Korean steel company with CIGS thin-film solar PV manufacturing tools. Daiyang has placed an initial multimillion-dollar purchase order with Veeco for a set of FastFlex web-coating systems to outfit a flexible CIGS cell production line in Yesan, Korea.

The tools on order are comprised of a molybdenum deposition system, a transparent conductive oxide deposition system, and a pair of CIGS (copper-indium-gallium-diselenide) absorber-layer deposition systems. Veeco said it expects to ship these systems during the fourth quarter of 2009, after which it hopes to close a follow-on order with Daiyang.

Piero Sferlazzo, senior VP of Veeco's solar equipment business, said that "Daiyang's selection of Veeco is confirmation of our leadership in thermal evaporation sources. Thermal source technology is quickly becoming the preferred CIGS deposition method because it provides customers with high-volume, low-cost manufacturing solutions that drive down the manufacturing cost per watt."

Daiyang joins the increasingly crowded field of companies attempting to commercialize CIGS thin-film PV, a sector seen by many analysts as having great growth potential and multiple end-use applications. In a recent market report by Greentech Media/ Prometheus Institute, CIGS will make up 12% of total producible solar-module capacity--or 2.97 GW--by 2012, while Nanomarkets forecasts that CIGS capacity will reach 1.4 GW that year.

BTU International wins US$2 million order from new thin film customer

A major thin film PV manufacturer has become a new customer of BTU International with the placement of and order in excess of US$2 million for the delivery of multiple BTU in-line thermal processing systems that will be used in volume production.

"This order demonstrates again that BTU's thin film solar equipment is the right fit for customers who are scaling to volume production," said Paul van der Wansem, chairman and CEO of BTU International. "Our core competency in engineering and technical performance coupled with our solar technology roadmap and global footprint are key assets which enable us to serve this fast-paced and growing market."

BTU's equipment has been used for both the CIGS and the CdTe thin film processes.

Business News Focus

DOE bestows US$535 million in guaranteed loans to Solyndra

In the first of such loans to be issued under Title XVII of the Energy Policy Act of 2005, Solyndra, Inc. has been granted a loan guarantee of US$535 million from the U.S. Department of Energy (DOE). The company will wisely put the funding into expansion, with plans to construct a second facility (Fab 2) in California. The loan is said to account for approximately 73% of the project's cost.

The 500MW facility is intended to produce sufficient solar panels to generate up to 15GW of energy on completion. Following the conclusion of the loan agreement between Solyndra and DOE, the planned facility is expected to create approximately 3,000 jobs, of which the facility's operation will account for over 1,000. The company anticipates several hundred more jobs will be created in the U.S. to allow for the installation of the company's PV systems.

According to a report by Barclays Capital Solar Daily, the acquisition of the loan by Solyndra was not related to the passing of the U.S. Stimulus Bill earlier this year. "Although a headline positive, this loan guarantee was part of the 2006 solicitations (first round of DOE program) and is not part of the recently announced DOE stimulus program.

The third round of DOE program (designed as part of the current stimulus package), which could potentially improve demand is unlikely to begin until June at the earliest. We expect the first decisions for the third round to be made by September (in best case scenario) or December (in a more realistic scenario)."

Solyndra currently has more than US$1.5 billion in orders on entering its second year of commercial shipments to customers in Europe and the U.S.

An installation of Solyndra's CIGS coated cylindrical modules.

Oerlikon Solar's 'Micromorph' technology receives IEC certification

Oerlikon Solar has said that its 'Micromorph' thin film-based solar modules have now passed all tests required for IEC certification through TÜV Rheinland. This means that customers should be able to reduce certification times

Oerlikon Solar's Micromorph production line.

from six months to less than six weeks, the company said. Oerlikon successfully completed both IEC 61646 (Module Performance Test) and IEC 61730 (Module Safety Test).

"We believe Oerlikon Solar is one of the premier equipment and module technology providers in the thin-film silicon solar PV market. They have proven their ability to scale a world-class technology and process to mass production, and passed all of our tests," states Willi Vaassen, Head of Renewable Energy division, TÜV Rheinland.

Oerlikon Solar also reiterated that it was in the process of assisting the production ramps of four additional Micromorph thin-film lines for customers that include Auria Solar, Chint, Heliosphera and Pramac. Two 'Amorph' technology users, Tianwei and Gadir, are also preparing ramps. The turnkey equipment and technology supplier expects the combined ramps of current thin-film customers in 2009 to be more than 240MW, while cumulative shipped capacity over the last two years has reached 600MW.

Thin film patent spat; first round goes to Applied Materials and customer

Applied Materials has claimed that the European Patent Office (EPO) has revoked a Patent No. EP 0 871 979, which is at the centre of a patent infringement case Oerlikon filed in June, 2008 in the German District Court of Duesseldorf, against SunFilm AG, a customer of Applied Materials 'SunFab' thin film technology and production line equipment.

The EPO panel ruled that the patent was invalid in its entirety, though Oerlikon can appeal the ruling. Oerlikon had licensed patents from IMT, University of Neuchatel, Switzerland. The company has yet to officially respond to the EPO ruling.

Goodbye AVA Solar, hello Abound Solar: CdTe PV company changes name

AVA Solar has a new name – Abound Solar. The cadmium telluride thin-film photovoltaics manufacturer says its new brand reflects the "company's commitment to providing an abundance of low-cost solar panels to solar integrators around the globe."

CEO Pascal Noronhas said that the the company is "excited about our evolution from AVA Solar to Abound Solar. Our new brand identity represents a change in the company's look, as well as our focus. We believe we are well-positioned to address the growing demand for solar power, and we are focused on scaling to create a source of renewable, abundant and universally affordable energy."

The company started building a fully integrated, 200MW capacity production facility in Longmont, CO, last spring. The fab is scheduled to start commercial production of 60 × 120cm TFPV panels in April, according to Abound, which would make it the second operational CdTe volume production facility in the U.S., after First Solar's Perrysburg, OH, site.

Abound's CdTe module manufacturing technology was developed and incubated at Colorado State University's material engineering labs over the last 15 years. The company says that with its dry, in-line, continuous production flow, the glass enters the process chamber and in less than two hours, a completed panel emerges from the end of the automated line.

The company has been supported by the U.S. Department of Energy and has received about US$150 million of private investment from the Invus Group, Doll Capital Management, and others, with the latest US$104 million equity financing round having been completed in August 2008.

Abound says that it has already signed supply contracts with leading global customers and has also applied for a DOE loan guarantee to expand its current manufacturing facility and begin construction of a second, larger plant.

Semiconductor heavyweights Tokyo Electron team with Oerlikon Solar in Asia

Tokyo Electron(TEL), a leading global supplier of semiconductor production equipment has entered into a strategic alliance to exclusively sell and service Oerlikon Solar's thin-film PV equipment and end-to-end production solutions in Asia, Oceania and Japan.

Oerlikon will draw upon TEL's significant sales and service network in Asia for FPD and semiconductor equipment. The deal will enable TEL to leverage existing staff, infrastructure and expertise that are being under utilised due to the projected 33% decline in the semiconductor market place this year.

Doubts emerge over DayStar Technologies as a going concern

DayStar Technologies has made a net loss of approximately US$20 million in 2006 and US$36 million in 2007.

"As we stated in our conference call on March 16, 2009 and reported in our 10-K filing, our commercialization plans require additional capital to be raised," said William Steckel, Chief Financial Officer. "In November 2008, we engaged J.P. Morgan Securities to act as our financial advisor to assist us in exploring select strategic transactions, which we believe represent the best source for our capital requirements."

Hein & Associates noted that the company still required 'substantial funds beyond its current cash on hand' to carry-out its plans, raising 'substantial doubt about the company's ability to continue as a going concern.'

Special News Feature

Plastic PV people: Ascent Solar makes steady progress toward market disruption

By Tom Cheyney

Although there are 30-40 companies working to commercialize copper-indium-gallium-(di)selenide thin-film photovoltaics products, one firm has an approach unlike any other. Rather than depositing its films on glass or metal foil, Ascent Solar does it's CIGS module processing on flexible plastic in a vacuum-based, roll-to-roll – and ultimately monolithically integrated – production flow.

The company (which is publicly traded, although partner Norsk Hydro owns 35%) continues its conservative, fairly transparent, "steady as you go" strategy.

Ashutosh "Ashu" Misra has been waiting a long time for this moment, so he's learned the value of patience when it comes to working with CIGS and CIGS-on-plastic in particular. Ascent's senior VP joined ITN Energy – the parent company which spawned both Ascent and its CIGS-on-foil cousin, Global Solar – in 1997 (with a break of a few years to serve as boss of Data Access America). ITN, which did yeoman's work pioneering thin-film PV process R&D with various government agencies in the 1990s and early 2000s, spun off Ascent in 2005.

I spoke to him in advance of the ribbon-cutting to inaugurate Ascent's recently dedicated 1.5MW pilot line in Littleton, about details of the company's process flow and tooling requirements, current R&D efforts, and the outlook for Ascent and CIGS TFPV in general.

The 140,000-sq-ft Thornton site will house both the company headquarters and its first 30MW volume production line. What once was a Fischer Imaging X-ray tool facility has been completely refurbished, with across-the-board upgrades (or brand-new installs) in power, HVAC, DI water, and the like, according to Misra. After laying out US$5.35 million to buy the building last year, Ascent has spent US$10 million on the renovations and some US$110 million on manufacturing and support equipment.

"Every peripheral system we had to build," said Misra. "This was not like a semiconductor fab where you'd walk in with everything in place."

Ascent Solar's new HQ.

The senior exec told me that they finished specifying and then ordered all process tools by the end of the third-quarter 2008, and that the equipment has already started to arrive. He put the average lead times of the tool suppliers in the six- to nine-month range, with OEMs choosing to manufacture one system at a time, others assembling two platforms simultaneously. Misra raved about the improvements that he's seen with the toolsets over the past couple of years, calling the amount of progress "humongous," especially compared to the early days at ITN and Global Solar.

"We have received our first CIGS tool, and it is on the floor for installation," he noted. The next to arrive will be a Stangl-made cadmium-sulfide buffer-layer wet process system, followed by the deposition tools that will lay down the molybdenum and indium tin oxide films – both manufactured by General Vacuum.

As with other CIGS companies' processes, the art of production-line balancing requires mixing and matching the various toolsets to meet the specified capacity and a few years to fully optimize yields and efficiencies, according to Misra; in the case of Ascent, while three CIGS absorber and three monolithic integration systems will be required to hit that 15MW mark, different numbers of Mo, CdS, and ITO tools will be installed.

The back-end equipment – including the proprietary laser etch/monolithic integration equipment and a fairly standard laminator tool – will be in place by year's end, keeping Ascent on track to ramp its first 15MW of production capacity at the Thornton fab in the first half of 2010. Misra said the company will then ramp the second 15MW of capacity in the latter half of next year.

The two most customized pieces of gear are the aforementioned CIGS tool and the monolithic integrator. An unnamed Japanese toolmaker, which works with Ascent through its trading partner Itochu, builds the shell of the CIGS platform, "and we do the rest of the integration of the sources and other stuff," he said.

Once the one-third-meter-wide, 150-meter-long rolls of plastic substrate complete their run through the molybdenum/back contact, CIGS/absorber layer, CdS/buffer, and ITO/transparent conductor layer processes, the total film-stack ends up between 2- and 2.5-µm thick, with an impressive across-the-web film deposition uniformity of ±2%.

The monolithic integration process, which takes place after all the thin films are deposited, "gives us the flexibility to finish the roll into multiple products," Misra explained. It employs a "combination of various types of printing techniques to lay down the insulating and conducting inks in vias or trenches."

While the opening of the Thornton plant gets all the attention, nitty-gritty process work still goes on at the newly dedicated 1.5MW pilot line in the company's Littleton facility. Misra said they're running one shift there now, with plans to add a second shift by next quarter and a third shift by the following quarter, which will bring the line up to a 24/7-type operation and push the capacity close to nameplate status.

After spending at least six months dialing in or "freezing" the process recipes, the line is now fully stabilized and ready to ramp. Module-level conversion efficiencies are in the 7-8% range, according to Misra, and he's comfortable with the company's roadmap for 1% per year improvements to reach the 9-10% efficiency range by 2011. The National Renewable Energy Lab announced late last year that it had verified efficiencies as high as 9.64% from modules made on the Ascent pilot line.

"I think 10% is very realistic, and we're also looking at improving the substrate material, so we can operate on a high-temperature substrate." The company is working closely with Ube Industries, the Japanese company that supplies Ascent's flexible polyimide materials, to push the tolerance of the plastics so they can handle process temperatures of another 50°C, to squeeze even more efficiency out of the CIGS.

Ascent has invested heavily in "intelligent process control," with an array of primary inline sensors "extracting information in real time and hooking it back to our closed-loop system to play with the variables of pressure, process or web temperatures, and substrate temperatures."

Misra admits that although such APC tools are "really maturing and much more robust" than before, crediting "help from the semiconductor guys," he'd like to see more advancements in those technologies, which would lead to "significant improvements in our process, with better efficiencies and better yields."

It's a trickier proposition to control a large, roll-to-roll vacuum process than one where individual glass modules can be tested and the line adjusted accordingly, before yields plummet. "When you're processing a thousand-foot roll, you're stuck inside that machine. You need to make sure you have a pretty good handle on your process."

Although Ascent is laser-focused on ramping production and improving manufacturing efficiencies, it has an active R&D effort. One notable area involves efforts to come up with a cadmium-free, dry-process alternative to the current CdS buffer-layer step. In addition to the messiness of the wet CdS process now in place, Misra noted that "in Japan, it's very tough to sell a product with cadmium in it there."

Another research project examines one of the holy-grail materials of flexible CIGS BIPV – a moisture-resistant barrier encapsulation layer that is reliable, doesn't degrade quickly, and isn't cost prohibitive to make or integrate into the process.

"We're making pretty good progress there," Misra said. "We're working on an in-house solution plus another solution from three or four suppliers that are big chemical and plastic companies. We've seen good results with thermal cycling and have internal samples under damp-heat tests."

Ascent has been shipping "limited amounts" of prototypes to its customers, although Misra wouldn't cop to just how many modules are going out the door. He did say that those partners are eager to increase the number of Ascent PV products in their possession, so they can run them through their paces.

Customers of record include Icopal SAS, Texsa, TurtleEnergy, and part-owner Norsk Hydro seeking BIPV solutions, along with ICP Solar on the EIPV and portables side, with some U.S. military contracts still in the mix.

Ashu in front of a CIGS process tool.

Misra remains a true believer in CIGS thin-film PV, but is realistic about the difficulties of perfecting the quarternary compound. "The greatest potential is with CIGS, but you have to give it time. The market has to be patient with CIGS." After all, he points out, thin-film king First Solar was no overnight success story, taking years to perfect its CdTe process – and burning through tens of millions of dollars of Walton family cash.

Considering Ascent's vastly differentiated value proposition for the EIPV and BIPV target markets – a competitively efficient, low-cost flexible plastic CIGS module that can be rolled onto or built into a rooftop, embedded into a building facade, or tailor-made for small electronic devices – perhaps it behooves the "market," within reason anyway, to hold the Colorado company to an alternative standard of "success."

Product Briefings

Bystronic Lenhardt

New Thermo Plastic Applicator from Bystronic Glass enables continuous butyl feed

Product Briefing Outline: Bystronic Glass Technology Center Bystronic Lenhardt has launched a horizontal Thermo Plastic Applicator (TPA), which is claimed to be the first machine of its kind for the application of high-viscous butyl on semiconductor thin-film substrates. The butyl effectively protects the semiconductor layer against humidity.

Problem: Boosting productivity of thin-film photovoltaics modules requires greater uptime and reduced maintenance. Module fabrication costs remain the highest in the assembly process and are therefore targeted for cost reduction. Prior to the lamination process, conventional butyl sealant stripes from a reel are permanently linked with production. When the reel material needs changing this stops the process line, impacting productivity.

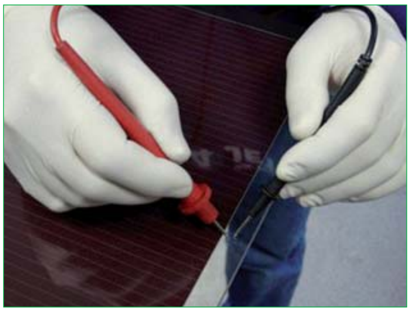
Solution: The technology is based on a decade of experience in the design of machines for the production of insulating glass, where thermo-plastic material is applied as spacer between the glass plates. In the solar power industry, horizontal machines as well as vertical designs are used for sealing all types of semiconductors – CdTe, CIS, CIGS, microcrystalline silicon or amorphous silicon (a-Si). The company claims that this is the first machine of this type that is capable of working in 24-hour operation without any interruption. Two high-performance pumps ensure that the viscous sealing material is always available, while the dosing pumps of the TPA apply the material accurately to a tenth of a millimetre.

Applications: All thin-film modules.

Platform: The machine can be included at the planning stages for newly designed plants, but can also be integrated into existing systems.

Availability: Currently available.

4JET Sales Service GmbH



4JET's 'INLINE' system handles abrasion-free edge deletion

Product Briefing Outline: 4JET Sales Service GmbH has added a new machine to its portfolio for thin-film photovoltaics production. The INLINE system can be equipped with several laser technologies and allow full area processing of the entire surface of a solar panel. Applications include edge deletion, selective perforation, P4 isolation scribes as well as marking or drilling of glass.

Problem: Achieving reproducible quality in edge deletion and selective laser ablation processes can be a costly task. Precision is crucial, but some systems can impact the durability and efficiency of solar panel systems.

Solution: The compact unit, a co-development of 4JET and Maschinenbau GEROLD GmbH, is suited to processing all standard panel sizes including G8 formats with 2600 x 2200mm dimensions. Glass panels are pre-centered and their position is measured precisely. 4JET's dynamic ABC (Automatic Beam Control) beam delivery system enables compensation of glass warpage and size tolerances of the panels. Depending on the application, the units are equipped with diode-pumped solid-state or fiber lasers; depending on the required throughput, several modules can be installed sequentially. The 4JET design allows full area processing of the entire panel surface and allows programming of each individual edge width depending on the glass tolerance. The INLINE platform also enables performing a cost-efficient P4 isolation cut that generates a sharp edged groove between the active area of the solar panel and the edge. Using an INLINE system with 532nm and/or 1064nm wavelength eliminates the need for an isolation cut in the more expensive P3 scribing systems.

Applications: Si, CIGS, and CdTe thin film.

Platform: The INLINE series is offered with different optional processes, including a newly developed process to expose molybdenum on CIGS solar panels, a process validation module and mechanical brushing systems.

Availability: Currently available.

LayTec GmbH

LayTec GmbH's SolR in-line monitoring system measures film thickness of all layers

Product Briefing Outline: LayTec GmbH has introduced its in-line monitoring system for thin-film photovoltaic processes. SolR is capable of monitoring the film thickness of all layers throughout the thin-film PV process, including transparent conducting oxide (TCO), absorber and buffer layers. SolR will be available in various editions for CIGS – as well as for CdTe-based thin-film solar cell processes.

Problem: Conventional post-growth evaluation methods of the thin-film production process are becoming obsolete as the need increases for real-time evaluation during thin-film growth. Particularly in regard to PV-based thin-film processing, the main challenge has been to obtain an accurate film thickness measurement despite the reduced reflectance due to intentionally rough absorber layers.

Solution: LayTec has found a very robust way to establish film-thickness measurements even under these challenging conditions. SolR helps thin-film PV producers to control their production online and thereby enhance their yield. It also helps accelerate development cycles to aid in transferring established processes to new lines, aiding the ramp to high yields and reducing ramp-up production costs. If the refractive index and the absorption coefficient of the oxide layer are well known, the layer thickness can be calculated directly from the measured reflectance. Reflectance measurements at longer wavelengths can determine the substrate temperature based on a double wavelength band-edge approach. During thin-film growth, substrates can experience a temperature offset between the process temperature and the substrate surface temperature that can be measured to improve control of the deposition process.

Applications: Transparent conducting oxide (TCO), absorber and buffer layers; CIGS and CdTe applications.

Platform: The monitoring system is based on spectroscopic reflectance measurements.

Availability: Currently available.

RENA GmbH

RENA's High Dynamic Flooding immersion process provides surface structuring

Product Briefing Outline: RENA GmbH's thin-film PVGlassEtch system uses its patented High Dynamic Flooding (HDF) immersion process and is designed to improve the efficiency levels of thin-film solar cells by structuring the surface of the transparent conductive oxide (TCO) layer using anisotropic etchants. This type of system is also ideally suited for other etching steps, including NP etching in the case of CdTe cells or KCN etching of CIGS cells.

Problem: Thin-film technologies have inherently lower conversion efficiency levels than crystalline solar cells. Improving efficiency levels is required for both a competitive and low-cost advantage perspective, requiring improvements to surface structuring. Other structuring methods such as spray or dip techniques can lead to clouding or flow marks on the substrates, thus leading to inhomogeneity.

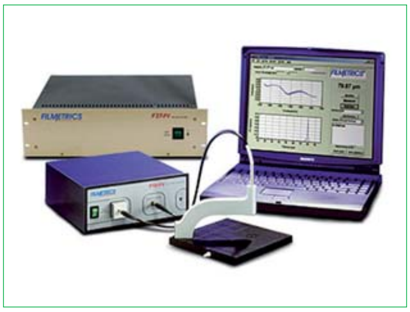
Solution: The surface of transparent conductive oxides is structured with RENA's HCl etching systems. The structure refracts the incident light thus lengthening the optical path in the underlying absorber material of the solar cell, effectively increasing the portion of absorbed light. This also means a relative increase in the degree of efficiency of the solar cell, an increase that can be measured in percentages, according to the company. Etching is carried out by means of the company's High Dynamic Flooding immersion process, which introduces the etchant in a 'turbulence-free' step on to the substrate in the form of a standing wave, without the formation of clouding or flow marks on the substrates.

Applications: Thin-film etching.

Platform: The system can process all standard substrate sizes (650/1150/1350/2250) as well as individual sizes. With a transport speed of 2.5m/min and a low 0.01% breakage rate, minimised media consumption and an uptime of >97%.

Availability: Currently available.

Filmetrics



Filmetrics offers comprehensive metrology solutions for all thin-film photovoltaic materials

Product Briefing Outline: Filmetrics has launched its thin-film photovoltaic dedicated measurement systems, the F10-PV and the F37-PV, which offer commercially available tabletop and in-line metrology solutions for industries utilizing all classes of TFPV materials. The addition of non-destructive thin-film thickness metrology to the TFPV environment is expected to greatly enhance production efficiency and yields, help develop new processes, and facilitate rapid transfer these new ideas to the production floor.

Problem: Typically built on or under transparent conductive oxides on glass, plastics, or metal substrates, the properties of TFPV films are notoriously difficult to measure due to their special optical properties. Getting the right thickness and composition of active layers is important; too-thin layers can affect efficiency and durability, while layers that are too thick can increase cost. The wrong composition can drastically decrease efficiency and manufacturing yield.

Solution: The Filmetrics F10-PV and F37-PV products are capable of monitoring the film thickness of active layers such as a-Si, CdS, CdTe, CIGS, TCOs and buffer layers. These types of devices are intentionally designed to absorb rather than reflect light, creating many unique challenges for performing metrology on these layers. Surmounting these challenges, the F10-PV and the F37-PV can accurately measure the thickness and optical properties of even the most complex structures on TCOs.

Applications: Thin-film photovoltaic thickness measurement.

Platform: The F37 measures deposition rates, layer thickness, optical constants (n and k), and uniformity of semiconductors and dielectric layers in real-time. The F10 measures reflectance and transmittance simultaneously. Options are available for measuring thickness and index.

Availability: Currently available.

HORIBA Jobin Yvon

Jobin Yvon's MM-16 NIR Spectroscopic Ellipsometer ideal for near infrared applications

Product Briefing Outline: HORIBA Jobin Yvon's new MM-16 NIR spectroscopic ellipsometer is dedicated to thin-film characterization, determining thicknesses, optical constants (n and k) and the optical bandgap of materials in the wavelength range 515-1000nm. The MM-16 NIR is an easy-to-use, rapid and versatile ellipsometer for demanding research, process development and industrial applications in the photovoltaic industry.

Problem: Continued development of higher conversion efficiencies of all types of thin-film modules requires extensive analysis of the films using surface analysis methods, which can support R&D improvements through to production.

Solution: The MM-16 NIR features a CCD detection system for rapid and accurate measurement down to one-second determination, and a 200μm microspot allows characterization of patterned samples. When fully automated, the system provides fast uniformity mapping of film thickness and optical constants. The design of the MM-16 NIR is such that it may be configured in several ways, with a 200mm x 200mm mapping stage (300mm x 300mm optional) for benchtop thin-film characterization available. With analysis times of one second, a wafer or panel can be characterized with high resolution very quickly. Configured with a compact, integrated goniometer to provide a very cost-effective benchtop metrology tool, the system can be integrated in production lines for in-line quality control of production processes.

Applications: Thin-film characterization from lab to fab.

Platform: The MM-16 NIR is controlled by the DeltaPsi2 software platform that is common to all HORIBA Jobin Yvon thin-film metrology tools. An optional Spectroscopic Reflectometer may be incorporated into the design for added capability. The tool can be mounted in-situ on process chambers for thin-film thickness control of deposited or etched layers.

Availability: Currently available.

"We don't sell modules, we sell electricity": a conversation with First Solar's Bruce Sohn

Tom Cheyney, Senior Contributing Editor (USA), Photovoltaics International

At First Solar's corporate headquarters in Tempe, Arizona, a morale-boosting slogan adorns posters stuck to the outside of cubicle partitions: "MILESTONE MADE! TEN ONE ONE." That's "Ten," for 10 years in business – at least in the company's First Solar incarnation. The original firm Glasstech Solar, led by visionary Harold McMaster, actually set up shop in 1984, then became Solar Cells, Inc. in 1992, which begat the present entity in 1999. The middle "One" stands for the gigawatt's worth of panels produced in the solar module factories in Ohio, Germany, and Malaysia – as well as the annual production capacity that will be ramped by the end of 2009. The final "One" stands for perhaps the biggest accomplishment of all – the dollar-per-manufactured-watt standard beaten by two cents by First Solar in the final quarter of 2008, a cost that has since shrunk to 93 cents per watt in the first quarter of 2009. But then, "Ten/One/0.93" doesn't quite have the same ring.

When Bruce Sohn joined First Solar as a member of its board in 2003 and then full-time as its President in March 2007, that Ten/One/One level of achievement may have seemed a distant goal as endowed as much with hope (and maybe a few prayers) as realistic expectation. A comparison of the company's financial and manufacturing performance at his hire date and in the most recent quarter shows a staggering growth rate – in dollars, watts, and production efficiencies.

Revenues for the first quarter of 2007 were US$66.9 million, with net income a promising US$5 million. For the first quarter of 2009, those same amounts were US$418.2 million and US$164.6 million; in other words, the income was more than double the sales from just two years before. During the same period, gross margins grew from the mid-40s to the mid-50s.

As for solar power products coming off the manufacturing line, tens of thousands of cadmium telluride (CdTe) thin-film PV panels have become millions of modules per quarter, with megawatt production levels jumping from the twenties to the two hundreds. During that time, the annualized capacity per line (the proverbial run rate) jumped from the mid-30s of megawatts to 49.4MW, and conversion efficiencies have popped a full percentage point, from 9.9% to 10.9%, with a roadmap for several more digits of improvement.

Photo: First Solar.

Bruce Sohn,
President of First Solar

> "Copy exactly and mapping that over into First Solar and using what we call copy smart, there's really not a lot of difference between the two other than the name."
> **Sohn, First Solar**

Sohn, a 24-year veteran of Intel and its ultrafocused manufacturing strategies, has played a crucial role during First Solar's prodigious yet well-managed, tightly controlled growth spurt. Deftly handling a laundry list of responsibilities, the Massachusetts Institute of Technology engineering graduate is charged with overseeing the thin-film PV juggernaut's operations for its module business, including technology development, manufacturing and expansion; its systems engineering, procurement and construction (EPC) group; and monitoring and maintenance activities.

In an exclusive interview, Sohn talks about the challenges of his job and how it has changed over his two-plus years in the executive cubicle (no suites or corner offices at First Solar). He discusses how his experiences at Intel, where he helped hone the chipmaker's "copy exactly" factory replication strategy, have been "mapped" to the PV company, including its own "copy smart" approach to cloning manufacturing facilities – and even its engineering, procurement and construction arm.

Other topics include more details on the company's manufacturing practices, the need (or lack thereof) for standards, the growing role of the EPC group in the U.S. market, the recent acquisition of OptiSolar's project development pipeline, and the nature of the competitive landscape.

No such thing as a typical day

Sohn laughs when asked what his "typical day" is like, as there is no such thing. He spends about half his time on the road, visiting the company's factories and development team offices, as well as customers, who are mostly in Europe. When he's back at the company's sixth-floor headquarters, he keeps tabs on his "direct reports" and operations via a combination of web-based tools and phone calls, while also closely collaborating with fellow First execs such as marketing/biz-dev maven John Carrington, money-man Jens Meyerhoff, and of course, the boss, CEO/chairman – and soon to be ex-CEO and executive chairman – Mike Ahearn. Most of the time, the big strategic picture weighs heaviest on Sohn's mind and task plate.

"In any particular day, I'll probably spend a fairly small amount on actually doing operational things," he says. "Whether it's talking about a customer development or working with supply chain management, for example, or future technology work and how that's going to integrate into the business, I would say most of what I work on is out farther in the future."

The former Intel fab manager still has a fondness for the operational side. "As an

Photo: Tom Cheyney.

Bruce Sohn shows off one of First Solar's modules at company headquarters.

old manufacturing guy, I find interest in all parts of the business but the reality is that I leave the day-to-day to the people who are more in tune and expert with the day-to-day, but I still find a fascination with it."

Scaling production, developing 'copy smart'

When he first joined the company in early 2007, his focus was squarely on how to scale the company's manufacturing and set up the internal business systems and processes to make that happen successfully. "When I came in, the focus was on starting the replication process," Sohn recalls. "We had not yet started up the factory in Germany. It was in the latter stages of construction and moving into the early start-up phases. There was a lot of focus on bringing up that first factory, and we spent a lot of time talking about what copy smart was for us, and how we apply that."

As he admits that he still has to catch himself from saying "copy exactly," Sohn explains the close relationship between the two factory-replication schemes. "Copy exactly and mapping that over into First Solar and using what we call copy smart, there's really not a lot of difference between the two other than the name," he notes. "There are some things that Intel can afford to do that we don't necessarily endeavour to do because Intel turns over its technology every two years, and we don't necessarily, since it's more of a continuous process and we approach it somewhat differently. Nobody should walk away thinking that copy smart is any better than copy exactly. It's not. It's just the application of the same basic approaches to a different industry."

Sohn continues his recollections of his first year on the job. "Back then the company was fairly small: we only had the three lines going, 60MW shipped in 2006, so we had to grow dramatically. That changed our scaling focus and then we've also expanded in the way we approach our technology and putting in roadmaps and things along those lines. We created more detailed roadmaps not only for the technology and efficiency but also for the cost reduction, which is core to our mission.

"There's been a lot of development of the business, putting in processes, putting in systems, making sure that we could scale," he continues. "The last thing I wanted to see was that we come in and we start to grow the business and we collapse because we don't have the processes in place, we don't have the systems in place, we don't have the culture in place, or we haven't enough people or the right kind of people that know how to manage and run a larger business."

> "We created more detailed roadmaps not only for the technology and efficiency but also for the cost reduction, which is core to our mission."
> **Sohn, First Solar**

As Sohn recalls, the company's approach to factory and production-line sizing and site location has evolved significantly. "At that time, we thought we would replicate much smaller 25MW facilities in locations all over the world. Then as we got into the cost and understood how we needed to scale the business and scale the costs over a larger volume, it became clear that we needed larger factories.

"In each of those factories at that time, a line was designed for about 25MW nominally and today those same lines are pumping out more than 49MW, so we've been able to almost double the output per line over the last two years as well, which is very important because in essence that saved the need to build some 20 lines or so."

"If we actually had to build those 20 lines, that's five factories – I'm not sure that we could have done it in these two years, even if we had wanted to," Sohn admits. "On the other hand, if we improve the efficiency, or we improve the run rate, or we improve the yield inside the factory, and then we propagate it using the copy smart philosophy, then we see it propagate at 20x the rate, or 23x the rate, because we have 23 lines running."

Perfecting volume CdTe manufacturing

Although First Solar has indeed ramped 23 module production lines across its three manufacturing sites (with the 24th soon to follow), the company remains notoriously guarded about the inner workings of its processes and manufacturing facilities as well as its R&D activities. Not coming close to taking the bait, Sohn won't answer any specific questions about film thickness uniformities or process temperature ranges or whether the research team is working on next-generation tandem-junction CdTe or even its own version of copper-indium-gallium-(di)selenide (CIGS). Nevertheless, he does shed some light on the company's overall approach.

"Your average designer in the IC industry who puts together 32nm devices and a billion transistors on a chip might look at our 'large-format wafer' over here with 116 cells of 1cm in diameter and say that he can't believe that would be very difficult to deal with," Sohn points out. "But the so-called simple device that we create, which is in essence a diode, has really humbled many a senior engineer.

"We do not build any of our equipment; most of the equipment we have was designed by us or designed in close cooperation with an equipment supplier," he explains. "One of the early things we did was integrate all of this. The ability to design a line that operates end-to-end, completely connected, where you put a piece of glass on the conveyor belt on one end, and two, two-and-a-half hours later, you've got modules going into a box that's ready to be shipped out to a customer, there's a lot of challenges to putting together a line like that. But once it's running, it really enables very high throughput and excellent quality control."

The company remains notoriously guarded about the inner workings of its processes and manufacturing facilities as well as its R&D activities. Sohn won't answer any specific questions about film thickness uniformities or process temperature ranges.

First Solar processes its modules using vapour transfer deposition (VTD), which Sohn says is "very similar to CSS (closed-space sublimation). It's a high-temperature deposition vaporization of the materials transported above the device. The key is that the dep rate [with VTD] is especially high. When you've got a capital-intensive business and you're trying to get the costs down, one of the best ways to do that is to have a very high dep rate across a large area and be able to deposit and keep the equipment running all the time."

Process control, says Sohn, is "something that's developing over time. In the early days, there was not a whole lot of online, in-situ kind of monitoring, and we're starting to do more of that. You just didn't need it before, since the process performance was relatively wide for a long period of time, so there wasn't a need to measure as frequently. Nowadays, we're improving our process control, we're tightening things up, we have better and better performance, more predictable output from our lines, so we are starting to evaluate more frequently, and I think you'll see an ongoing trend in that direction."

With its tightly protected proprietary process and manufacturing technologies, don't expect First Solar to jump on the solar PV industry standards bandwagon any time soon. "There are not a lot of places where there is much standardization, but I'm not sure that there are very many companies clamouring for it right now," Sohn opines. "For differentiated technologies, part of the differentiation is the lack of a standard, your own standard is the differentiation, so to speak. There are some exceptions that probably make sense, for example, where people use glass with similar thicknesses. The glass industry would probably really appreciate it if we would all hone in on a similar set of glass sizes."

Photo: First Solar.

A CdTe module comes off the assembly line at First Solar's Perrysburg, OH, production plant.

But the most important common denominator is outside the factory altogether. "Don't forget that the interface ultimately turns into a standard because the power grid is expecting a particular output, a particular performance, and the transformer tends to be the standardizing agent, the interface between any power plant and that transmission grid."

'Gunning for the fossil-fuel industry'

Although there are more similarities than differences between the semiconductor and solar domains, there is a fundamental distinction between his former industry and his current one, Sohn notes, and that is cost, which he says "is absolutely critical to our business. In most businesses, the product is sort of the market, and you try and grow that market. That's different in our business, because what we're creating is energy, power, and the power industry is one of the best examples of a commoditized industry in the world. That industry already exists and it has a particular cost structure to it.

"It may look like we sell glass in those boxes we ship out, but we don't really sell modules, we sell electricity, and the cost of that electricity, if we're going to be successful, has to match up in some way with the cost of traditional forms of creating electricity. That's very much different from the semiconductor industry."

Contrary to what one might think is First Solar's competitive landscape, Sohn and his colleagues have a different way of looking at the marketplace. "A lot of people, when they ask us about competition, always want to know about the other photovoltaics or solar companies that are out there, but that's not our interest. Other companies may be kind of gunning for us because we're the industry leader, but from our perspective, we're really gunning for the fossil-fuel industry.

> "For differentiated technologies, part of the differentiation is the lack of a standard, your own standard is the differentiation, so to speak."
>
> **Sohn, First Solar**

"We want to give utility companies a viable choice between dirty, traditional fossil fuel-generated energy and clean, environmentally friendly, photovoltaic-generated energy. That's what we see as the core vision of our company. If we're going to solve the world's problems, we have to do it on a massive scale. And you can't do things on a massive scale if it's always going to be subsidized.

"So our objective is to drive down the cost, so now a utility company executive has to choose, 'Do I really want to put in this gas peaker plant or do I want to put in this solar power plant? Do I have to invest in this coal-fired plant and can I put in a solar power plant?' That's the choice that we're trying to create in the marketplace."

Cost reduction makes happy customers

This relentless commitment to cost reduction helped land key early contracts for First Solar and underscores the company's recognition of the importance of that old chestnut of "putting your money where your mouth is."

"We try and make sure that we drive a cost roadmap that continues to scale down over time," explains Sohn. "We were so committed to that when we signed our contracts with our initial six customers, we committed to them over a six-year period that we would reduce the cost of our modules about $6^1/_2$% per year, matching the EEG (German Renewable Energy Sources Act) digression at the time. That was a long-term promise to our customers, which was something that they needed to ensure that they could maintain their margins and strengthen their business over time.

Photo: Tom Cheyney.

There are more cows than solar modules at the future site of the Topaz solar farm in central California.

"That's what we're really trying to do," stresses Sohn. "We want to make sure that we can keep our costs in a position that facilitates the ongoing flow of our modules into the marketplace, but also serves to strengthen our customers and make sure that they can be effective in maintaining their returns and so forth as they do the installations."

OptiSolar and the challenges of growing the project pipeline

Over the past year or two, rarely does a lunar cycle go by without yet another announcement of First Solar adding to its European, North American, or even Australian project pipeline or having an installation completed using megawatts of their ebony glass-on-glass laminate PV modules. The rate of growth of its U.S. utility business has been especially impressive, with big wins scored with Sempra, Southern California Edison, and Tri-State in New Mexico. But the biggest fishes in the project barrel are the development assets acquired by First from OptiSolar, including the massive proposed 550MW (AC) Topaz Farm PV power station site to be built to feed electricity to Pacific Gas & Electric in central California's Carrizo Plain area in eastern San Luis Obispo County.

Don't expect to see any "Welcome to Future Home of Topaz Solar Farm" signage out on Bitterwater Road off California Highway 58 though. The miles of flat farm and ranch land are anything but shovel-ready for solar, and the location raises questions like the ability of the two-lane highways to handle fleets of trucks carrying million of panels, hundreds of inverters, and other balance of system components.

"Those are the kinds of logistics that we still need to be working on," admits Sohn. "The Opti team really had not gotten into the detail on the engineering side of the project, so we're starting to do that. I think that our organization already does have a lot of that sort of competence; handling logistics, the flow of materials; we're starting to learn that, the layout and the design, the optimization on a particular property.

"That's real important from a utility company's perspective," he posits. "Utility companies are really not interested in buying solar modules, at least that's been my experience. They have very little interest in buying a solar module but they are perfectly happy buying millions of them if they're buying a solar power plant. That's what we're delivering to them – a power plant."

The company plans to start development of the Topaz site "sometime next year," says Sohn. "We're still working out the details. There's quite a bit of permitting and things like that we have to go through. It won't be limited by engineering, it will be limited by permitting and regulatory processes, which unfortunately is typically the issue with these projects.

"That's one of those things that slow things down in the United States in particular," he grouses. "It's common to take 18-24 months from the time that you start to develop a project to the time you

Photo: Tom Cheyney.

In a few years, millions and millions of black First Solar panels will stretch as far as the eye can see at the Topaz solar farm site in central California.

put the first shovel in the ground in the U.S. Whether it's dealing with the property and the real estate acquisition, the general technical permitting, the environmental permitting, the transmission approval processes, or the power purchase agreements that go along with these projects, all those things have a lot of regulatory requirements associated with them. That's a real challenge for us, and it's something that's significantly different from what we see in Europe."

By contrast, Sohn points out that "you can go and talk about a project and in the course of a few months, you can start the construction over there. What can take 8, 10, 12 weeks over in Germany can take the same number of quarters in the U.S. That's really a reflection of the effectiveness that was coded into the EEG. There's no need for a utility company or any of the regulatory bodies to be slow about permitting these projects. It's to their advantage to get it going quicker over there."

Applying copy smart to the EPC side

First Solar's manufacturing and technology scalability mantra is now being applied to the construction side, explains Sohn. "What our strategy is with engineering and construction is to do in the field what we've done in our factories. So we use terms like 'copy smart' out in the field. We talk about installing these arrays in a very reproducible sort of manner, so we can teach someone how to do these installations, and then be able to install them very rapidly.

"Two of the parameters that we use internally are 'velocity of installing,' in kilowatts a day, and the other is 'time to energy,' from the time you start a portion of the array to the time that that part of the array is actually generating energy. Obviously, we want to increase the velocity and shorten that time to energy. Because that's the objective – again, we're not selling modules, we're selling energy, and if it's not producing energy, we really haven't sold anything, both in a figurative sense and in a revenue recognition sense.

> "What our strategy is with engineering and construction is to do in the field what we've done in our factories. So we use terms like 'copy smart' out in the field."
>
> **Sohn, First Solar**

"That's a lot of our focus right now," he continues. "We apply theory of constraints in the field, we apply logistics management, just-in-time inventory management control, MIS utilized to maintain communications in the field, apply our safety methodologies in the field, all of those sorts of things, the kind of things we learned in building a factory and replicating a factory, we're putting out in the field."

'You gotta think big'

As the interview winds down, Sohn waxes passionate about what's needed from the solar energy industry to help ameliorate the intertwined geopolitical, socioeconomic, and climate change issues. "If you're going to solve those problems, it's gotta be much bigger. We gotta talk multigigawatts going out there, because that's really where we're headed. It can't but be just one gigawatt here and one gigawatt there. We gotta be thinking about what's the 5GW company, what's the 10GW company, and what limits us from getting up to 2 and 5 and 10?

"It quickly gets to the point where it's not necessarily the technology, it's not necessarily the supply chain, it's the things related to the development of the projects, the governmental policies. Those are the kinds of things that may significantly limit the industry's ability to scale to those levels where we can solve those world problems."

About the Author

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Flexible CIGS thin-film PV establishes module manufacturing base, moves closer to BIPV market readiness

Mark McIntyre, Global Solar Energy, Tucson, Arizona, USA

ABSTRACT

Despite the low-cost, high-efficiency, radical form factor promise of many thin-film photovoltaic technologies, scaling these materials to large-volume production has presented a wide array of challenges. Because of the recent polysilicon shortage, an incredible amount of resources have been focused on this goal and many thin-film alternatives are now available. One of the most intriguing of these materials, copper indium gallium diselenide (CIGS), has great potential to reset the thin-film market and make new applications cost effective and viable. CIGS technology is differentiated from competing PV materials by a combination of factors. The manufacturing cost of thin-film cells can be very inexpensive since they require few raw materials and can be made with an efficient, scalable roll-to-roll process. CIGS has been established as the most efficient thin-film technology in converting sunlight into electricity. A flexible substrate will ultimately enable energy and building-integrated applications beyond the capability of rigid, heavier PV products.

Introduction

Global Solar Energy, a manufacturer of thin-film PV cells, has been able to scale up manufacturing capacity of CIGS on a flexible stainless-steel substrate to 70MW at production facilities in Tucson, Arizona and Berlin. The company's strategy has been to gain early entry to the market, attract dynamic technology partners, and leverage these partners' expertise to accelerate development of next-generation flexible CIGS systems.

The first step on this path has been accomplished by building on well-known module assembly methodologies established by silicon PV, specifically the tabbing and stringing configuration of cells and glass module encapsulation. By adopting these industry standards, significant technology hurdles have been bypassed and the kind of large-scale

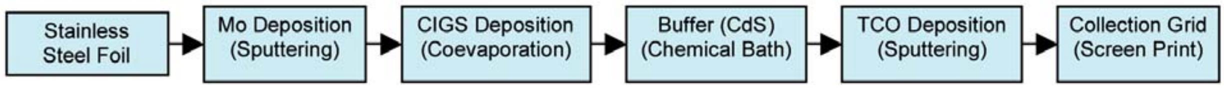

Figure 1. Flexible CIGS roll-to-roll manufacturing flow.

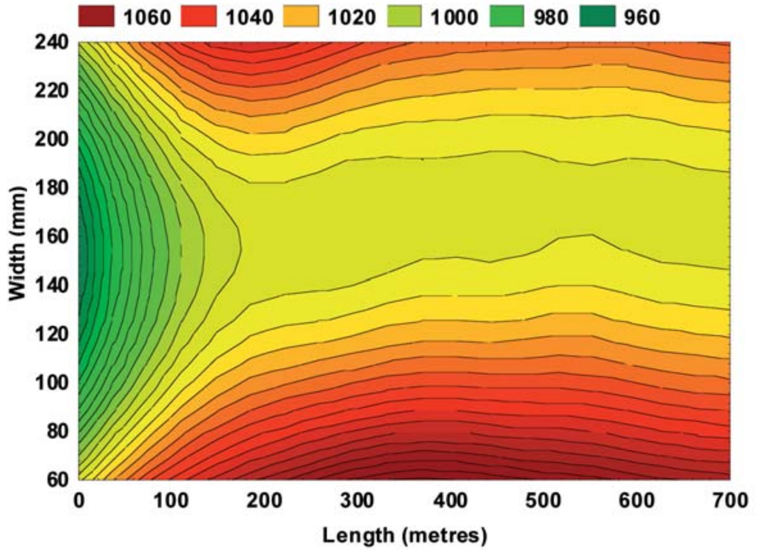

Figure 2. Contour plot of Mo thickness (a.u.) down and across the web as measured by XRF (distance weighted least squares fit).

Figure 3. Equipment for CIGS deposition by coevaporation.

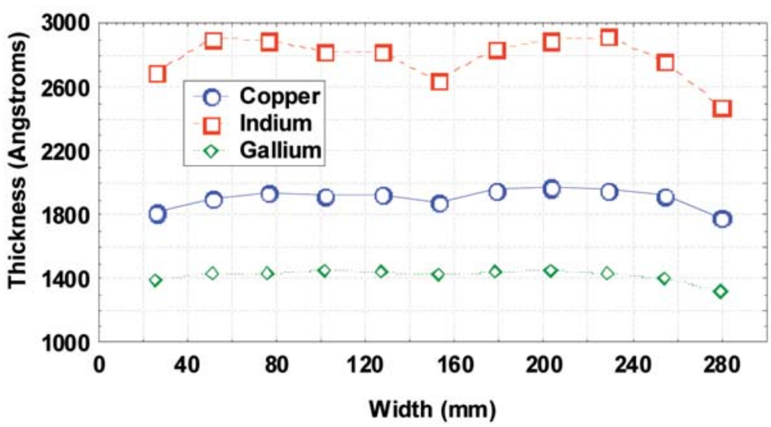

Figure 4. Equivalent thicknesses of copper, indium, and gallium in a CIGS film (across the web width) as measured by ex-situ XRF.

manufacturing base needed to be cost-competitive and to attract partners with critical expertise has been established. The company's 'strings' of CIGS cells are now being sold to glass module manufacturers for use in solar power fields.

Global Solar is working with several leading technology companies to address those 'bypassed technology hurdles' and implement its long-term strategic roadmap to bring to market a flexible, lightweight, high power-density photovoltaic solution for OEM product manufacturers. A flexible moisture barrier and integrated cell interconnection are the two critical technologies that the company believes will enable it to capitalize on these sustainable competitive advantages of CIGS thin-film technology. This article describes a flexible CIGS thin-film PV manufacturing process, the current product being manufactured in high volume, the technology developments being pursued, and the future market opportunities that will result from these efforts.

> "A flexible moisture barrier and integrated cell interconnection are the two critical technologies that the company believes will enable it to capitalize on these sustainable competitive advantages of CIGS thin-film technology."

CIGS manufacturing process

The company's manufacturing process can be broken into two distinct parts: material deposition and string assembly [1,2]. The first manufacturing segment emphasizes roll-to-roll processing, as shown in Figure 1. Cell size and shape are introduced at the end of the first manufacturing segment when the cell dimensions are defined by screen-printing a conductive ink 'collection grid' on the top surface of the PV material. At this point, the PV material is cut into cells and connected in series into 18-cell strings.

The material deposition processes follow a batch manufacturing flow using stainless-steel flexible webs up to 1000 metres long, one-third of a metre wide, and 25µm thick. Each web is processed independently through the coating steps. Since each web and mandrel combination weighs between 40 and 60kg, they are


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loaded and unloaded into the deposition tools by crane and conveyed between processes on carts.

Batch-style production decouples the optimization of the individual processes and the balancing of production flow. Each deposition process is independently optimized and production capacity bottlenecks can be addressed by adding additional tools. Multiple toolsets also provide redundancy to mitigate the impact of equipment downtime. Finally, batch production permits offline characterization between process steps for improved quality control.

Substrate and back electrode

The stainless-steel foil substrate was chosen over other options (polyimide film, glass, etc.) because it enables significant competitive advantages compared to other thin-film technologies and processes. The foil is relatively lightweight and flexible – valuable characteristics for emerging building-integrated photovoltaic (BIPV) applications. The stainless-steel substrate also allows the highest material processing temperatures, which help facilitate the best photovoltaic conversion efficiencies in CIGS. A stable platform for the deposition is provided by the foil's coefficient of thermal expansion, another critical factor in maintaining performance stability and product lifetime.

The back-electrode materials of chromium and molybdenum are deposited by pulsed-DC sputtering. The thin chromium coating enhances adhesion of the molybdenum, while the molybdenum protects the substrate and readily accepts

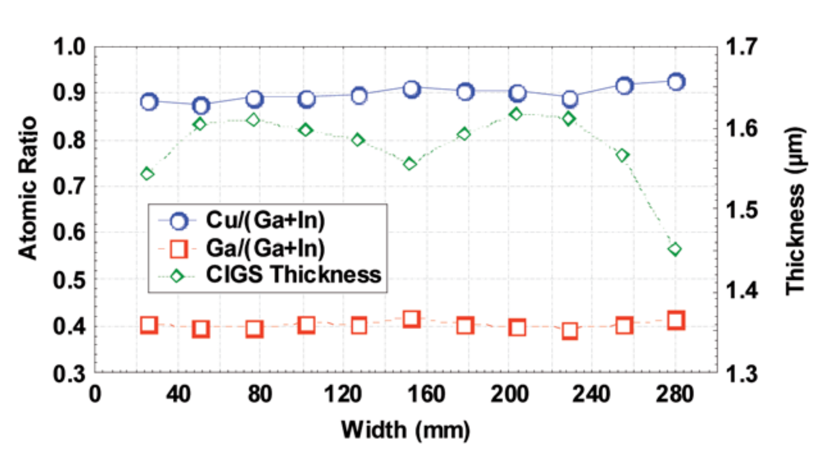

Figure 5. Atomic ratios and thickness of a CIGS film (across the web width) as measured by ex-situ XRF.

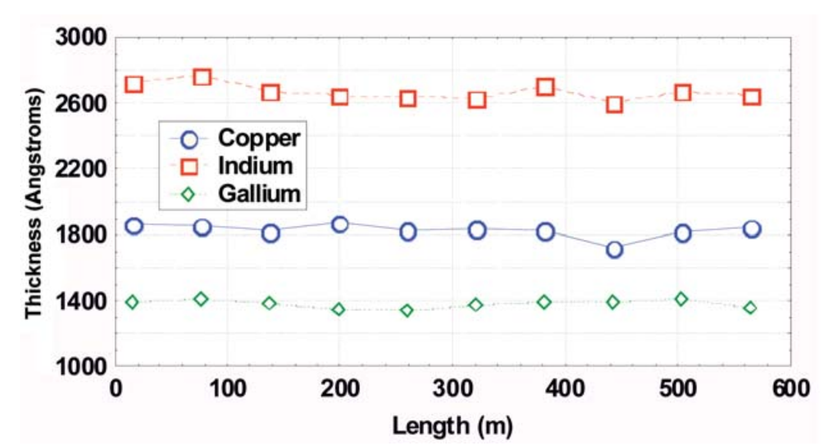

Figure 6. Equivalent thicknesses of copper, indium, and gallium in a CIGS film (down the web length) as measured by ex-situ XRF at the web centre.

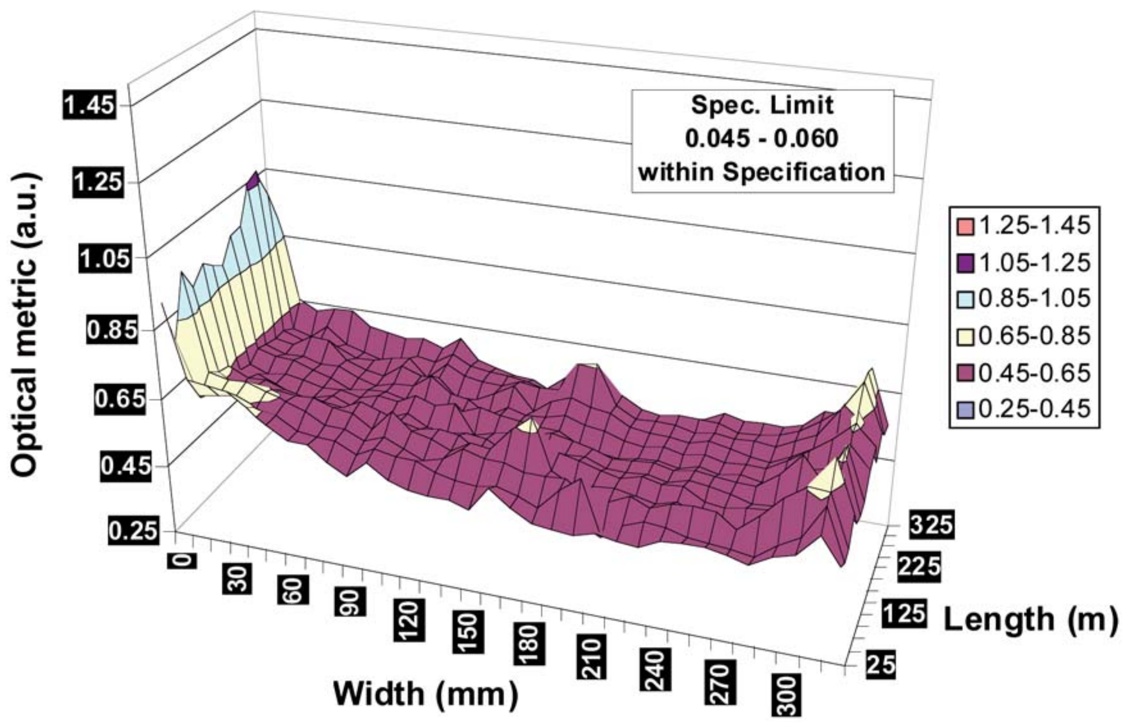

Figure 7. Optical confirmation of CdS coating thickness within specification down and across the web.

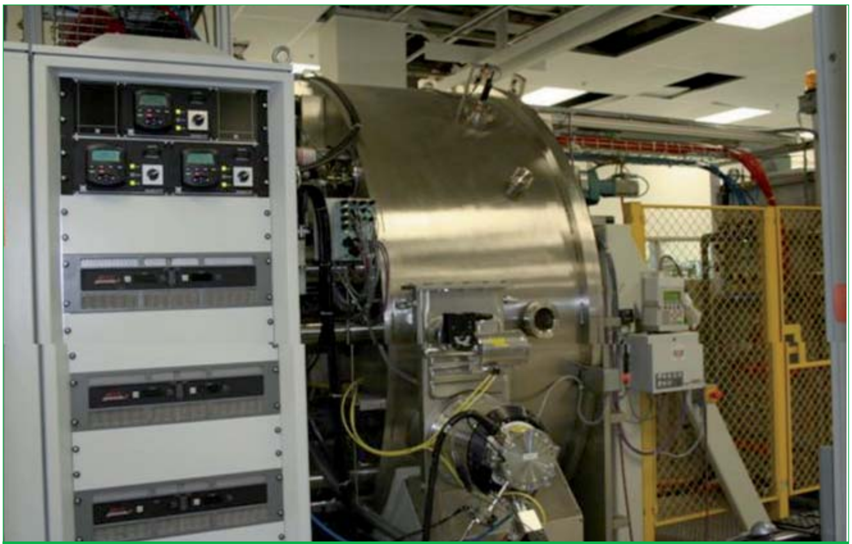

Figure 8. Front-electrode deposition by sputtering (a similar tool is applied for the back electrode).

the CIGS layer. The thickness of the back electrode is optimized for maximum performance and minimal cost [3]; the Mo coating thickness is characterized by XRF (Figure 2). Along the majority of the web length, the thickness uniformity is +/- 3%, and the thinnest coating occurs in the web centre and at the beginning of the web.

Absorber layer

CIGS is a direct bandgap material with good light absorption properties and a bandgap energy well-matched to the solar spectrum. This p-type semiconductor material has excellent long-term stability and has been called a "smart" or "self-healing" material because of its copper-related properties.

CIGS is deposited by multisource coevaporation of the elements (Figure 3). The effusion sources are loaded with the least expensive forms of the metals (shot, wire, etc.). In practice, the effusion source control reactivity is small because of the large thermal masses of the sources. The total deposition time for the CIGS coating, put down at a thickness of 1.7μm, is 2.6 minutes.

Coating uniformity of the copper, gallium and indium films, is critical to achieving optimal CIGS string performance and high yields. In practice, thermal evaporation cross-web uniformity is more difficult to achieve than uniformity down the web length. The cross-web CIGS uniformity is chiefly determined by the design of the effusion sources, deposition zone geometry (location of sources and shielding), and zone pressure. However, the new CIGS coaters and effusion sources have been designed with increased degrees of freedom to permit better control of coating thickness across the web than was allowed by the previous generation of coaters.

The cross-web profiles of the elements are similar for a typical CIGS film deposited in the new coaters, as shown in Figure 4. All elements are deposited from identical effusion sources in nearly the same environment, resulting in similar profiles. When combined to make CIGS, the thickness varies across the web width, but the composite ratios Cu/(Ga+In) and Ga/(Ga+In) remain relatively uniform (see Figure 5).

The coating uniformity of Cu, Ga, and In along the web length has been evaluated by XRF for CIGS-coated webs up to 670m

Figure 9. Collection grid printing system for CIGS cells.

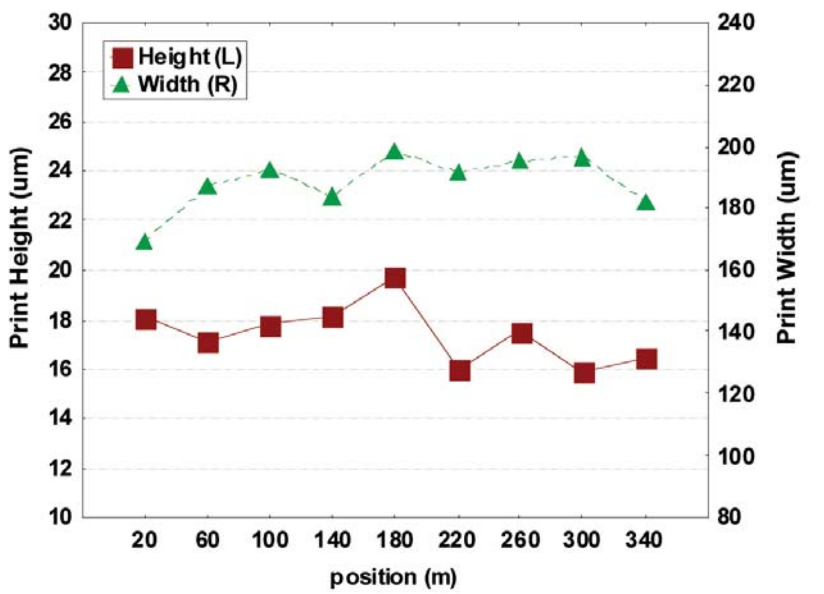

Figure 10. Collection grid finger average print characteristics along the web length.

in length (Figure 6). In this instance, the web was sampled at identical cross-web locations down the length of the web. The effusion sources contain relatively large charges of the elements. The large thermal masses provide stable evaporation rates within the response time of the control loop, and uniformity along the length of the web is generally excellent.

Buffer layer

The cadmium sulphide (CdS) layer, which acts as the 'n' part of the p-n junction that forms the PV cell, is deposited in a wet chemical bath. CdS and the deposition method used have diverse beneficial properties and are important factors in the manufacturing of a robust PV material.

Targeted CdS thickness is approximately 80nm. If the CdS coating thickness is less than optimal, open circuit voltage (V_{oc}) and fill factor are reduced; in much the same way, if the coating thickness exceeds the optimal value, short circuit current density (J_{sc}) is decreased because of increased absorption of light within the CdS coating.

A non-destructive optical technique (see Figure 7) has been developed for qualification of the CdS coating thickness on production webs. The characterization is performed after the CdS has been applied on the CIGS coating, and prior to the deposition of the TCO coating. The CdS coating thickness is typically within specification in the utilized portion of the web, as web edges are not utilized. In addition, the CdS process effluent is treated by a purification system to reduce metals and other contaminants levels below those considered hazardous, with only solid waste generated.

Front electrode

A transparent and conductive layer is sputtered onto the top surface of the photovoltaic material and acts as the front electrode for the device, allowing electrical contact to the device, acting as the current collection layer and also stabilizing and protecting the semiconductor layers below. The TCO, an n-type material that complements the underlying CdS n-type buffer coat, is deposited by a pulsed-DC sputtering tool such as that featured in Figure 8. The total TCO coating thickness is approximately 100nm.

Collection grid printing

The final deposition step – the screen-printing of a conductive grid – serves as the collection circuit for the photoelectrons that have reached the cell surface, which in turn defines the cell dimensions and the contact areas for the ribbons used to assemble the strings. The area where the web is cut to create the individual cells is not coated with ink; if this happens, there is a strong probability that the ink will be smeared through the cut layers and create a short between the top and bottom layers of the PV cell.

The collection grid is formed by roll-to-roll screen-printing of a silver ink (Figure 9), which is thermally cured in the same step, prior to rewrapping the web. The nominal cell dimensions are 210 x 100mm, with three cells printed across the web's width.

Designed to minimize resistive losses, cell shading and required silver ink volume, the collection grid's first order of business is the determination of the design targets – a task that can be achieved through proper screen design and tool setup. However, other variables such as inkpot life, screen wear and environmental conditions can push the process out of control. Resistive losses can be severe if the grid fingerprint geometry deviates substantially below the design goals for height and width. Excessive ink application can also add unnecessary product cost.

The ink-print process has been characterized by optical profilometry, in which process cells are extracted at intervals from a single printed reel 350m in length, and the grid fingerprint height and width are characterized at two locations on each cell. The mean ink height and width down the web has been determined to be within acceptable limits (Figure 10).

Web slitting

The last step before the string assembly process is the slitting of the completed webs of photovoltaic material. The initial 300mm-wide stainless-steel rolls have been processed through sputtering, evaporation, and plating operations. As noted earlier, one key challenge of high-volume manufacturing of CIGS thin-film material remains the deposition uniformity, especially in the cross-web direction. Variation of film uniformity across the short dimension of the roll can greatly impact the ultimate cell, string, and module performance.

To minimize the impact of this type of uniformity variation, the rolls are slit lengthwise into three reels, as illustrated in Figure 11. Each reel is 100mm in width (one cell wide) and 1000m in length. Slitting in this direction significantly tightens the range of film variation within the reel, which in turn directly transfers to a tighter distribution of cell performance within each string. When the cells are attached in series, the net performance of the assembled string is affected by the performance of the poorest cell. So, by matching cell performance as closely as possible, the highest possible string performance – and ultimately, module performance – can be achieved.

Tab and string

At this point in an analogous crystalline-silicon process, the PV material would be supplied as cells to the module manufacturer, which would feed the cells into a tabber-stringer system at the front end of the process flow. The tool would construct series-connected strings of Si cells using commercially available equipment, process recipes, and materials.

"The thin-film PV reels become the de facto feedstock for the customized and automated tabber-stringer. All remaining assembly processes occur within this tool and are fully automated."

For flexible CIGS PV material, however, there is no industry-standard stringing solution available. To address this obstacle and offer module manufacturers a 'drop-in' replacement for silicon cells, the stringing process has been integrated into the company's manufacturing capability. This stringing solution leverages the Si cell tabbing and string configuration and automated equipment technology as the shortest path to market for CIGS cells.

The thin-film PV reels become the de facto feedstock for the customized and automated tabber-stringer. All remaining assembly processes occur within this tool and are fully automated. Figure 12 depicts a general overview of the process flow. Single reels of printed cells are input to the stringer, and the cells are then separated and attached in series to one another by bonding conductive ribbons between the topside collection grid of one cell (negative pole) and the backside of an adjacent cell (positive pole). With three ribbons per cell, as shown in Figure 13, the strings are then electrically characterized and sorted according to their electrical output characteristics.

Product description

The primary product is an 18-cell PowerFlex solar string, a configuration designed as a 'drop-in' replacement for crystalline silicon photovoltaic strings that allows the CIGS thin-film technology to leverage the well-known encapsulation methods and tools used by the established module manufacturing base. This product is being marketed and sold to Solon and other PV module manufacturers for deployment in utility-scale power field projects.

Each cell is 100 x 210mm in area and can generate a nominal peak 0.4V, 5A, and 2.2W under standard test conditions. The power output of the 18-cell string is nominally 40W, depending on its net efficiency. The string assembly shown in Figure 14 measures roughly 1.8 metres long; the typical physical and electrical parameters of the string are summarized in Table 1.

Module construction

The module manufacturers commonly combine four CIGS strings in a traditional glass/PV/backsheet module construction. Although the string format may appear familiar to module customers, the material does require some accommodation. CIGS and thin-film string performance have been shown to be sensitive to moisture and environmental conditions, thus proper encapsulation is critical in achieving the longest possible product lifetimes.

Extensive material testing and module analysis have been performed to identify and validate CIGS-compatible module construction materials. This work has resulted in a module design that meets certification standards such as IEC 61646, “Thin-film terrestrial photovoltaic modules – Design qualification and type approval,” based on tests conducted at the Arizona State University Photovoltaic Testing Lab. The company has also worked closely with equipment manufacturers to develop automated handling solutions that integrate the flexible CIGS strings into an existing module production line.

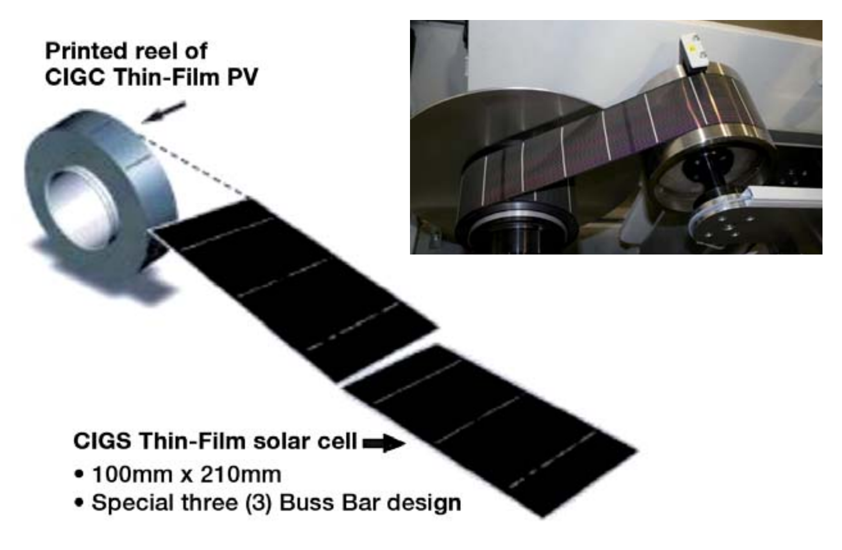

Figure 11. Illustration of printed reel of flexible CIGS thin-film PV.

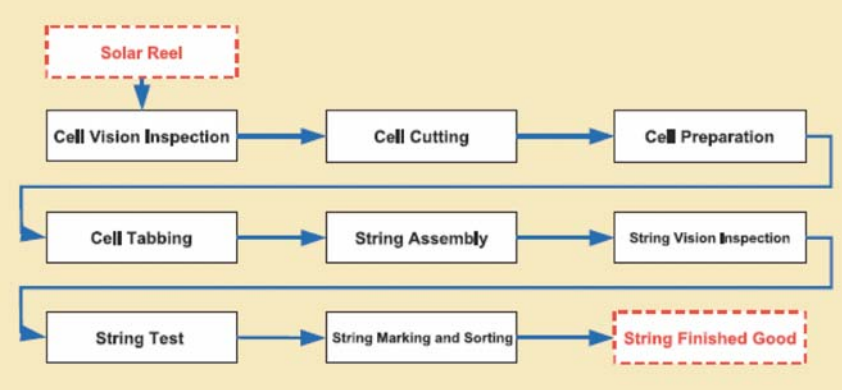

Figure 12. Tabber-stringer process flow for flexible CIGS thin-film PV.

Applications

Utility-scale power generation

One of the largest CIGS power fields in the world sits adjacent to the company’s Tucson facility. This 750kW DC field, which has been operating since November 2008, contains 6600 CIGS-strings-in-glass modules. The installation has been estimated to be capable of generating 1.1 million kWh of electricity annually for the nearby PV manufacturing plant. As Table 2 reveals, the actual field output has exceeded this rate by almost 25% over the first months of operation, demonstrating the viability and availability of CIGS-based utility-scale power generation.

The only significant solar plant design consideration for CIGS modules is making sure that the inverter has an adequate input voltage range. Since CIGS has a different fill factor and thermal coefficient than crystalline silicon, the inverter input voltage must incorporate a slightly broader range over possible operating conditions. Other field design elements such as site requirements, array support structures, sizing and wiring configurations, monitoring, and operations systems are mostly transparent to the CIGS cells and fall within industry standard practices.

Building-integrated photovoltaics

BIPV describes photovoltaic technology integrated into building materials to replace traditional roofing, shading, and façade products, with the goal of reducing material and installation costs and meeting the aesthetic requirements of building design. BIPV has the potential to become a mainstream technology if it can meet these market goals. As with most product technologies, the cost threshold is the critical factor that differentiates a mainstream product from a niche product. Solar America Initiative participant Dow Chemical, with its ‘solar shingle’ approach to packaging CIGS cells within a roofing material, is among those companies pushing closer to developing cost-conscious commercial BIPV products.

BIPV products can leverage the potential of flexible, lightweight, high-efficiency CIGS technology to deliver:

- Lower installation costs. A flexible CIGS product will closely resemble the dominant roofing materials being used in the construction industry – composite asphalt shingles in residential roofing and roll membranes in commercial roofing. This will facilitate installation by the existing industry workforce without significant specialized training or additional manpower.
- Low manufacturing costs. Thin-film CIGS has the potential to reduce building product material and manufacturing costs to levels that will achieve grid parity and a competitive levelized cost of electricity (LCOE). This economic strategy requires efficient, high-volume, low-cost, automated mass production capabilities.
- Product aesthetics. Although not explicitly part of the cost equation,

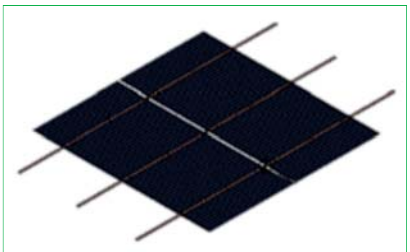

Figure 13. CIGS string and tab configuration (two-cell segment).

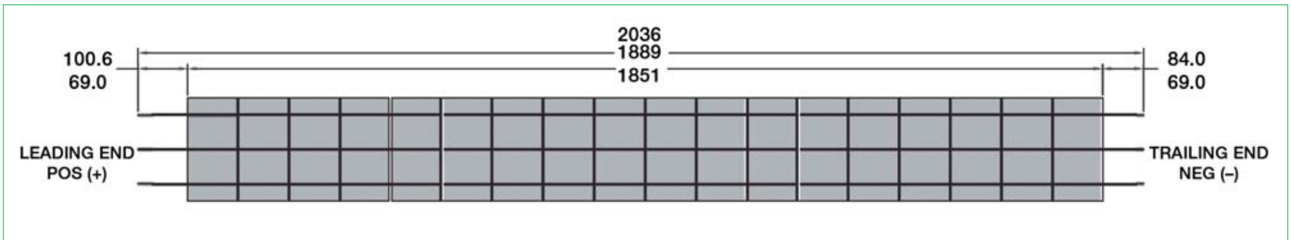

Figure 14. PowerFlex 18-cell CIGS string.

Parameter	18-cell String	Single Cell
Area (m^2)	0.39	0.022
Weight (g)	123	6.8
P_{max} (W)	39.5	2.2
V_{max} (V)	7.3	0.4
I_{max} (A)	5.4	5.4
V_{oc} (V)	10.3	0.6
I_{sc} (A)	6.7	6.7

Table 1. Typical physical and electrical parameters for 18-cell flexible CIGS string and single CIGS cell.

Year	Solar Energy Generated Month	Energy (MWh)
2009	Mar	124.37
2009	Feb	109.01
2009	Jan	110

Table 2. First-quarter 2009 energy output for Global Solar's Tucson CIGS thin-film PV module field.

aesthetics will be essential for demand generation as PV moves from the power field to the building market. Flexible CIGS can mimic traditional building material design forms to foster market acceptance and can fit into many applications where weight and conformal requirements limit the use of traditional silicon PV technologies.

Ultimately, CIGS PV has the potential to provide lower material costs and higher efficiencies than competing flexible thin-film technologies. Of these two factors, module efficiency stands as the most important consideration, since it is a nonlinear factor in the LCOE model.

Technology development

To enable CIGS-based flexible roofing and curtain wall products, ancillary technology solutions must be developed just as they have for the glass module. The key element needed for a 25-year BIPV product lifetime is a flexible moisture barrier that can replace glass. A natural starting point in the search for this film can be found in the OLED (organic light emitting diode) display development work that has been taking place for years. Many leading polymer companies have moisture barrier technologies that grew out of the OLED market and are being evaluated for solar applications.

Moisture barrier films have been sampled, test structures created, and thousands of hours of high-temperature (85°C), high-humidity (85% RH) screening tests performed. Existing encapsulation materials, such as ETFE, PET, and MET, have served as baseline controls capable of water vapour transmission rates down to 10^{-3}g/m^2 per day. One critical challenge in the evaluation of new barrier materials is that they have exceeded the detection limits of the industry's analytical methods used to measure their performance.

Most industry sources – including Fujifilm, which has developed an advanced "transparent super high barrier film" that can be deposited on various types of flexible base materials – believe a barrier level of 10^{-6}g/m^2 per day is needed to achieve the product lifetimes that will make BIPV products viable.

The accelerated DH test results are translated into product lifetime estimates by the compilation of lifetime data on flexible CIGS assemblies for many thousands of hours. These data are then compared in performance against the IEC-certified glass encapsulation baseline data. In the past year, there have been significant advancements in these barrier materials, and suppliers are beginning to plan for pilot production.

One company that has seen significant strides in this regard is DuPont Photovoltaic Solutions, claiming advances on such properties as transparency, ultramoisture barrier resistance, UV stability, and long-life durability on CIGS barrier materials for flexible BIPV applications, something it sees as a natural extension of its Teflon PV frontsheet product line.

To close the gap between commercially available vapour barrier performance and the level of protection required, on-going work also seeks to reduce the vulnerability of the CIGS assembly to the environment. The focus of this effort is development of new materials and methods of cell interconnection that are less vulnerable to moisture and have the additional benefits of being well-suited for roll-to-roll lamination and semi-customized product form factors. This work includes characterization under different environmental conditions of each CIGS cell layer and interface, as well as the materials and interfaces of the string assembly. GE Global Research has been actively engaged in analyzing the degradation kinetics of CIGS cells, and has come up with a model that will be used extensively to understand the tradeoffs between cell moisture sensitivity and package construction, as well as the ultimate impact on real-world lifetimes of various cell/package combinations.

Understanding the behaviour of the strings at this level has allowed material suppliers to accelerate development of new materials and solutions.

Conclusion

The presence of a flexible CIGS thin-film PV product in the market has attracted significant interest and enthusiasm from technology companies, which has led to the accelerated development of critical ancillary materials. As these new technologies reach commercial status and OEMs introduce new products, promising novel applications and new business models will become viable. High-performance flexible TFPV materials are beginning to blur the lines between the solar, building, and power generation industries.

References

[1] Britt, J. S., Wiedeman, S., Schoop, U. & Verebelyi, D. 2008, "High-volume manufacturing of flexible and lightweight CIGS solar cells," *33rd IEEE Photovoltaic Specialists Conference*, San Diego, California.

[2] Britt, J. S., Huntington, R., Van Alsburg, J., Wiedeman, S. & Beck, M.E. 2006, "Cost improvement for flexible CIGS based product," *Proceedings of 4th World Conference on Photovoltaic Energy Conversion*, IEEE, pp. 388-391.

[3] Britt, J. S., Kanto, E., Lundberg, S. & Beck, M.E. 2006, "CIGS device stability on flexible substrates," *Proceedings of 4th World Conference on Photovoltaic Energy Conversion*, IEEE, pp.352-355.

About the Author

Mark McIntyre is business development manager for Global Solar Energy. He is tasked with identifying and developing new applications for the company's technology and is primarily focused on BIPV applications. McIntyre's 25 years of experience are garnered from roles such as project engineer and program manager at Northup Grumman and, most recently, as an account manager for Fujifilm Electronic Materials, where he provided enabling technology to the semiconductor industry. McIntyre holds a B.S. in physics from the University of Arizona, and an M.S. in physics and an M.B.A. from Arizona State University. He was an adjunct faculty member in the Maricopa Community College (AZ) system for five years.

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Boosting performance and reducing the cost of thin-film photovoltaics with rotary magnetrons

Mark Osborne, News Editor, *Photovoltaics International*

ABSTRACT

A variety of thin-film technologies are now entering a volume manufacturing phase. The benchmark has already been set by First Solar, Inc. in its conversion efficiencies, volume ramp and lowest cost-per-watt in the PV industry. Large-area thin-film deposition is a critical process step, dictating cell performance, reliability and manufacturing throughput. However, adoption of thin-film solar cells has been limited in the past by relatively complex and costly manufacturing processes.

The advent of rotating cylindrical magnetrons for sputtering is demonstrating the potential to significantly reduce thin-film manufacturing costs. In this paper we discuss the basics of the technology and the developments taking place with some of the leading suppliers of sputtering target technology for the PV industry.

Technical barriers to volume production of thin-film technologies and market acceptance are declining rapidly. Although the current economic environment has affected many thin-film start-ups, causing them to delay or reduce planned ramps, the majority of market researchers expect a rapid growth in thin-film production over the coming years.

The Prometheus Institute expects thin-film technologies to make up 35% of all module production by 2010, equating to just over 8GW. Figure 1 shows a forecast for key thin-film technology production to 2012.

Up to now, the solar generating field has been dominated by polycrystalline silicon photovoltaics that are less expensive to make but also much more limited in their geographical applicability because they do not conduct light.

The adoption of rotating cylindrical magnetrons by thin-film manufacturers for the majority of required deposition materials and process steps is demonstrating the potential to significantly reduce thin-film manufacturing costs by increasing throughput by 10% to 20%, reducing downtime for changing the target by 80%+ and nearly doubling target material utilization to between 70% and 80%.

Traditional thin-film photovoltaic manufacturing

Thin-film photovoltaics are produced by sputtering or depositing a thin metal film such as indium tin oxide or aluminium zinc oxide onto a substrate such as glass. The sputtering process takes place in a vacuum chamber that contains the target consisting of the material to be deposited as well as the substrate. Argon is introduced into the chamber and ionized. The target material is maintained at a

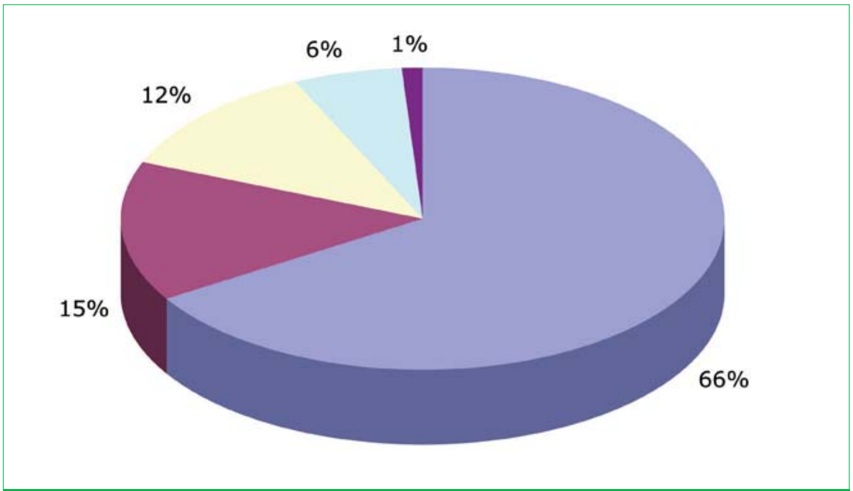


Figure 1. The Prometheus Institute: module fabrication volumes forecast to 2012 (MW).

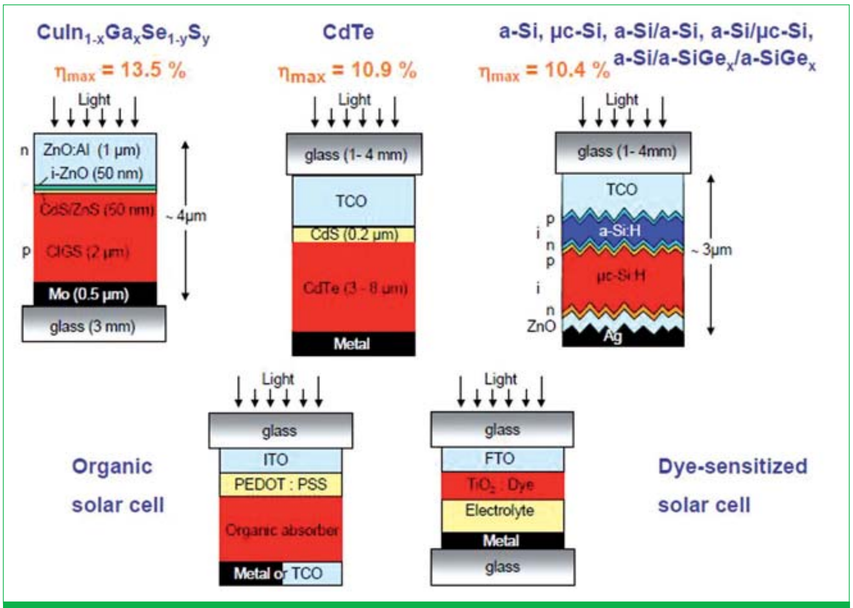


Figure 2. Typical variety of materials and cell structures used in thin-film technology. Many steps - such as TCO – require sputtering for correct deposition.

negative potential. The positively charged argon ion accelerates towards the target and strikes it with sufficient force to remove material.

The traditional approach uses a planar magnetron cathode. The weakness of this approach is that the usable volume of a planar is limited – a typical 5-inch by 20-inch by 0.5-inch planar target has a volume available for sputtering of about 50 cubic inches. Magnetic fields do not cover the entire target surface so some areas of the target are exhausted while others are barely touched.

> "Low utilization rates may be acceptable for pilot production levels but in a volume environment, targets become exhausted very quickly."

The utilization of a target by a typical planar magnetron is limited, according to Mark Bernick, President of Angstrom Sciences, Inc. "Even the most high performance linear arrays today typically only get in the 40% to 45% target utilization range, and that is with static magnets, which is typical for flat planars. With cylindrical rotating targets you can eliminate the trenching effect and utilize much more of the target. This equates to 2x utilization and 3x the area in the same tool footprint, so you gain 5x the efficiency."

Low utilization rates may be acceptable for pilot production levels but in a volume environment, targets become exhausted very quickly, requiring the line to be shut down periodically, reducing productivity and raising production costs.

Although there are inherent limitations with planar targets, this has not led to the technology's being omitted from thin-film PV manufacturing. Its lower up-front purchasing costs and widely understood parameters have been used for many R&D experiments and pilot production requirements. Furthermore, depending on the materials being deposited and their processing barriers, planar targets are being used in volume production.

"Unfortunately with some materials, providing them in tubular form is technically problematic," noted Bernick. "Some companies have retained planar targets and accepted that they will use several more planar targets compared to one cylindrical due to bonding material difficulties. Most metals are fine, though ceramic materials can be a problem."

Christopher Mihill, Managing Director of Testbourne Ltd., noted that some customers have retained planar targets for volume ramp due to the material challenges presented, even though they know the cost impact. "At the moment the material being used by the customer cannot be pressed into a rotatable shape."

> "The utilization of the target in a rotating cylindrical magnetron is considerably higher than a planar magnetron because rotating the target through the magnetic field assures that all areas of the target are eroded (exhausted) simultaneously."

Advantages of rotating magnetrons

Productivity and cost concerns are being addressed by a new generation of rotating cylindrical magnetrons that offer significant advantages over planar magnetrons. According to Angstrom Sciences, a typical rotating cylindrical magnetron with a 5-inch outside diameter, 4-inch inside diameter and 20-inch length has an available target volume of 108 cubic inches in the same footprint as a planar magnetron.

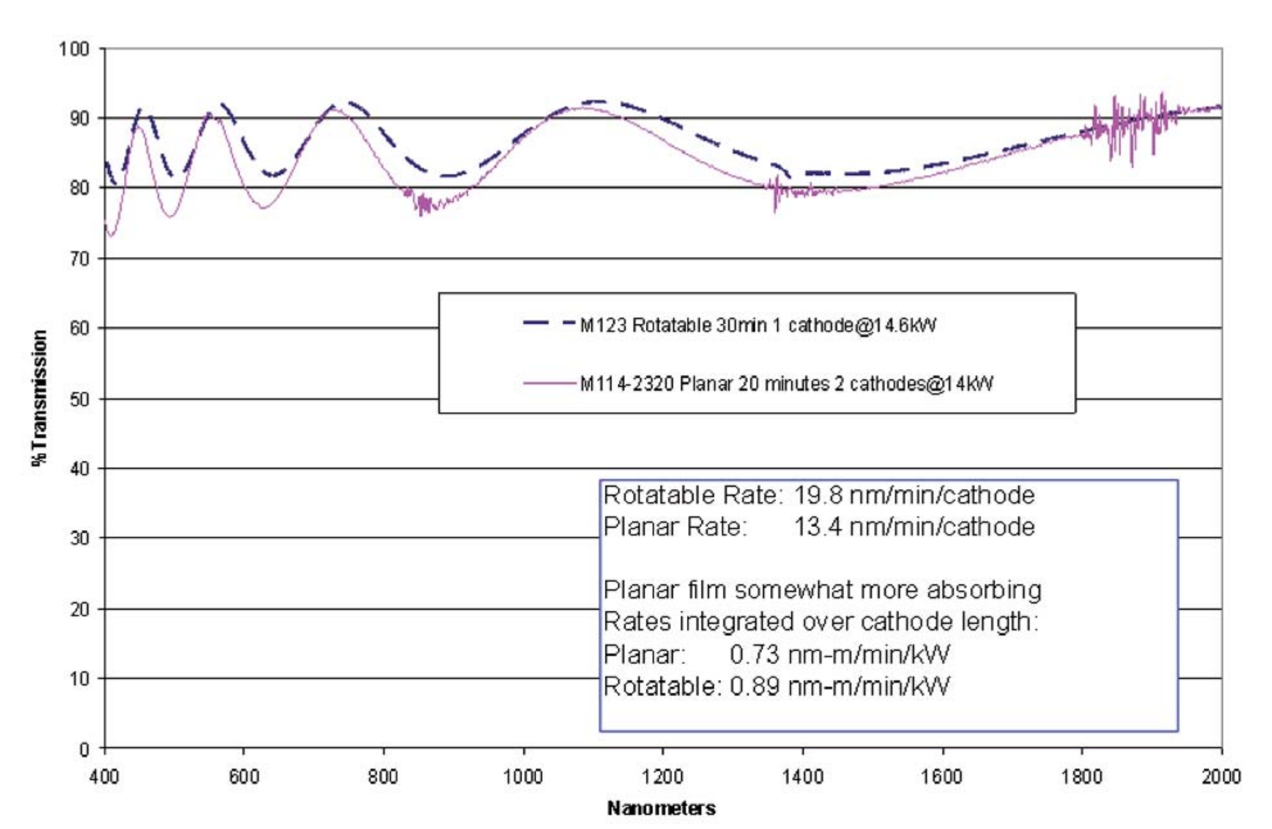


Figure 3. Rotating magnetron improves deposition rate by 10% to 20%.

Figure 4. Von Ardenne dual magnetron system.

The ability to fit more target into a given footprint is important given that processing is performed in a vacuum chamber and increasing the size of this chamber is very expensive. More than doubling of the target volume in the same space reduces downtime by increasing the interval at which the target needs to be replaced.

The amount of material in the target that can actually be used is limited by inevitable non-uniformities in the magnetic field used to direct ions to the target. The utilization of the target in a rotating cylindrical magnetron is considerably higher than a planar magnetron because rotating the target through the magnetic field assures that all areas of the target are eroded (exhausted) simultaneously. The best rotating magnetrons, according to the suppliers we surveyed, have a utilization rate of approximately 80%.

The increase in the amount of target material that is available for sputtering increases the sputtering yield as shown in Figure 3. The effective available target volume in a planar target is 50 cubic inches times 40%, or about 20 cubic inches. On the other hand, the effective volume per rotatable target is 108 cubic inches times 80%, or about 86 inches. This means that one rotatable target will last more than four times as long as a planar target resulting in a substantial reduction in downtime for changing targets and a resulting improvement in throughput. While the material in the target that is not utilized may be reclaimable, the vast majority of the cost of the target is involved in forming and bonding rather than material costs. The improvement in utilization provided by a rotating cylindrical target substantially reduces target costs.

John Madocks, Founder and President of General Plasma, Inc., noted other advantages to rotating cylindrical targets. "They also give you tremendous opportunity to cool the target as the heated zone is constantly moving away from the plasma. This enables the operator to turn the power up on the target to improve the rate of deposition. Something in the range of 10x the power density over planar can be used."

In a hypothetical planar configuration to match cylindrical target productivity, Madocks noted that such a situation would require 10 cathodes, a corresponding number of power and gas supplies all within the traditional chamber size. Adding more rotary magnetrons into the chamber boosts productivity further.

Optimizing the deposition profile

Electromagnetic simulation has been used to optimize the deposition profile of rotating magnetrons to reduce the debris landing on shields and potentially on the substrate. Figure 5 shows the typical magnetic field generated by a rotating magnetron. The magnetic field lines are largely focused off to the side, indicating that much of the target material will be aimed sideways at the shields rather than at the substrate.

> "The vast majority of the cost of the target is involved in forming and bonding rather than material costs."

Figure 6 shows how this field was improved by using electromagnetic simulation to optimize the geometry of the magnet. The field now points much more perpendicular to the substrate. In Figure 7, the blue line shows the typical deposition profile for a single rotatable magnetron while the red line shows the optimized deposition profile. The rotating magnetron with the optimized geometry can reduce the amount of debris landing on the shields and on the substrate by 33%.

The improved utilization offered by rotating cylindrical magnetrons also helps reduce the potential problem of re-deposition. Re-deposition is caused when the target material is deposited upon the un-eroded areas in the target. This re-deposited target material is poorly adhered to the target so over time it can break loose and fall onto the substrate causing contamination and potential quality problems. Cylindrical magnetrons greatly reduce the risk of re-deposition because the un-eroded areas are smaller and are completely off the substrate quality area.

Boosting performance

With some key inherent advantages offered by rotating cylindrical magnetrons, limitations do exist in boosting target utilization further than 80%. Although work would seem to be ongoing in tweaking these numbers, Madocks from General Plasma in particular cautioned over higher utilization claims.

"There is a lot of talk about achieving as much as 90% utilization rates; however this can confuse customers. The ability to add slightly more material at the ends of the cylinder would boost overall utilization of the target, but the trade-off is uniformity. It is therefore a balancing act between racetrack performance and uniformity which in itself could impact overall productivity of the line due to yield issues."

There would also seem to be little advantage in moving to higher purity materials. The consensus would seem to be that material purity levels currently supplied for sputtering are more than adequate.

Though reluctant to discuss the areas available to boost target performance, suppliers are continuing to develop the technology further, especially in the area of material density deposited, which can in turn boost cell conversion and yield levels. While not all material layers require thickness reduction for cell efficiencies, small gains in material cost reduction could be advantageous.

Koen Staelens, Product Market Manager at Bekaert Sputter Products, believes that intensive R&D efforts, as well as the in-depth understanding of customer applications that has come about via the company's being able to supply sputter hardware and targets, has pushed the performance barriers.

"We are often in a unique position to understand a customer's material requirements by first undertaking in house testing as well as the engineering to obtain the best solution via customization," commented Staelens. "We are also continually improving the hardware such as magnet bars for different materials and thicknesses. Improving reliability is also undertaken to improve the length of the coating runs. On the material front, we are constantly looking for new materials to boost density of the layers."

Volume production

The expected ramp of multiple large-scale thin-film facilities in the coming years could generate bottlenecks in the material supply chain, not least in sputtering targets, especially with an emphasis on using rotary targets.

The clear consensus amongst the suppliers interviewed was that raw material supply would not be an issue, and that the suppliers would be able to ramp production of targets to meet that demand.

Testbourne's Mihill characterised this confidence by noting that "although many thin-film companies are currently at low manufacturing levels, a particular customer is expected to require 600 to 1,000 targets as they ramp and between 4x and 8x that number in the future. We don't see any problem in matching that kind of requirement when it materialises with additional production lines for the targets."

"Though intrinsic limitations exist, there is a significant advantage associated with rotary magnetron technology over planar technology for thin-film manufacturers' ramping capacity."

Another benefit to thin-film manufacturers ramping is the cost reduction expected from lower material costs for target making as the economies of scale become significant. This will in turn enable suppliers to reduce the cost of targets over time, further helping to reduce the cost-per-watt.

Conclusion

One of the key factors in increasing the penetration of thin-film photovoltaics is reducing manufacturing costs. Rotary magnetrons have demonstrated their ability to substantially reduce thin-film photovoltaic manufacturing costs by increasing deposition rates, reducing downtime and reducing target cost. Though intrinsic limitations exist, there is a significant advantage associated with rotary magnetron technology over planar technology for thin-film manufacturers' ramping capacity that benefits should be realised over a long period of time.

"This technology [rotary magnetrons] can play a major role in helping thin-film photovoltaics achieve their full potential to increase the supply of renewable energy at an affordable price," concluded Angstrom Sciences' Bernick.

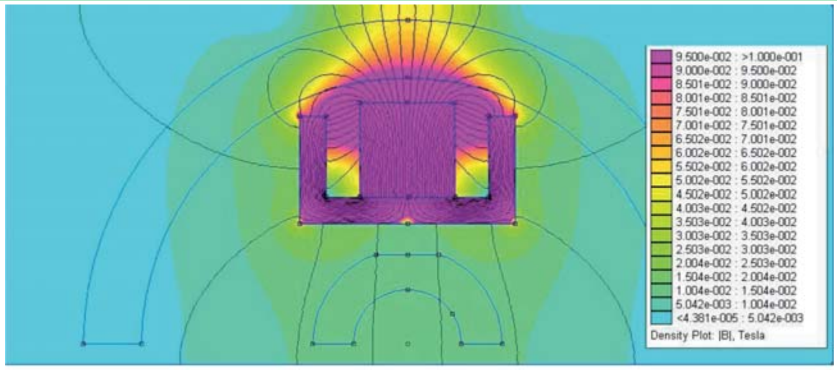


Figure 5. Electromagnetic simulation of rotary magnetron without optimization.

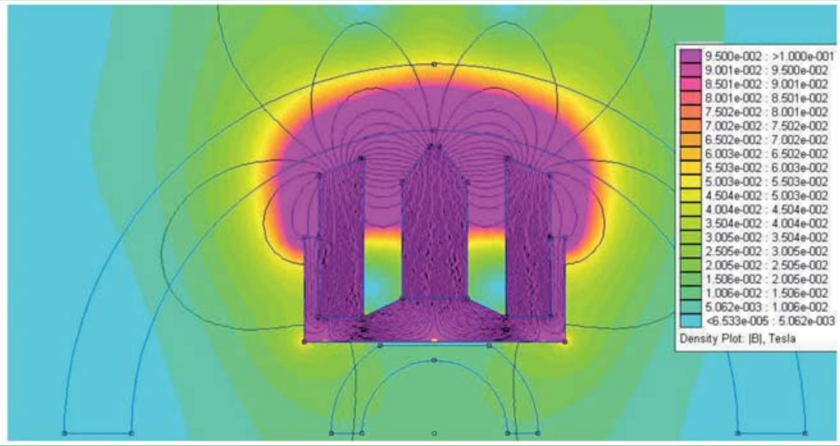


Figure 6. Electromagnetic simulation of rotary magnetron that has been optimized to improve the erosion profile.

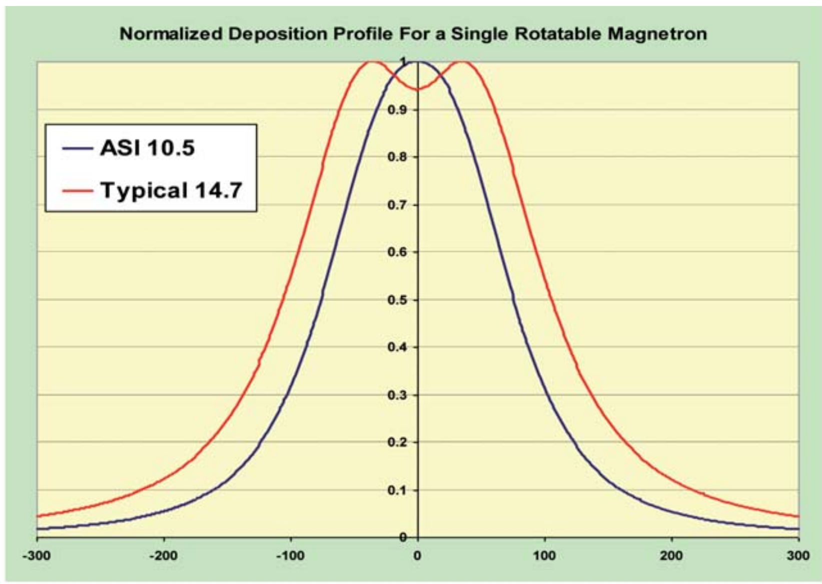


Figure 7. Rotary magnetron with optimized fields (blue line) directs more target material at substrate than un-optimized rotary magnetron (red line).

Acknowledgements

The author would like to thank all of the companies and their executives that took part in this feature for their time and insight into the subject matter, particularly **Mark Bernick** and his team at **Angstrom Sciences, Inc.** for providing a detailed amount of background information and technical basics used in this feature.

About the Author

Mark Osborne is news editor for *Photovoltaics International* and has been covering the semiconductor and related industries for over 10 years.

PV Modules

Evergreen Solar rises above its competitors in TÜV performance test

Evergreen Solar, Inc., developers and marketers of low-cost silicon wafer manufacturing technology and String Ribbon solar power products, has announced high ratings in two significant performance tests.

Evergreen Solar's ES-Series String Ribbon solar panel, a product that delivered the most kilowatt hours of electricity out of 14 competitors, is currently undergoing a yearlong test that was due to end in April 2009, conducted by TÜV Rheinland Group. Another test, conducted by PHOTON, also confirmed high ratings for the company, with the panels delivering 1038 kilowatt hours of electricity for the entire year. Unlike other companies that can only guarantee initially 95-97% of the nameplate power rating, Evergreen's solar panels are claimed to guarantee 100%.

Evergreen Solar's ES-Series String Ribbon solar panel.

Module Production News Focus

SCHOTT Solar to continue aggressive solar module ramp in 2009

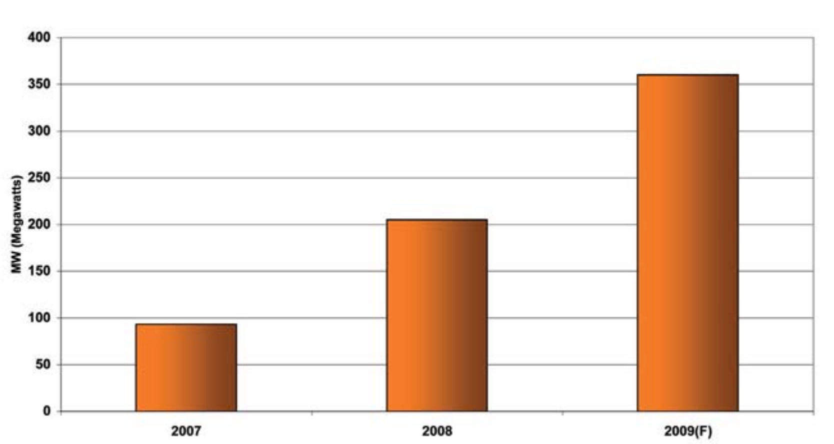
SCHOTT Solar AG has reiterated plans to continue aggressively expanding its solar module manufacturing capacity in 2009, after doubling production in 2008 to 205MW, compared to 98MW in 2007. The company said that capacity at its 'Photovoltaics' arm, which includes c-Si and thin-film modules, is scheduled to reach a total of 360MW by the end of 2009. Its 'Concentrated Solar Power' arm would expand to 1GWel, this year.

"We are highly satisfied with the past fiscal year, as we have reached important milestones of our ambitious expansion plans in both segments, while at the same time achieving a sustainable increase in profitability," said Chief Executive Officer Dr. Martin Heming.

The company has also announced record sales in 2008, growing 70% to €482 million, compared to sales of €283 million in 2007. It has invested €141 million in property, plant and equipment and intangible assets in 2008, compared to €88 million in 2007.

However, the company noted that although it received strong orders in Q1, the industry environment was challenging and difficult to currently project solar demand in 2009, due to the economic crisis.

Source: Photovoltaics International



SCHOTT Solar AG's PV module production expansion plans.

PV module market to contract by 15% in worst growth year since 1994, says Greentech Media

Greentech Media and the Prometheus Institute for Sustainable Development claim that 2009 will see the weakest growth year since 1994, and that the industry will be dominated by Asian multicrystalline and CIGS, with solid share for CdTe and super monocrystalline technologies, by 2012.

Using a newly formulated integrated supply-demand model, the report, '2009 Global PV Demand Analysis and Forecast: Anatomy of a Shakeout II' (which is the companion to the groups' 'PV Technology, Production, and Cost, 2009 Forecast: Anatomy of a Shakeout' report), also forecasts a contraction of the PV module market by 15% – to US$12 billion this year – on 5GW of global demand.

The authors point out that with global demand growth roughly flat from 2008 to 2009 and a doubling of feedstock and module production capacity over that period, the world has almost instantly shifted to a demand-constrained market. The analysis of a buyer's market must use a buyer's metric. Some key findings of the study are:

- A predicted fall in module ASPs to below US$2.50 per watt in 2009 will be followed by a further decrease in 2010 to US$2.00 per watt as demand-side financing pressures force manufacturers to cut prices.
- Global module capacity will grow to 27.5GW by 2012, which will be enough to produce 23GW of PV modules; thin film will account for 34% of that total. Market share for thin-film modules, in terms of incremental demand, will increase from 28% in 2008 to 50% by 2012.
- The cost of c-Si modules is expescted to decrease by around 50% to US$1.40 per watt by 2015, while the cost of CIGS modules will fall to US$0.75 per watt over the same period.
- High-efficiency monocrystalline and low-cost thin-film technologies will see a 30% cost advantage over traditional multicrystalline producers as a result of efficiency adjustments.

Helios achieves cell production of 60MW and initiates second module line

Italian module producer Helios Technology S.p.A. has achieved its target of 60MWp cell capacity at its manufacturing plant in Padua. The company has also begun production on its second module line, which has a capacity of 25MWp, and will potentially bring the company's total module capacity to 50MWp by the second quarter of 2009.

Helios's two 30MWp cell production lines – the second of which has recently reached full capacity – operate in a continuous cycle and produce both mono- and polycrystalline photovoltaic cells (<16.5% polycrystalline and <17.5% monocrystalline).

The company's initiation of its second module production line will see the

output of modules comprising 60 mono- and polycrystalline cells with maximum power outputs of up to 235Wp.

Signet Solar chooses Dr. Schenk inline metrology for thin-film PV production line

Thin-film PV module manufacturer Signet Solar has chosen inline metrology systems from Dr. Schenk for its volume production fab. Signet will use the quality and process control gear in its factory near Dresden, which houses the first TFPV manufacturing site to receive factory acceptance for an Applied Materials-supplied SunFab turnkey line.

"The mass production identifies problems that can only be overcome by integrating additional inline metrology," said Gunter Ziegnebalg, managing director of Signet Solar. "We do not want to run the line in blind flight, therefore we decided to monitor the process, to further improve it, and to control the quality of our modules with the solutions of the market leader Dr. Schenk."

Dr. Schenk recently launched its SolarMeasure suite of products for measuring the physical and electrical characteristics of PV panels; the line includes tools for electrical insulation testing, haze and layer thickness monitoring, and resistivity and dimension measurement.

86 laid off by GE Solar in Delaware facility

GE Solar, a branch of the General Electric Company, has announced the layoff of the second and third production shifts as well as some engineering staff at the its Newark, Delaware manufacturing site. About 86 employees were released, down from 200 total workers.

A spokesperson for GE said, "The market for the solar technology manufactured at the Newark, Delaware facility has seen a sudden and dramatic decline, which required us to align our output with the market demand. The Newark plant will continue to manufacture solar modules, but operations in this area will be reduced from three shifts to one shift, requiring fewer workers."

Kyocera to build new Chinese solar PV module plant, will quadruple capacity at site

Kyocera has announced plans to begin construction of a new crystalline-silicon solar PV module manufacturing plant in Tianjin City, China. The facility will help boost production capacity from 60MW to 240MW at Kyocera Tianjin Solar by 2011.

The groundbreaking ceremony for the new plant was held on the site adjacent to the current facility in February 2009.

The company said the timing of the construction of the new plant, which will manufacture modules mainly for the Asian market, is timed to align the production capacity of solar modules with the increase in production of solar cells, which Kyocera plans to expand to 650MW by March 2012.

The new factory is scheduled for completion in spring 2010. On completion of the plant, all Kyocera Tianjin Solar manufacturing operations will be transferred to the new facility.

The company completed expansion and upgrading of its Tijuana, Mexico, module-making plant last year; the factory is targeted to reach a capacity of 150MW by 2011. Kyocera also recently announced plans to build a major solar-cell fab in Yuso City, Shiga, Japan.

Webel-SL Energy Systems to invest over US$35 million in 30MW Indian module plant

Webel-SL Energy Systems Ltd. has, according to a report in the Wall Street Journal, revealed it is to invest approximately 1.8 billion rupees (US$35.7 million) to build a second cell and module manufacturing facility in Kolkata, eastern India. The facility will bring Webel's annual manufacturing capacity from 12MW to 42MW.

Rising demand in India, as well as increasing sales orders from Europe, the U.S. and Australia, prompted the company to establish what will be its second module plant in India. The recent news of China's introduction of a solar subsidy program is also a potential boon for the company. The new facility was expected to be operational by the end of April.

3S Industries throws open doors of new Service & Technology Center

Housed in a highly modern, 1,500m^2 building, 3S Industries AG's new Service & Technology Center in Freiburg was opened recently amid much celebration. The centre will offer services such as technical support, pilot assembly and certification of modules, training seminars tailored individually to the needs of customers, as well as the services of a new semi-automatic module line.

The opening speech, which centred on the future of solar module production, was given by Dr. Patrick Hofer-Noser, CEO of 3S Industries AG. Also in attendance was Secretary of State Gundolf Fleischer MdL from the Ministry of Finance of Baden-Württemberg, in which region 3S's new technology centre is located.

The company's developments in stringing, laminating and testing will be boosted with the addition of the company's second complete semi-automatic production line. 3S can now offer services such as technical support and training courses in the Freiburg centre. The company will also offer materials and production testing services, such as testing new cells, soldering bands, EVA foils, backing foils, glass plates and liquids.

Greek Parliament approves HelioSphera.

Greek Parliament approves HelioSphera's €30 million subsidy application

HelioSphera's expansion has received a boost with the news that the Greek Parliament has approved its subsidy application for €29,879,500. The subsidy will fund HelioSphera's €180,000,000, 60MW production facility in Tripolis, Greece, which is expected to begin mass production in 3Q09.

The company was recently tapped for at least 9MW of micromorph thin-film modules by Italian photovoltaic module and component distributor Tecno Spot between 2009 and 2010.

Isofotón teams up with State of Ohio on new U.S. module facility

Isofotón North American, a subsidiary of Isofotón, has signed an agreement of cooperation with the State of Ohio for the establishment of a new Isofotón production centre. The proposed module manufacturing facility will assemble cells manufactured in the Production Center in Malaga, with construction on the 60MW plant planned for between 2010 and 2011.

The agreement is viewed by the company as the first step in a process of breaking into the U.S. market and a chance to identify strategic utility partners in the country. Isofotón North America has kept up a presence for the Spanish company since 2004, and the modules produced at the proposed Ohio plant will be destined for sale on the U.S. market.

Spire's new engineering platform to enable module materials and design assessment

Spire Corp. has decided to share its module-making recipe through the provision of a new development engineering platform for universities, R&D purposes, companies and government laboratories. The platform includes such Spire tools as the Spi-Stringer, the Spi-Laminator and the Spi-Sun Simulator, and training on all of the equipment and processes is included in the platform package.

The reason for the development of the platform is to enable said organizations and establishments to evaluate new materials and designs for producing solar modules, supplying basic information on recommended materials for the process as well as a basic crystalline module design. The "How to Make a PV Module" instruction book is intended to aid in the evaluation of each researcher's and company's technology and pave the way for further improvements.

"This development engineering platform will allow for a broad range of researchers and organizations to become involved in solar energy for a modest investment," said Roger Little, Chairman and CEO of Spire Corporation. "The availability of this development platform is intended to accelerate the introduction of new PV module technology into the industry. It is also intended to provide students with access to real world equipment and processes which may lead them into a career in solar energy."

Kyocera Solar opens new PV module plant in Tijuana, Mexico

Mexican President Felipe Calderón was among government and company officials on hand February 5 to inaugurate Kyocera Solar's second PV module manufacturing plant in Tijuana, Mexico. The two-story production facility, which connects to the pre-existing Kyocera panel fab, will have a maximum annual output of 750,000 crystalline-silicon modules, equivalent to a nameplate capacity of 150MW.

Kyocera's new facility in Mexico.

President Calderón also announced his intention to implement a large-scale program of renewable energy in Mexico, which will include Mexican-made solar modules such as those produced at Kyocera.

"Kyocera gives us a clear case of how we can transform critical moments into new opportunities using long-term vision," he said through an interpreter. "I know that Kyocera will sell these panels quickly as warm bread, even before the U.S. economy recovers, especially with a society that is clearly looking to renewable energy, such as California."

Kyocera has said it expects to invest an estimated 30 billion yen (about US$300 million) in plant and equipment during the course of the expansion plan, both at these module manufacturing sites and at its solar-cell production center in Yohkaichi, Japan.

Module Sales & Business News Focus

After superb 2008, SOLON expects moderate growth in 2009

According to its 2008 Annual Report, SOLON continues to be among the fastest growing solar companies in Germany, but due to an unstable market, is expecting moderate growth in 2009.

Solon power plant installation at Ager, Spain. Finished in September 2008, it will generate 11.4MW from 1,432 panels.

While the company sees potential for further growth, the economic crisis creates a lack of predictability in terms of how much SOLON could potentially grow in 2009. Since performance in the U.S. and southern Europe cannot be estimated clearly, SOLON has decided not to make public any fiscal targets until later in the year.

In terms of 2008, revenues improved by 62% to €815.1 million, with the System Technology segment responsible for 55%. The company experienced a production increase of 49% at 176MWp, with the total operating performance increasing by 70% to €875.3 million. SOLON earned €60 million before interest and taxes, up from €35.2 in 2007. Earnings per share went up from €2.16 to €2.46. The company, as a whole, increased those employed from 706 to 943. While the company has presence in over 20 countries, the majority of the revenue in 2008 was made in Spain and Italy.

Although recent market projections point to further rapid growth in Italy, potentially reaching nearly 1GW of installations for 2009, the hole left by Spain could prove difficult to fill and would seem to affect SOLON's ability to grow at similar rates seen in 2008.

aleo solar paves the way for Greek business expansion

Following a successful marketing drive over the past 18 months, aleo solar has decided to establish a sales office in Athens, Greece in anticipation of a significant increase in sales orders in the future. The module manufacturer has already installed between 20 and 25MW of plants in the country and expects this to increase.

"Our close cooperation with leading Greek project developers, the support of banks involved in project financing and an understanding of the way in which authorities and utilities work together has enabled us to become a well-known player in this young market," commented Christopher Dunne, Director of Market Development.

The Greek market is expected to boom over the coming few years, given the Greek government's introduction of a special subsidy program for rooftop installations up to 750MW. Greek feed-in legislative changes will undoubtedly see many solar developers show interest in the country's attractive conditions.

Soleos to purchase up to 30MW Purchases from Suntech

Suntech Power Holdings Co., Ltd., and Soleos Solar GmbH, a PV systems manufacturer and installer, have announced the two companies have agreed that, for the first half of 2009, Suntech will supply Soleos with at least 6MW of modules.

CEO of Soleos, David Mabille said, "We are very pleased to extend our relationship with Suntech, who has a well-earned reputation for delivering highly efficient PV products. Given the growing demand for premium-quality modules in the European market in countries such as Germany, France, Italy and Belgium, we anticipate purchasing up to 30MW of solar panels from Suntech over the course of the year."

China Sunergy signs new supply deals

China-based solar cell manufacturer China Sunergy has signed several new supply deals that total 55MW for 2009. Erfurt, Germany-based asola Advanced and Automotive Solar Systems GmbH is to receive 30MW of silicon solar cells in 2009 as part of a long-term supply deal that could reach 480MW of solar cells through 2018, approximately 50MW per annum from 2010 onwards. The second deal is with SolarMax Technology, Inc., a system integrator based in the U.S. which plans to use 25MW of solar cells from China Sunergy throughout 2009.

Scheuten Solar inks deal to supply PV modules to Aehlios

Scheuten Solar has signed a multiyear deal to provide Multisol solar modules to French PV systems installer Aehlios. The contract, said to be worth "several tens of millions of Euros," covers the supply of nearly 10 MWp of panels.

Scheuten Solar, which will manufacture the units at its Gelsenkirchen factory, joins SolarWorld, Sharp, Sanyo, Solara, and Photowatt as module suppliers to Aehlios.

Product Briefings

Bystronic

Bystronic's roller laminators press thin-film modules in 60-second cycles

Product Briefing Outline: Bystronic Glass's technology centre, Bystronic Armatec, has developed a pre-nip laminating system for pressing thin-film photovoltaic modules. The new technology is based on Bystronic Armatec's more than 25 years' experience in engineering machinery and equipment for the production of laminated glass.

Problem: Pressing the units using a pre-nip system is an important step in the process. A conventional vacuum laminator requires more time to undertake the process step, increasing cycle time and reducing potential productivity.

Solution: The individual glass sheets are initially washed, positioned with a very high accuracy, and the PVB film is applied completely automatically. During the application, the tool does not pre-cut the film but unwinds it directly from the roll, a method that has proven successful in the manufacture of laminated glass. As a result, the time-consuming storage of pre-cut film for relaxation is no longer necessary. Once the film and the cover glass have been accurately placed on the substrate and the film overhang trimmed, the module is conveyed into the pre-nip for the laminating treatment. During the pre-nip process the module passes through a pre-heating zone, three main heating zones and two roller presses. The temperatures in the heating zones range between 130ºC and 240ºC. Medium-wave quartz infrared heaters produce the actual heat in the film. All parameters, such as conveyor speed, pressures or heater settings, can be programmed individually. The company claims a constant high production quality. While the modules stay in place for three or four hours, the next load of 240 pre-laminated modules is prepared, enabling a harmonious production flow with no waiting time.

Applications: Thin-film module lamination.

Platform: The system can be supplied in fully automated and semi-manual operation.

Availability: Currently available.

Thermotron

Thermotron's module test chambers handle all sizes and testing conditions

Product Briefing Outline: Thermotron's solar module test chambers are specially sized to accommodate all PV solar module sizes, featuring workspace dimensions that will comfortably accommodate solar panels ranging in size from 2' x 4' up to 4' x 6' (1200mm x 600mm to 1200mm x 1800mm). Panels exceeding 6' (1.8m) in length may require a walk-in-sized room for testing.

Problem: Performance testing of modules is required for design qualification, endurance and accelerated life testing for certification and type approval.

Solution: Compressor sizes from 6hp to 20hp provide flexibility in selecting the proper refrigeration system to match the performance capacity required for solar tests being conducted. In addition to extreme temperature testing from +180°C to -70°C (356°F to -94°F), these chambers include a reliable, accurate, and efficient full-range humidity system for simulating conditions from 10% RH to 98% RH. The chambers meet the demanding requirement of maintaining controlled humidity conditions while simultaneously cycling between hot and cold temperatures. Solar Panel Test, Measurement, and Data Acquisition are also supported by the chamber instrumentation. Each chamber is equipped with power supplies to provide appropriate current and voltage to solar panels under test and monitor proper operation.

Applications: Module testing on sizes of 1200mm x 600mm to 1200mm x 1800mm. Panels exceeding 6' (1.8m) in length may require a walk-in-sized room for testing.

Platform: Chambers are outfitted with adjustable fixturing solutions specifically developed for easy loading and unloading of solar panels. The easy-to-use 8800 Programmer Controller has all of the most common solar test specifications pre-programmed into memory and features a 12" colour touch screen monitor with an intuitive graphical user interface. USB ports, Ethernet, and computer interface are all supported to enhance communications with the test equipment.

Availability: Currently available.

DuPont Photovoltaic Solutions

DuPont's PV5200 series encapsulants designed for new thin-film module manufacturing materials

Product Briefing Outline: DuPont Photovoltaic Solutions (DPVS) has launched its new DuPont PV5200 Series photovoltaic encapsulant sheets, based on polyvinyl butyral (PVB) polymer technology. The new PVB sheets offer physical and processing performance levels proven in laminated glass manufacturing, with additional features designed in to meet the needs of thin-film solar power generation.

Problem: The encapsulants have been optimized for mechanical, adhesive, melt-flow and chemical stability properties in contact with new thin-film module manufacturing materials.

Solution: The first in a series of products emerging from recent DuPont development efforts, the encapsulants offer faster, more efficient module production and longer service life. Focused on glass-on-glass thin-film module constructions, new DuPont PV5200 Series encapsulant sheets assure excellent glass adhesion and proven safety glass performance, with high visible light transmission. The sheets are made of a clear, pliable material with excellent flow characteristics, well suited to module encapsulation using nip-roll/autoclave, vacuum laminating and novel solar module processing methods.

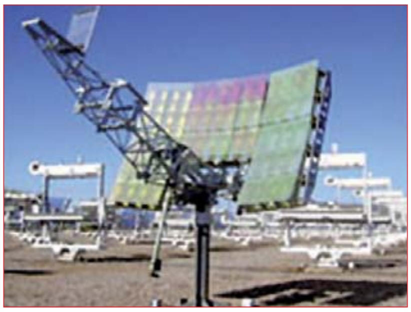
Applications: Glass-on-glass thin-film modules.

Platform: The new PVB-based encapsulant sheets are offered in thicknesses from 0.38mm to 1.14mm for sampling and use by solar module makers.

Availability: Currently available.

Product Briefings

Atlas Material Testing Technology



Atlas offers ultra-accelerated exposure testing system without overheating

Product Briefing Outline: Atlas Material Testing Technology has introduced its new outdoor testing device, which can provide approximately 63 years of south Florida UV radiation exposure in a single year. Atlas developed this new solar concentrator technology in partnership with the National Renewable Energy Laboratory (NREL) and the Russian Institute of Laser Optical Technology (ILOT) under a U.S. Department of Energy (DOE) program.

Problem: Building high irradiance solar concentrators or laboratory solar simulators for durability testing appears straightforward; however, such devices at ultra-high irradiances typically cause overheating of test samples resulting in unnatural material changes compared to the changes in the end-use environment.

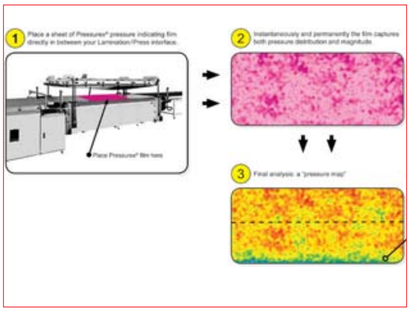
Solution: Similar in concept to Atlas's moderately accelerated 'EMMA' technology, the ultra-accelerated device tracks the sun while concentrating reflected sunlight on test specimens mounted in a target area. The newly-patented mirror system used in the concentrator has very high reflectance in the UV and near-visible wavelength ranges while attenuating reflectance in the longer wavelength visible and IR portions of the solar spectrum.

Applications: Exposes many different types of materials to ultra-high UV irradiances, and maintains high fidelity to the natural solar UV spectrum and keeps specimens at acceptable exposure temperatures.

Platform: Using multiple focusing mirrors arranged on the curve of a 10-metre sphere, the UV energy may be variably concentrated on a target area approximately 10cm x 10cm. Custom mounting and cooling features can be added depending upon specific material exposure requirements. Optically the mirror system has a direct normal 100/1 concentration factor. Atlas Material Testing Technology is ISO 17025 and ISO 9001:2000 registered, and products are designed and manufactured to conform to international, national and industry standard test methods including ISO, ASTM, DIN and JIS, among others.

Availability: Currently available.

Sensor Products, Inc.



Pressurex sensor film from Sensor Products offers low-cost module production quality control

Product Briefing Outline: Sensor Products, Inc. has introduced 'Pressurex,' a surface pressure-indicating film that reveals pressure magnitude and distribution between any two contacting or mating surfaces. Through the quality control process, photovoltaic efficiency is increased by reducing the production of solar modules that have been subjected to improper pressure.

Problem: In the PV industry, peripheral cracks on solar cells can be caused by uneven pressure distribution on lamination and frame presses during assembly operations. Edge or surface damage and micro cracks can allow moisture ingress, resulting in degraded solar module performance. Thin-film modules of CdTe- or CIGS-on-glass or flexible substrates are more susceptible to moisture ingress and require stringent quality control checks.

Solution: At least three specific assembly steps would benefit from the use of Pressurex sensors: lamination, the frame press stage, and attachment of junction boxes. For EVA and PVB lamination, the film assures proper pressure magnitude to cause polymerization and securely bond multiple layers together. With respect to the frame press stage, the film helps verify adequate frame-to-module edge sealing. The film is placed at the interface of two contacting surfaces which, when compressed together, apply a force to the sensor film. The film captures this applied force permanently and irreversibly by changing colour, the intensity of which is proportional to the amount of pressure applied, which can then be checked using a colour calibration reference chart.

Applications: Process control and monitoring of solar module production equipment.

Platform: Mylar-based sensor film reveals surface pressure from 2-43,000PSI (0.14-3,000kg/cm²); temperature range up to 752°F (400°C); material gauge from 2 to 5 mils. The product is supplied in rolls up to 2ft x 100ft (0.6m x 30m).

Availability: Currently available.

Robert Bürkle GmbH

Bürkle's single-opening laminator e.a.sy-Lam is designed as a flexible starter model for module production

Product Briefing Outline: Robert Bürkle GmbH has launched the 'e.a.sy-Lam', a starter model for solar module production. The machine capacity starts with 5MWp and can be ramped to 20MWp. Companies often start production with a single-opening variant. After successful production start and as orders begin to increase, companies adapt their capacities with another single-opening laminator and then migrate to high-throughput systems, such as the multi-opening Ypsator system.

Problem: Scaling module production requires laminator technology that retains the inherent reliability and quality attributes of low-volume systems when shifting to high-volume production. However, it is also important for module manufacturers to be able to utilize the same basic tools for both crystalline and thin-film module lamination.

Solution: The e.a.sy-Lam laminator has many of the technical attributes of the high-throughput multi-opening Ypsator system. The machines have both visual and technological aspects in common: both lines can, for example, laminate both crystalline and thin-film modules. The individual solar modules are constantly tempered to reduce glass breakage due to the modules and the heating platens not touching each other during transport and evacuation. A homogenous temperature distribution is reached by the heating of the heating platens with thermal oil that ensures an optimal process guiding. Controlled cooling of modules under pressure prevents the module from warping while shortening process times. In order to avoid standstill times, the membrane can be rapidly exchanged through easy access.

Applications: The platform can be customized for both crystalline and thin-film modules.

Platform: Two laboratory machines with a standard useful area of 1.0 x 1.7m and 1.4 x 2.2m and production machines with two variants having a useful area of 2.1 x 3.5 and 2.3 x 4.4m are available.

Availability: Currently available.

Line integration of PV module manufacturing technology in the light of a rapidly changing environment

Nande van Aken, **Bodo von Moltke** & **Dr. Kai Siemer**, SOLON SE, Berlin, Germany

ABSTRACT

Over the past few decades, the PV equipment manufacturing market has seen a significant change in technologies. Cell sizes are being increased, while cell thickness has decreased at an ever-increasing speed of technological innovation, from 4" 340µm cells in the 1990s to 6"+ 180µm being the current industry standard. Thin-film modules pose completely new challenges to module manufacturing technology with a strong integration of the manufacturing of the active layers into the module production flow. This articles analyses the pros and cons of an increased level of line integration from the viewpoint of an established PV module producer.

Introduction

Suppliers of production equipment have improved the equipment and manufacturing technologies to accommodate changes in product and material technology, often in close cooperation with module producers as their customers. New players have entered the equipment market, often coming from other industries and leveraging their know-how and technologies for application in the PV industry. With an increasing level of professionalism being displayed in production management, what with optimization of production planning, bottleneck considerations, and tools like process control, more and more suppliers are offering highly-integrated turnkey production lines.

"In the early days of module production, when volumes were low and throughput was not the major focus, the process flow was realized in a job-shop style of production with individual process stations and several customized products."

Highly-integrated module production lines

Levels of line integration

Despite the change in materials and production technology, the basic process flow for silicon-based PV modules has not changed in several years (see schematic in Figure 1). Solar cells are joined to form strings, which are interconnected to form a module; the module is then laminated with encapsulation material; electrical connections are formed using junction box (j-box), and a frame is applied. Finally, the modules are flashed and tested.

In the early days of module production, when volumes were low and throughput was not the major focus, the process flow was realized in a job-shop style of production – as shown in Figure 2 – with individual process stations and several customized products. Cell interconnection was divided into two steps whereby cells were tabbed with solder ribbons ('tabbing') and the electrical connection to the next cell was realized in a different machine ('stringing').

With the unprecedented growth seen by the industry in the first few years of this decade, production volumes grew, and as a result capacity and bottleneck planning became pertinent issues. Production flow was organized into line concepts where the individual steps were connected, while cycle times of different pieces of equipment became more and more matched. Many highly optimized production lines run in this manner today, where individual process steps

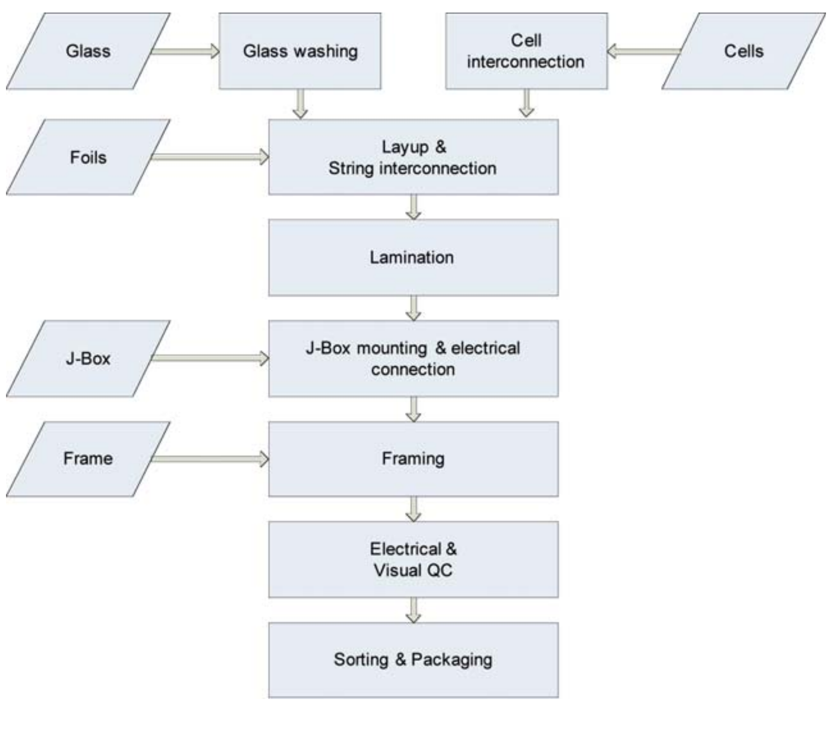


Figure 1. Principle process flow for PV module manufacturing.

Figure 2. Job-shop module production (SOLON, 1998).

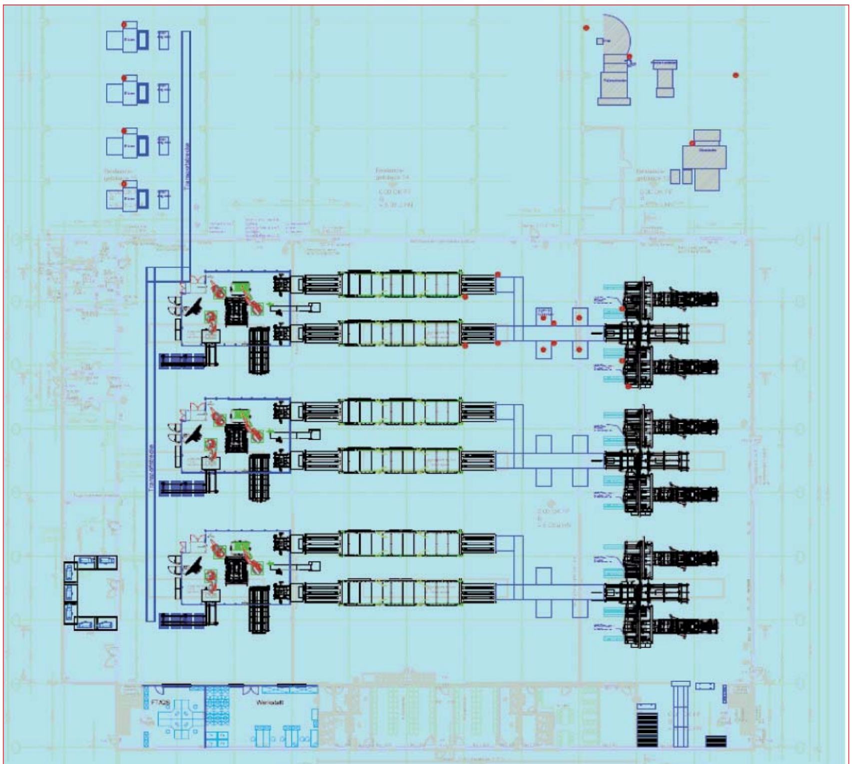


Figure 3. Layout for 120MW production line (SOLON, 2008).

are optimized individually, throughput and capacity planning are considered for the full line, and automation is installed on the level of single process steps or at particular points of interface (see Figure 3).

The evolution of production lines corresponds to the development of product concepts, ranging from low-volume customized solutions in the '90s to high-volume power plant products in the current market, as shown in Figure 4.

A highly integrated line utilizes an increased level of automation. Typically, process steps such as string interconnection, j-box mounting and framing use a higher degree of process automation than they would in conventional lines. Also the material and module handling, with all transportation within the line is carried out by machines as opposed to manual transportation by a human operator. Materials such as glass plates and modules in progress are moved automatically from one process step to another, and are quite often automatically fed into the line, as illustrated by Figure 5.

Highly integrated lines are often equipped with complete interlinked machine and production data collection systems to allow the tracking and documentation of materials and processes used in the manufacture of the products, as well as a central production control system to steer material and product flow through the line.

As matching of all single process steps is not always possible, the direct interconnection between all process steps makes it necessary to implement buffer systems at certain stations, resulting in an optimized output for the entire production line. Due to the reduced amount of operators in the line, highly integrated production requires a significantly higher degree of automated process control, usually in the form of vision systems or measurement tools.

Figure 4. Evolution of product concepts: architectural customized solution (1999, left); power plant product (2006, right).

Two approaches to highly integrated lines

There are some established players in the equipment market among the suppliers of highly integrated manufacturing lines, usually those that already have the major production equipment in their portfolio, like stringers and laminators. Additional automation and interconnection into an integrated line is often realized in-house or under contract and only less critical building blocks are realized through cooperation partners.

On the other hand, there are new suppliers entering the market that quite often have accumulated the knowledge of the potential benefits of line integration from other industries or have a particular manufacturing know-how that they wish to leverage into the PV industry. Robot technology has found its way into PV module manufacturing through this strategy. These suppliers usually offer an individual process step, like framing, plus an integration service, and tend to form alliances to supply fully integrated lines. Several of such alliances have been seen in the market over the last years. Only in a few of such concepts can individual building blocks be exchanged upon customer demand.

Shorter time-to-market for new players

Highly integrated production lines use standardized building blocks, standardized interfaces, and processes known and established by the supplier of the line. Building up a production from scratch to a level provided by a turnkey supplier requires:

1. Selection of equipment vendors for each step
2. Definition of interfaces between process steps
3. Development and implementation of production and control processes
4. Implementation of a quality management system
5. Training of engineers and operators.

> "As some of the integrators are experienced in worldwide operations, line integrators can bring significant benefits to line installations in remote sites."

A new player in the field of module manufacturing can easily source points 1 to 3 from a one-stop shop, and can typically get support on 4 and 5, giving the manufacturer at least a six- to twelve-month head start over taking the route of building up all necessary know-how in-house. This approach can also save the module manufacturer from making expensive mistakes during the learning curve. In using the integrated line, it can be possible to source the product design at a certain quality level. The resulting shortening of time-to-market can easily pay off the higher investment required to implement an integrated line.

Advantages for established module manufacturers

Established manufacturers will already have process know-how in-house, as well as an existing supplier base and production equipment. For this group in particular, it is much harder to justify the investment required of a highly integrated line. However, there are contractual advantages or project management competencies that can prove beneficial for these companies, as the manufacturer in question can make the decision to have just one contract partner who is responsible for guarantees, installation, and service.

With particular focus on those coming from industries that also use automation, line integrators can tend to have a strong focus on project management. Although this does not necessarily mean that timescales are

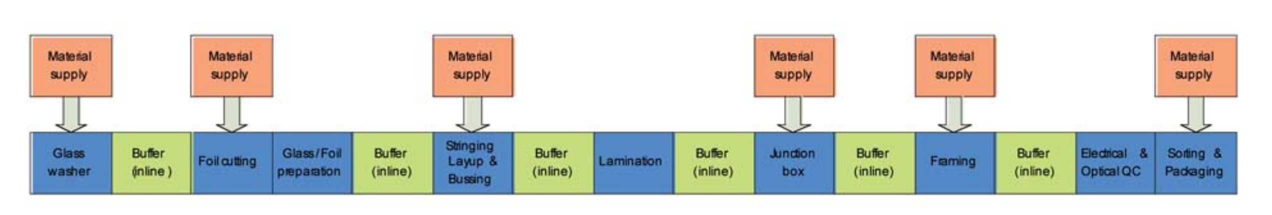


Figure 5. Principle process flow of a highly integrated line.

kept to the satisfaction of the module manufacturer, the integrator can cover resources that the manufacturer does not necessarily want to build up beyond the ramp-up project. As some of the integrators are experienced in worldwide operations, line integrators can bring significant benefits to line installations in remote sites where intercultural communication, travel, time shifts, and delegation of workforce raises additional challenges to the project.

Capacity variations and cost considerations

The current slowdown of the industry shows how important flexibility in production output can be. Naturally, the higher the investment, the higher the financial impact is of changing a production output. In contrast, the financial impact of output changes is reduced for a line with a limited depreciation but larger workforce. Though this is a platitude, it is often neglected at the time of line-concept planning.

Further cost drivers in this regard – besides depreciation and labour cost – are yield and uptime. Yield can be increased by introduction of individual automation of critical processes, which are hard to control in manual operation. Line integration does not necessarily improve the yield. However, any initial line ramp-up coupled with a changeover of production generates additional yield losses. An integrated line will fundamentally have a downtime that is worse than the downtime of the bottleneck equipment, which can be easily overcome by making the right choice of buffer steps and buffer positions, in turn increasing the investment needed for such a line.

> "With the increasing speed of technological innovation in materials, process know-how requirements are being shifted more often from customers to equipment suppliers."

Moving process know-how

With the pervasive technology change occurring mainly in the materials sector, equipment suppliers are building more and more of the required process know-how in-house. New cell generations are usually tested at the sites of the lead customers among the module manufacturers and the stringer manufacturers in parallel. The reason for this method is that such a major change in the materials technology directly impacts the technology of processes such as soldering technology or cell handling.

A general trend is forming. With the increasing speed of technological innovation in materials, process know-how requirements are being shifted more often from customers (i.e. module manufacturers) to equipment suppliers, a trend that is being driven further by additional line integration.

Limiting the growth of the PV industry?

Are today's modules ready for grid parity?

Looking at the performance of the PV industry over the past few years, it has shown tremendous improvements in production quality, process stability and product costs. Still further innovation is required to reach grid parity for larger parts of the worldwide electricity market. In the early years of PV module manufacturing, automation was driven by the requirements of process quality, like automated stringing and lamination. For the past few years, however, automation has started to increase efficiency of production flow, cycle time and labour resources; to date, none of these approaches has led to significant innovations in the design of the product. The logical step of designing a module suited for automation still has to take place.

Future innovation requires flexibility

The main driver for innovation over the past few years has been in material changes - mainly cell sizes and thicknesses, though not limited to cells. This has led to a technological lifetime of down to two years for some major equipment. With the current slowdown in industry growth, the areas of innovation will be widened ever further to new products, new applications, and additional customer benefit, in addition to all ongoing efforts at reduction of product and production costs.

It is the nature of innovation that the exact path of improvement is not predictable. It certainly requires in-depth know-how in the fields of materials, products and processes, as well as crucial changes to production flows and processes. Extrapolating the past into the future shows that the product of tomorrow – and thus the production lines to build those products – will look different from today's most efficient lines.

In highly integrated lines, even minor changes in mechanical dimensions or the usage of second-source material with only slight variations in process parameters can require hours of changeover. A major change in the product usually cannot be covered by an existing line, but will require either major re-design efforts or a lot of expensive variability in the automation.

Highly-integrated lines form a de-facto standard for production processes (and thus for products)

Highly integrated, highly automated production lines always refer to comparably high investments. Such lines need to run at high workloads for the longest possible lifetime to amortize the additional invest. During the technological lifetime of the investment, only minor product changes can be allowed from a financial perspective. Increasing the technological lifetime of equipment corresponds to discussions about standardization of products. It is the obvious interest of line integrators that the innovation frequency of the *product* will be decreased.

Highly-integrated lines limit flexibility for production processes (and thus for product design)

A longer innovation cycle driven by actual or de-facto standardization is in contrast to the increasing speed of product innovation needed. A module manufacturer, having invested heavily in a fixed line concept, will meet with the major hurdle of having to adapt to new developments, problematic because of the associated fixed investment, as well as the investment needed to change the lines. Installed lines need to be filled with the products for which they were designed.

The efforts of equipment vendors are focussed on improvements in line integration, in individual processes, and sometimes in product modifications to enhance automation possibilities. The efforts of module manufacturers operating integrated lines are, conversely, focussed on total line management than on understanding and improving individual process steps. Module manufacturers having such process know-how in-house can more quickly and efficiently adapt to any material or process changes.

> "Flexibility – needed for product innovation over the next few years – can be only accomplished with more individual building blocks instead of a fixed fully integrated line concept."

As a result, a higher share of integrated lines will reduce the effort spent on product innovation and increase the innovation time cycle. In today's market, when growth needs innovation, longer innovation cycles put growth rates at risk. The need for competitive differentiation and the availability of technological know-how also foster innovation. Flexibility – needed for product innovation over the next few years – can be only accomplished with more individual building blocks instead of a fixed fully integrated line concept.

Outlook

In the long run, more standardization in the PV industry can be expected. Once module prices approach grid parity, innovation will move into process improvement rather than new product technologies. Standardization makes sense when the growth driven by increasing demand is larger than the growth brought about through new applications and products. Nevertheless, the market is not yet ready for such a move. We need further product innovation to grow implementation of PV in order for it to be classed as a major source of renewable energy. Time will tell: when the industry is mature enough for standardization, it will then be possible to source more standardized lines at a higher level of integration.

In the meantime, we expect the supplier market to split between companies focussing on mass manufacturing of standardized products on the one hand – although these products may vary between companies, and companies with a strong knowledge base of products and processes, where the latter will drive the technological innovation.

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Snapshot of spot market for PV modules – quarterly report Q1 2009

pvXchange and **eclareon**, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Introduction

A spot market always shows the up-to-date prices of solar modules, because it does not consider the long-term delivery contracts of the producers. These days, the spot market for PV modules is global, because the short-term satisfaction of local supply deficits is possible with short transportation times and relatively low logistics costs. pvXchange provides a closed online trading platform for sellers going 'public' with a short-term offer. Other participants of the market can decide if they want to buy the goods at that price, while potential buyers may post their interest and in turn be contacted by interested sellers. Each issue of *Photovoltaics International* will enable the tracking of spot prices of modules through statistics provided by the pvXchange trading platform.

Sustainable growth perspectives of global PV 'buyers' market'

The trading volumes and prices for PV modules on pvXchange in the first quarter of 2009 reflect the global shift from sellers' to buyers' market, in which for the first time in years a massive oversupply situation has been experienced. In the wake of the sudden contraction of the Spanish market, Germany has turned into the main 'backstop market' for available modules worldwide. After a rather sluggish start during the first two months, the German market picked up a strong momentum in March 2009, and most actors are optimistic that by the end of the year a newly installed capacity of at least 1.7-2.0GW is feasible. Among the various emerging PV markets worldwide, Italy (+300-400MW) and the US (+ 350MW) in particular show solid growth perspectives for 2009, followed by a long trail of further emerging markets across the globe.

A high hidden potential is also identified in China, where the government seems committed to supporting the export-dependent national PV industry by promoting the fledgling home market. Overall, the total demand worldwide for 2009 is still quite difficult to predict at this early stage of the year, but most pundits like EPIA reckon that 7GW is a realistic figure.

Strong increase in volumes traded on pvXchange in 2009

The number of new suppliers and module types offered on pvXchange has been increasing drastically since 2008. Among the many newcomers are thin-film producers (most of whom are using amorphous and micro-amorphous silicon technology) that have a very hard time finding buyers in competition with the established and very price-competitive c-Si brands. It is evident that many large contingents of volumes >200kW are offered on pvXchange by both well-known and 'no-name' suppliers. On the buyer's side, we notice a clear trend back to established brands with proven quality. The vast majority of purchase requests are from German and Italian buyers, reflecting the dominance of these markets on a European scale. Based on the volumes traded during the first quarter (11.7MW), we expect a total volume of approximately 130MW by the end of the year.

Spot market prices for modules slumping by 20%

Prices for PV volumes traded on pvXchange show a very fast decline since the beginning of the year, with average price levels decreasing by 10.8 % from 2.76€/Wp to 2.48€/Wp between January 1st and March 31st 2009 on average (mono-Si). Over the last six months (October 2008 to March 2009), prices for mono-Si modules decreased by roughly 20%, beaten only by modules from First Solar, whose CdTe modules lost about 24.5% since October 2008.

A drastic slump in prices is noticeable for the so-called no-name brands, especially those produced by Chinese manufacturers. However, established brands have also shown a massive downward trend.

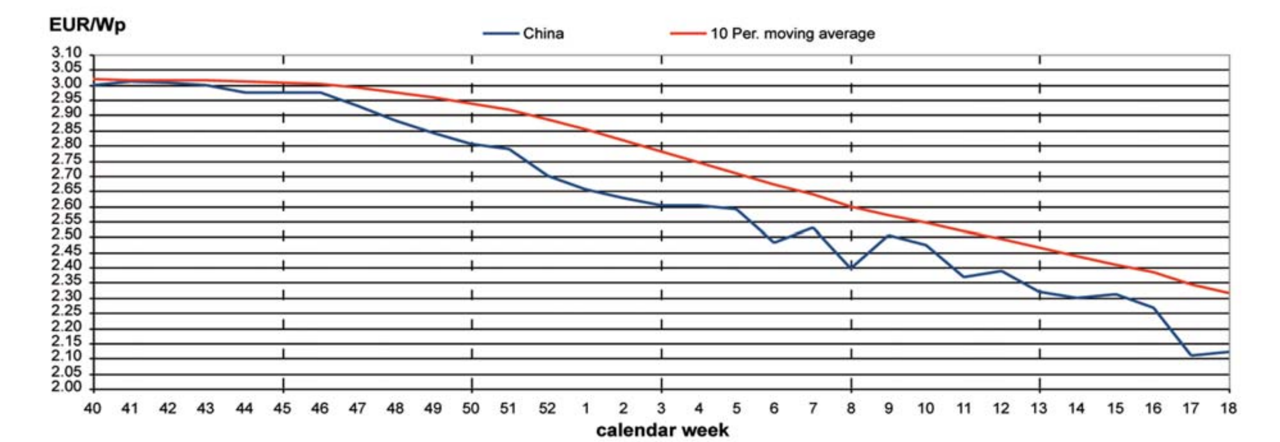

Figure 1. Development of market prices for modules produced by Chinese manufacturers from Oct. 2008 to Apr. 2009 (in EUR/Wp).

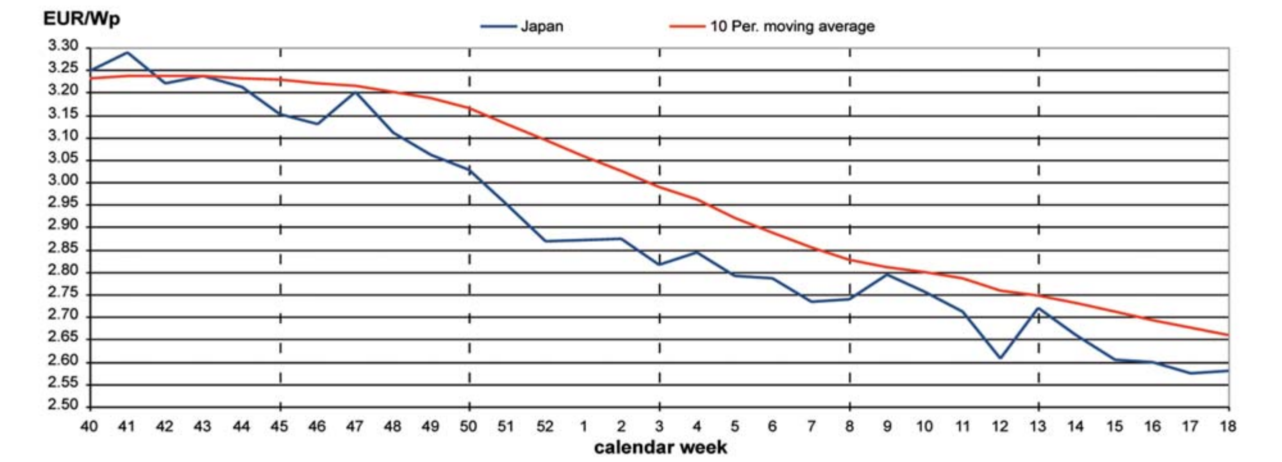

Figure 2. Development of market prices for modules produced by Japanese manufacturers from Oct. 2008 to Apr. 2009 (in EUR/Wp).

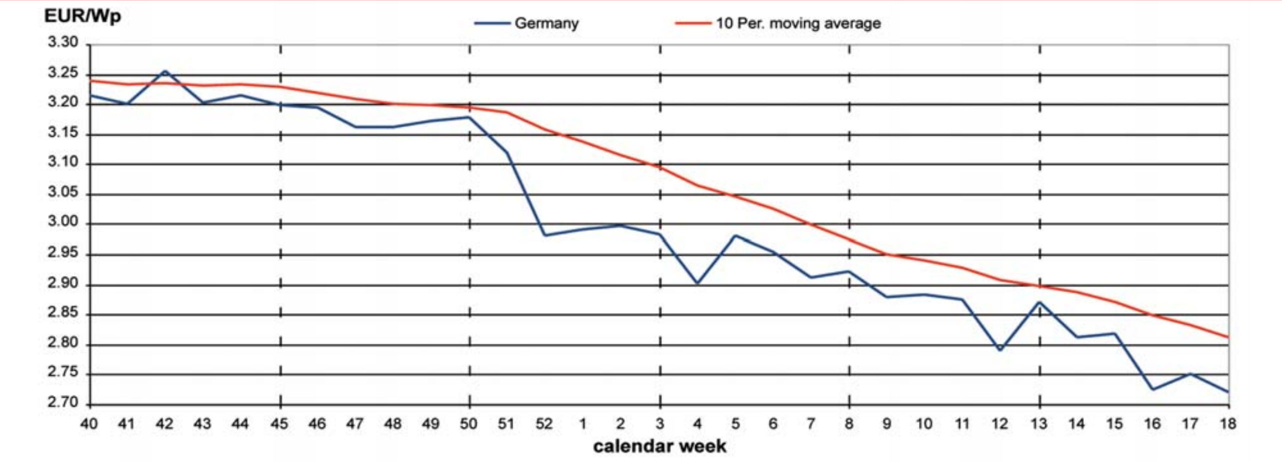

Figure 3. Development of market prices for modules produced by German manufacturers from Oct. 2008 to Apr. 2009 (in EUR/Wp).

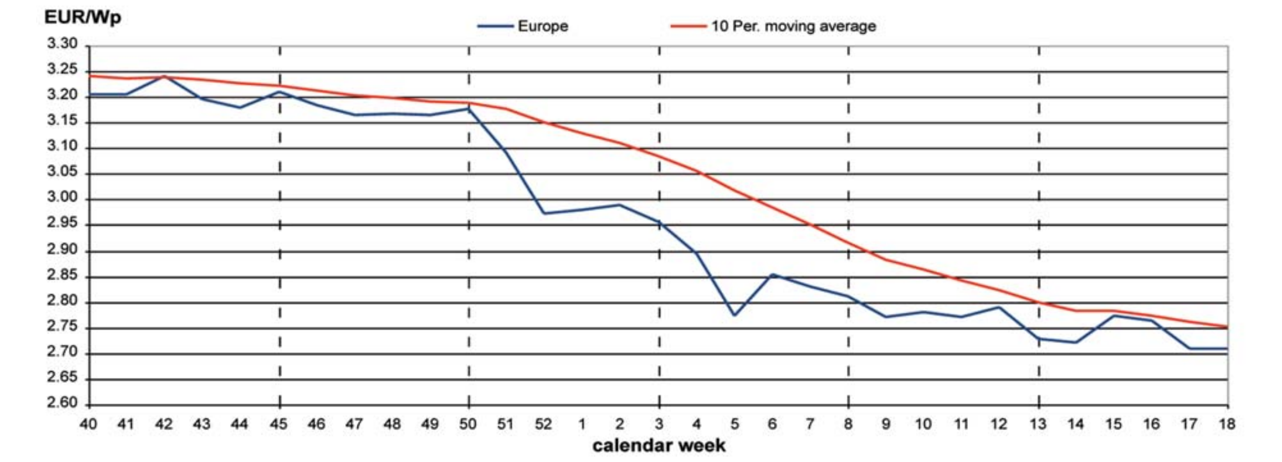

Figure 4. Development of market prices for modules produced by European manufacturers from Oct. 2008 to Apr. 2009 (in EUR/Wp).

In general, prices for Chinese modules decreased by 13.2% during the last 3 months and by 23.3% since October 2008. In contrast, prices for German-brand modules decreased by 'only' 6% during the last 3 months and by 12.4% during the last 6 months.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2008, the company procured solar modules with an output of around 100MW. This represents a trading volume of approximately €300 million. With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale. Based in Europe, pvXchange also has a presence in Asia and the USA. This market report is a quarterly synopsis of a monthly updated analysis made in co-operation by *pvXchange* and *eclareon*.

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PV module characterization

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ABSTRACT

The current industry situation of more competitive business approaches, increased PV project sizes and investments but declining profit margins renders an accurate knowledge of PV performance a vital factor in remaining competitive. Comprehension of expected lifetime and energy yield of PV generators is essential. Therefore, accurate characterization of PV modules is quickly becoming a more and more significant issue. This article gives an overview of the characterization topics of PV modules in terms of safety, failure susceptibility, overall reliability, system performance and energy rating.

Safety

Mechanical safety

While tests for mechanical safety are relatively easy to perform (2,400 Pa for the mechanical load test according to IEC 61215, 61646 and 61730) and should not pose severe problems to the manufacturers, some modules fail these tests, possibly due to enlarging module size without taking into account the mechanical properties (see Figure 1). This issue can be overcome using the following: enhanced mounting clamps with rubber inlays; extra support on the backside; frames with additional cross bars; thicker glass; smaller formats or stiffer back materials.

Electrical safety: isolation

Initial electrical isolation problems are typically due to an insufficient distance of the electrically active areas from the metallic frame, and later throughout the operation phase are due to moisture ingress from the edge.

Electrical isolation is tested using four different methods:

- Application of a high voltage between the terminals and a wrap of conductive foil around the module. The test voltage for the different tests is: for IEC 61215 & 61646 – 1kV plus twice the maximum system voltage for 1 minute; for IEC 61730-2 class A requirements – 2kV plus four times the maximum system voltage; for class B requirements – 1kV plus two times the maximum system voltage. If the measured insulation resistance times the area of the module is less than 40MΩ/m², the module has failed.
- Applying an impulse voltage (MST14 at IEC 61730-2) of up to 8kV at a rise time of 1.2µs and a fall time of 50µs.
- Measurement of the wet leakage current (module drowned) at 500V or the maximum system voltage (10.15 at IEC 61215 & 61646 and MST17 at IEC 61730-2). If the measured insulation resistance times the area of the module is less than 40MΩ/m², the module has failed.
- Using the ground continuity test (MST 13 at IEC 61730-2) for modules with a metal frame or a metallic junction box to demonstrate that there is a conductive path between all exposed conductive surfaces of the module and that they can be adequately grounded in a PV system. The resistance between each conductive component of the module shall be less than 0.1Ω for a current of 2.5 times the maximum over-current protection rating.

Figure 1. Breakage at 2,400 Pa: a-Si 1.4m² module with 2mm x 3mm glass.

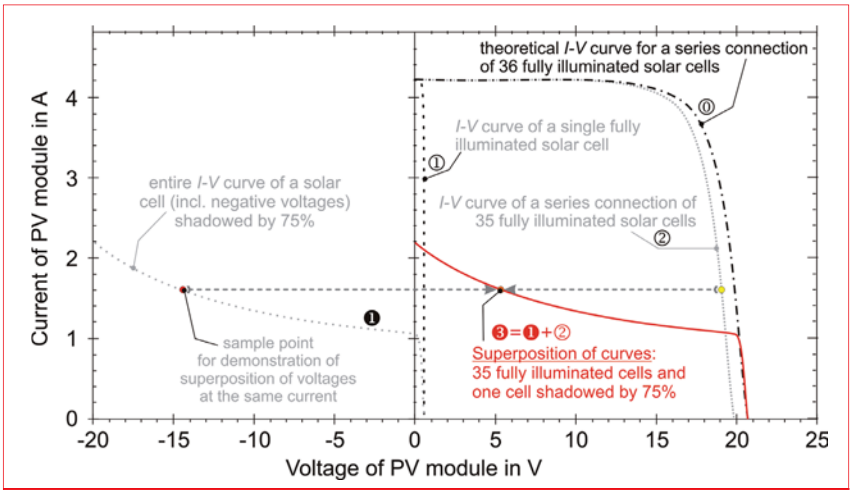

Figure 3. I-V curves showing a fully illuminated module (⓪); an illuminated module with one cell less (②); a shadowed cell (❶); and the resulting I-V curve of a module with one shadowed cell (❸).

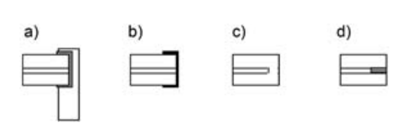

Figure 2. Strategies used to counter moisture ingress: a) wrap sealant in the module frame; b) metal tape around the edges; c) glass bonding; d) in-laminate sealant (showing the cross-section at the edge of a PV module).

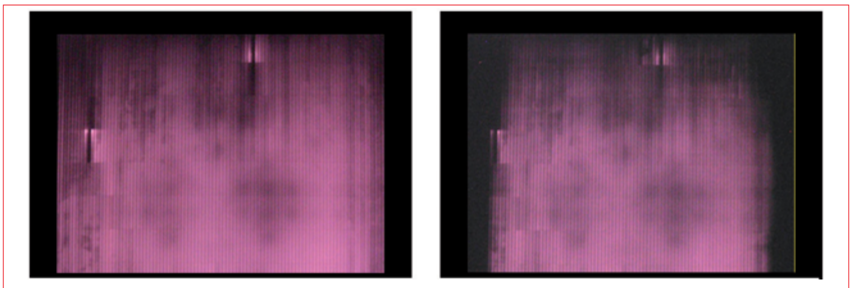

Figure 4. EL photography applied to a-Si modules, showing initial state (left) and after 1000h of damp-heat treatment (right – considerable reduction of photovoltaic active areas due to TCO corrosion (see TCO corrosion section overleaf).

To simulate several years of use, a damp heat test (1000 hours at +85°C and 85% of relative humidity), a thermal cycling test (200 times between -40°C and +85°C) and a humidity freeze test (10 fast drops from 85°C to -40°C at 85% humidity) are applied, at which point the isolation test and the wet leakage current test are repeated.

While PVB is more susceptible to moisture ingress than EVA, EVA is more commonly used.

However, PVB would tend to provide a better fit to the building code requirements.

Several different strategies are used to inhibit the moisture ingress (see Figure 2), including: wrap sealant in the module frame; metal tape around the edge; glass bonding, and in-laminate sealant.

While glass bonding offers the most secure sealant for moisture, it is quite costly. Manufacturers are currently researching using 'breathable' membranes in the sealant in different configurations.

Reliability

Hot-spot susceptibility

While the photovoltaic conversion process itself is very reliable, the interconnection of the cells in series may cause problems. As with all series connections, the element with the lowest current defines the total current. The current of a single cell may be reduced by local shadowing (due, for example, to dirt on the surface of the module), which therefore limits the total current and power output, as shown in Figure 3. If the string is large enough, the (reverse) voltage at the shadowed cell can surpass the negative breakthrough voltage and could lead to a local power dissipation that could even destroy parts of the cell ('hot spot').

The hot spot problem can be avoided by reduced voltage or a reduced cell area (limitation of current) or via appropriate bypass diodes or cells with a low reverse breakthrough voltage (which are – interestingly – usually 'bad' (low efficiency) cells).

Failure susceptibility

Electroluminescence

Failure diagnostics are essential to finding out issues of failure susceptibility. Electroluminescence (EL) is a suitable process for checking that the entire module area is incorporated in the photovoltaic energy conversion process. Electroluminescence is the use of a solar cell in a reverse manner to how it was intended to be used: instead of converting irradiance into electricity, electricity (supplied via the cell's electrical contacts) is converted into radiation in the near infra-red and is emitted via the cell's surface. The intensity of the radiation emission is an indicator for the local efficiency and quality of the photovoltaic conversion process. An extensive description of the EL tool can be found in the authors' contribution to the first edition of *Photovoltaics International*, entitled: 'Wafer, Cell and Module Quality Requirements,' on page 59.

Failures in the lamination process

Failures in the lamination process can be caused by various factors:

- Old and oxidized EVA
- Insufficient glass-washing
- Wrong temperature
- Insufficient duration and pressure of the lamination process
- Lack of curing of EVA due to shortened process.

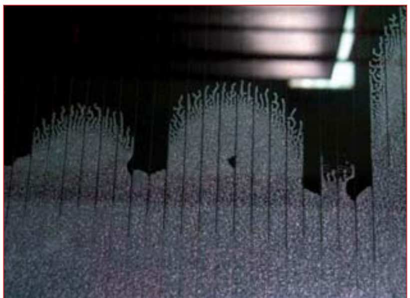

Figure 5. TCO corrosion: commercial a-Si module after 1000h of IEC damp heat treatment (85°C at 85% RH) at a voltage of -1,000V against ground at PI Berlin. >20% of the area becomes corroded and inactive.

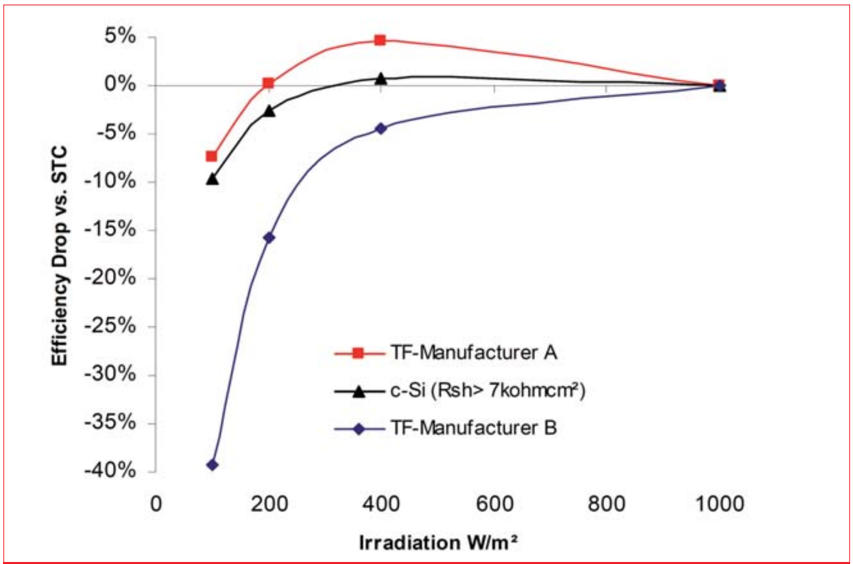

Figure 6. Change in power output as a function irradiance level for PV modules based on crystalline and thin-film technologies.

These failures can be detected by a gel content test of the cured EVA or by a backsheet peel-off test (forcing the peel off the backsheet from the module).

System compatibility and system performance

TCO corrosion

Some technologies that use a transparent conductive oxide (TCO) for the front contacts frequently experience problems if a high negative voltage is applied to the TCO (see Figure 5).

The effect can be explained by the sodium ions' electrochemical corrosion with water at the TCO/glass interface, causing de-lamination of the TCO.

Major drivers of this process are:

- Negative cell polarity vs. ground
- Moisture ingression
- High operation temperature
- Na (sodium) content in glass.

Therefore, module manufacturers tend to recommend inverters that allow for a positive voltage of the module against ground.

Energy rating

An electrical energy rating can be carried out from knowledge based on experience of long-term-outdoor tests or simulation – or a combination of both – to achieve validation.

Energy rating based on laboratory measurements

Parameters that influence the energy yield have to be measured in detail as input data for energy yield simulations and comparison of technologies, including efficiency at different irradiance levels (weak light performance), temperature coefficients, spectral efficiency and optical parameters (performance at flat incidence angles, refractive indices).

Energy rating via simulation

The correct simulation of direct and diffuse irradiance via their spectral-spatial appearance allows for an accurate representation of the module reaching irradiance. After passing the different layers of the encapsulation and being reflected according to the Fresnel laws - considering actual incidence angles and refractive indices, this irradiance forms the cell-reaching spectrum. The photoelectric conversion efficiency depends on

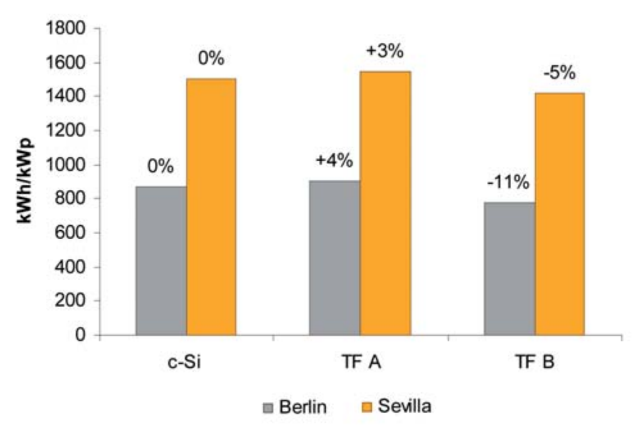

Figure 7. Effect on energy yield of the weak light performance differences as shown in Figure 6 (c-Si and two thin-film modules (TF A, TF B)) for different locations of installation.

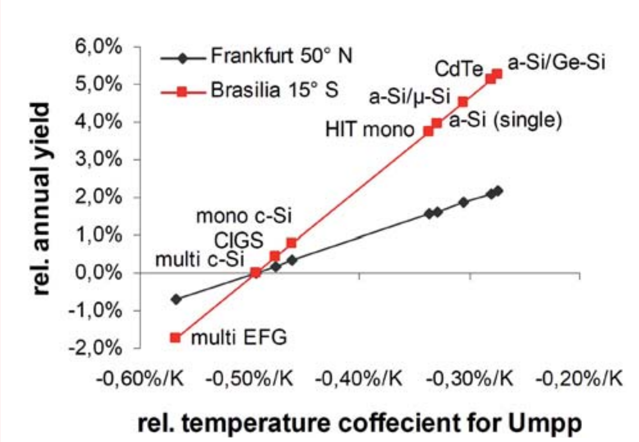

Figure 8. Relative change in energy yield (related to multi-crystalline silicon) of different technologies (along with their inherent temperature coefficients) for two different locations.

matching of the cell-reaching spectrum with the cell's spectral response and the actual operating cell temperature (which is derived from a balance of energy flow of absorbed irradiance, electricity generation and heat dissipation). The procedure for energy yield simulation is shown in Figure 10, with the results depicted in the graphs of Figures 7, 8 and 9.

A further analysis of the different parameters (e.g., performance vs. module inclination angle) can be carried out (see Figure 11). An interesting effect is that the inclination angle of the module does not influence the irradiance on the plane of the module, but has a significant effect on the convective heat transfer of the module. For horizontal mounting (module elevation angle: 0°), the convection capability and convective heat transfer at the module are reduced, thus causing high operating cell temperatures and a considerable dip in conversion efficiency around noon. This dip is drastically reduced for more inclined modules, allowing an effective flow of air and convection along the module.

The minima of conversion efficiencies 20 minutes after sunrise at 6 a.m. and 20 minutes before sunset at 6 p.m. can be explained by the extremely flat angle of incidence of the direct irradiance during those times of the day. From these examples, it is clear that the quality of yield prediction depends rather on the comprehension of the entire optical-thermal-electrical composition of the installed PV panel than on the knowledge of an isolated PV module.

Energy rating using outdoor data

Collection and study of outdoor, real-world data is the most accurate, but also the most time-consuming method of collecting data on energy yield.

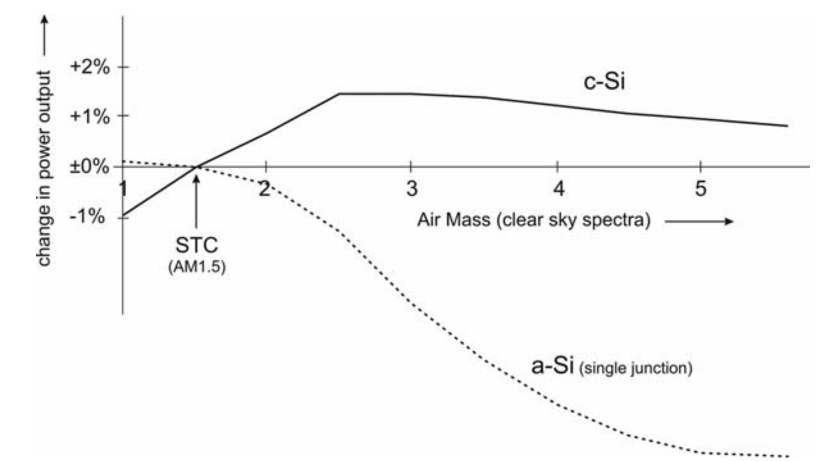

Figure 9. Change in power output as a function of the spectrum (AM) for PV modules based on crystalline and amorphous silicon.

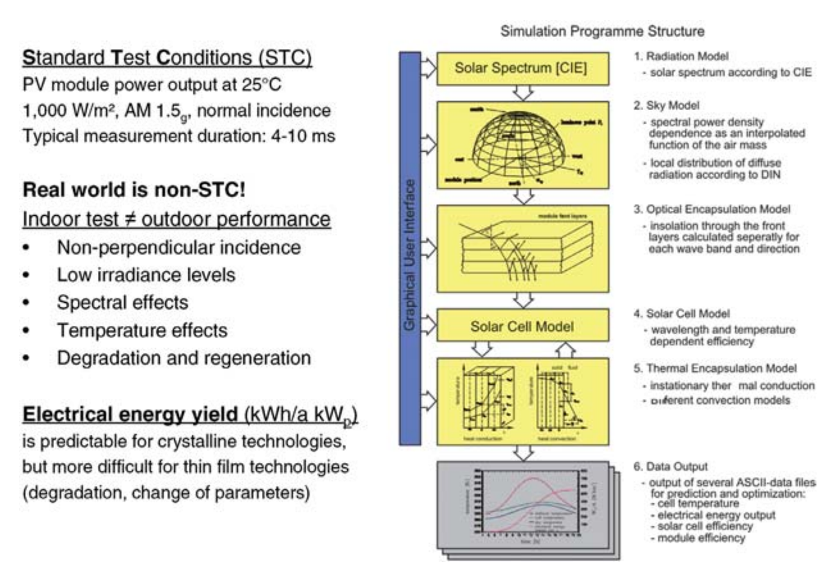

Figure 10. Structure of simulation process - yield becomes more important than power output at STC.

Degradation

While the power output of crystalline technologies showed only a little degradation, a-Si modules degrade considerably. To accelerate the process of degradation, so-called 'light soaking' at high irradiance levels (600 (800) – 1,000W/m^2) and at constant temperatures (50°C ± 10°C) is applied according to IEC 61646. Current-induced light soaking was tested in order to facilitate light soaking: for a-Si, degradation was similar, but current-induced light soaking did not reach the degradation level achieved via light soaking (6% difference, see Figure 13).

A PV module based on a combination of amorphous and microcrystalline silicon has shown almost no degradation at all

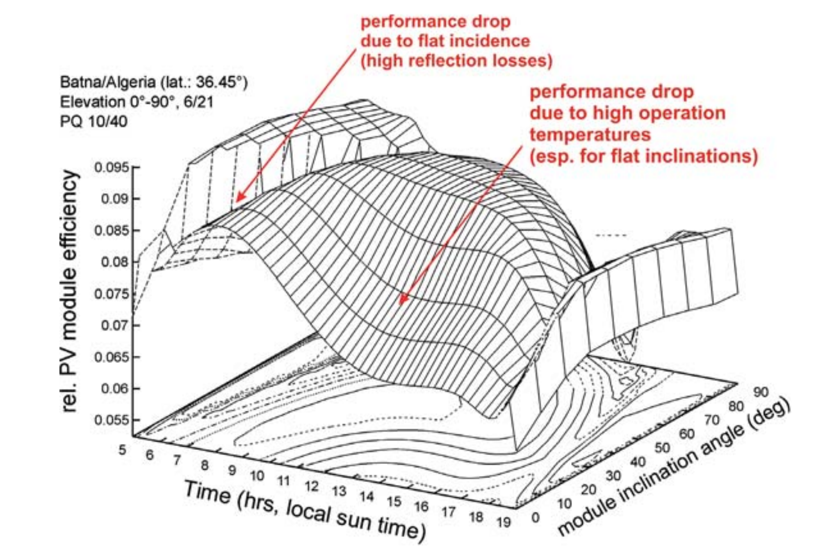

Figure 11. Results of simulation of a PV module. Image shows course of PV conversion efficiency during a day as a function of inclination angle of the module.

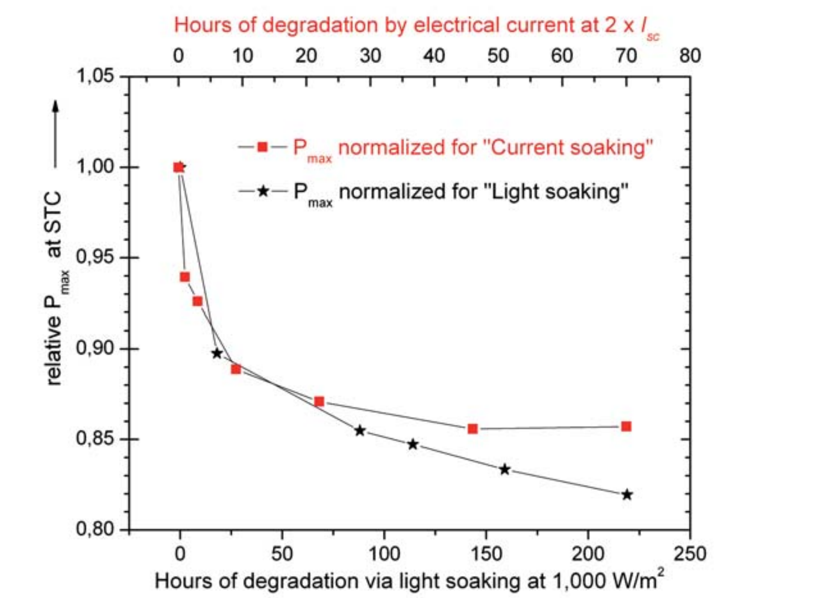

Figure 12. Comparison of degradation of an a-Si PV module via light soaking and via current (twice I_{SC}).

by current soaking, while conventional light soaking has shown a similar level of degradation on an a-Si module.

Conclusion and outlook

The experience of PI shows that energy rating is most critical for thin-film technologies, while

- Degradation is still the most important factor on energy yields for a-Si and µ-Si/a-Si
- TCO corrosion mostly solved by in-laminate sealing or injected frames and adequate inverter technology
- Degradation and spectral effects in silicon thin-film modules require new modeling in future simulation
- The tandem-junction structure of µ-Si/a-Si is complicating energy yield prediction due to the interdependence of degradation and spectral effects.

Authors' references

Grunow, P. & Krauter, S. 2006, 'Modelling the encapsulation factors for photovoltaic modules', *Proceedings of the 4th World Conference on Photovoltaic Energy Conversion (Joint congress of IEEE/PVSEC/EUPVC)*, Waikoloa, Hawaii, USA, pp. 2152–2155.

Krauter, S. & Grunow, P. 2006, 'Optical modelling and simulation of PV module encapsulation to improve structure and material properties for maximum energy yield', *Proceedings of the 4th World Conference on Photovoltaic Energy Conversion (Joint congress of IEEE/PVSEC/EUPVC)*, Waikoloa, Hawaii, USA, pp. 2133–2137.

Krauter, S. & Grunow, P. 2006, 'Optical simulation to enhance PV module encapsulation', *Proceedings of the 21st European Photovoltaic Solar Energy Conference and Exhibition*, Dresden Germany, pp. 2065–2068.

Krauter, S. & Grunow, P. 2008, 'Wafer, Cell and Module Quality Requirements', *Photovoltaics International*, Vol. 1, pp. 59–65.

Krauter, S., Grunow, P, Preiss, A. Rindert, S. & Ferretti, N. 2008, 'Inaccuracies of input data relevant for PV yield prediction', *Proceedings of the 33rd IEEE Photovoltaic Specialists Conference*, San Diego, USA.

Krauter, S., Preiss, A., Ferretti, N. & Grunow, P. 2008, 'PV yield prediction for thin film technologies and the effect of input parameters inaccuracies', *Proceedings of the 23rd European Photovoltaic Solar Energy Conference and Exhibition*, Valencia, Spain, pp. 740–743.

Krauter, S. & Preiss, A. 2009, 'Comparison of module temperature measurement methods', *Proceedings of the 34th IEEE Photovoltaic Specialists Conference*, Philadelphia, USA (in progress).

Preiss, A. & Krauter, S. 2009, 'Yield prediction and comparison of a-Si modules', *Proceedings of the 24th European Photovoltaic Solar Energy Conference and Exhibition*, Hamburg, Germany (in progress).

PV Modules

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Prof. Stefan Krauter received his Ph.D. in electrical engineering from the University of Technology Berlin (TUB) in 1993. In 1996 he co-founded Solon, and 10 years later – after a visiting professorship at UFRJ and UECE in Brazil – he co-founded the Photovoltaic Institute Berlin, for which organisation he acts as a senior consultant and sits on the board of directors. He is a professor for PV Energy Systems at TUB and at the Biberach University for Applied Sciences (HBC).

Dr. Paul Grunow received his Ph.D. in physics in 1993 from the Hahn Meitner Institute (HMI) and Free University Berlin (FUB) and carried out his post-doc studies on thin-film solar cells at the Federal University of Rio de Janeiro in Brazil (UFRJ-COPPE). He cofounded Solon AG in 1996 and, together with Reiner Lemoine, founded Q-Cells AG in 1998. In 2006 he co-founded the Photovoltaic Institute Berlin where he sits on the board of directors and acts as a senior consultant. He also is a lecturer at the University of Applied Sciences for Technology and Economics Berlin (HTW).

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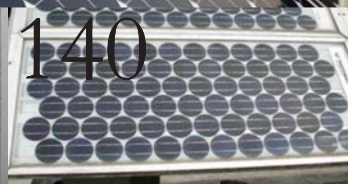
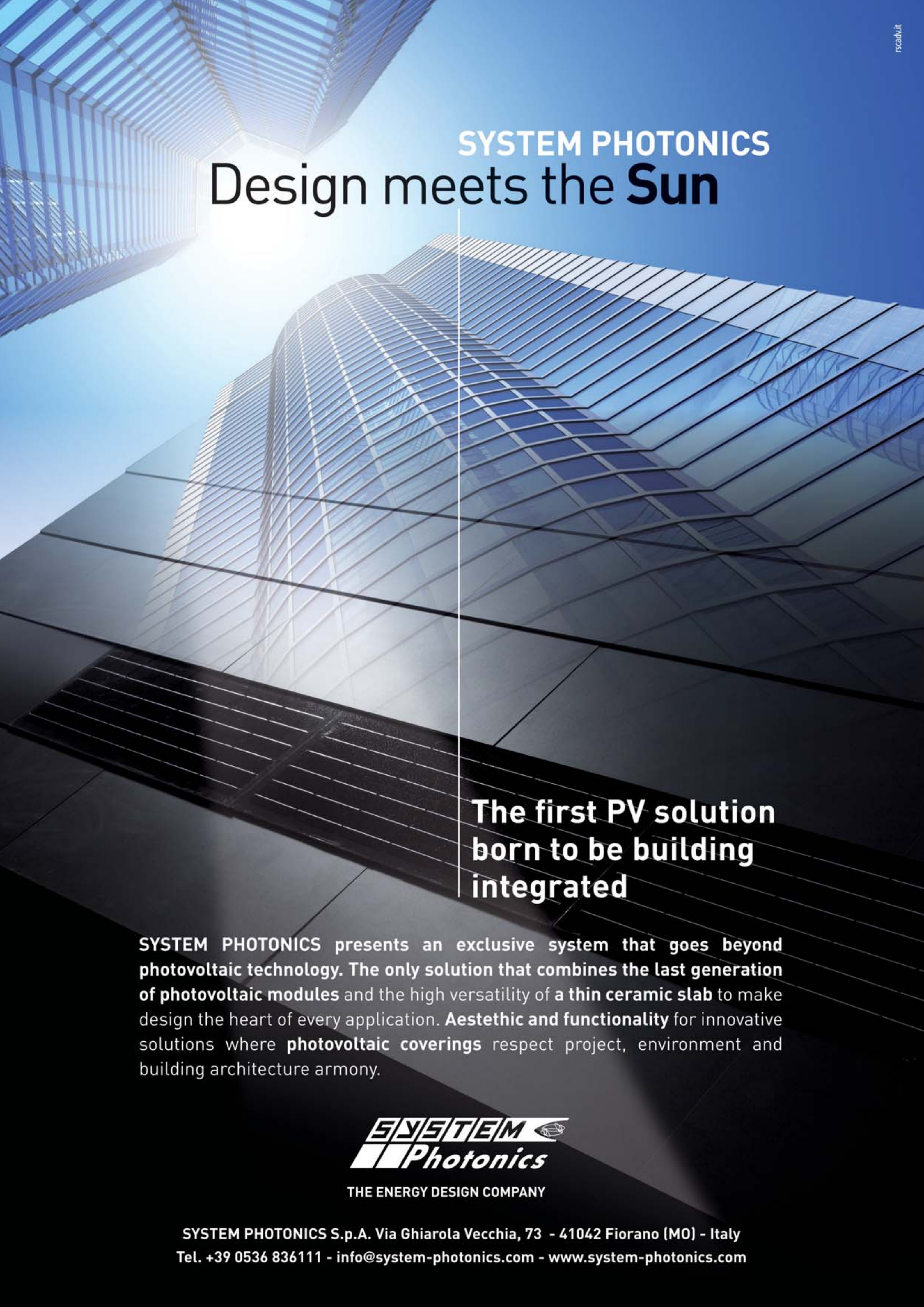
Power Generation

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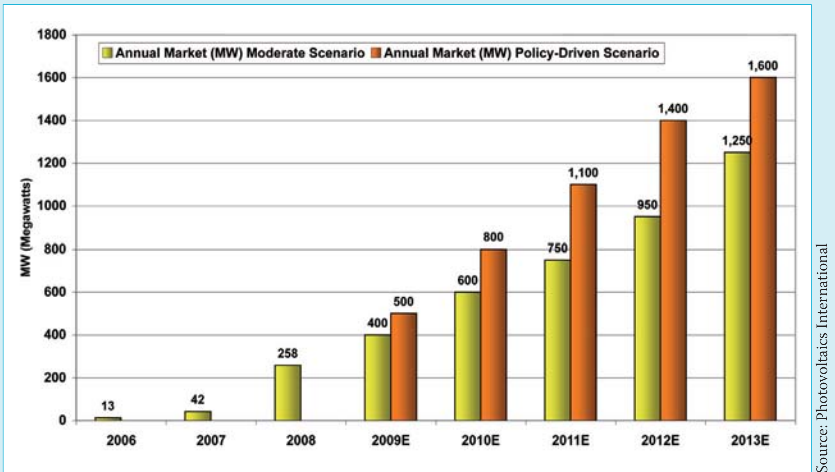
Italy to more than double installed solar PV capacity by end of 2009

Incentives will lead to a more than doubling of Italy's installed solar photovoltaic capacity – from about 440MW to 900MW – by the end of 2009. The Italian power management agency GSE said that some 338MW of PV capacity was installed in 2008 – said to be the third-biggest annual rise in solar capacity in the world, on a par with the United States and behind Spain and Germany.

About 34,000 new PV installations with a total capacity of 435MW have sprung up in the southern European country since new government incentives took effect in mid-2007. Those numbers compare to about 2,500 PV installations with a total capacity of 22MW deployed over two years, after the first incentive scheme was introduced in 2005. Italy could exceed 70,000 by the end of 2009 with a total capacity of 900MW.

The Spanish market exceeded market forecasts to reach more than 2.5GW of solar power installations by the end of 2008. This created a boom-to-bust cycle that is not good for the industry, something Italy could mimic.

Looking at the two forecasted scenarios recently released by the European Photovoltaics Industry Association (EPIA) for the Italian market, the 'moderate scenario' projection points to 400MW installed in 2009. The 'policy-driven' scenario points to an additional 100MW installed, bringing the total to 500MW for the year.



EPIA annual installed market growth forecast for Italy 2006-2013.

Suntech shocked many of its competitors in December, 2008 when it announced it had already secured 130MW in orders in Italy for 2009, implying more was to come. Based on current market forecasts from the EPIA, the China-based PV producer appears to have secured about a third of the available market for 2009.

Rivals such as Sunpower have already acquired PV installers and distributors in Italy as a base to expand sales in the country, yet have been reluctant to give guidance on the expected sales in Italy. Trina Solar has built a good business in Italy in 2008 while other rivals have started establishing sales operations in the country.

The revised Italian installation figures would now suggest that many market forecasts are too conservative, which could mean that installations go through the roof and the Italian Government imposes a draconian cap in 2010.

U.S. Region News Focus

SunEdison poised to call the shots in U.S. solar market

Recently, North America-based solar energy provider SunEdison became the first U.S. supplier to surpass 100GWh in delivered electricity generation. It also activated a record 86 photovoltaic solar energy systems in the U.S. during 2008, totalling 25.5MW.

The company has also been highly successful in raising capital to fund projects to the tune of US$450 million from Wells Fargo; HSH Nordbank; Union Bank, N.A.; MetLife; Applied Ventures; Black River Commodity Clean Energy Investment Fund; MissionPoint Capital Partners; and Allco Renewable Energy Group Ltd.

"The PV PPA firms that can continue to build their financing pipelines will be in a position to dictate the terms to the PV industry for the near-term future. Therefore, both established vendors as well as start-ups with products in the PV cell, inverter and monitoring markets will need to increase their efforts to address the PV PPA firms' concerns, as well as show both enhanced financial returns and minimal risk," noted Gartner in a weekly newsletter to clients.

This is a complete turnaround from 2008, noted Gartner, as vendors could pick and choose which customers to supply as shortages continued across the supply chain.

With financing the key constraint and over-supply of PV modules guaranteed, firms with access to capital set the terms and financing firms determine what technologies they are willing to accept or deny, based on the maturity of the technology and the viability of the vendor. This could place added pressure on start-ups that lack both funding and mature product.

FPL to build 75MW solar power plant at Kitson's Babcock Ranch development

Real estate developer Kitson & Partners and Florida Power & Light have signed an agreement that could lead to the construction of one of the world's largest solar PV power plants. The deal calls for FPL to build and operate a 75MW installation at the Babcock Ranch development in southwestern Florida, a 17,000-acre planned city that Kitson claims will be a model of energy efficiency and environmentally-friendly building practices and will include an integrated smart grid, sustainable water management, and green roofing solutions.

FPL's chief development officer, Eric Silagy, said that the utility has "secured the necessary land, local zoning, and transmission access" for the PV power plant.

Once the Florida state authorities approve the project, groundbreaking on the grid-connected facility could begin later this year, with construction of the city center targeted for mid-2010 and construction of the first residential and commercial buildings targeted for late 2010.

FPL spokeswoman Jackie Anderson told PV-Tech that the process of selecting which type or types of solar modules or balance-of-system components that will be deployed for the Babcock Ranch project will not begin until the plans have been approved by the Florida state legislature.

First Solar takes over OptiSolar's PV pipeline in US$400 million transaction

First Solar has purchased OptiSolar's photovoltaic project pipeline for US$400 million in an all-stock deal. First Solar will complete construction of the plants developed under the pipeline over the next few years, with plans to sell those plants to various regulated utilities, diversified energy companies and other independent power producers.

First Solar has confirmed that it will keep on the OptiSolar core development team that designed and executed the PV project pipeline.

As a result of recent appreciation in the price of the company's common stock shares, First Solar is planning to issue approximately 3 million shares of common stock at a 3.5% dilution instead of the expected 5% dilution.

Recurrent Energy receives 350MW solar power pipeline from UPC Solar

The solar energy provider, Recurrent Energy, has purchased a solar pipeline of up to 350MW from the Chicago-based renewable energy development company, UPC Solar. Aside from making it one of the most promising distributed solar power providers and bringing the company's focus on smaller utility-scale power assets ranging from 2-20MW, the purchase allows opportunities of development across continental United States, Hawaii, and Canada, including those PV plants planned for Ontario. Recurrent Energy will use UPC Solar's development team to finish solar projects in Canada.

As one of several renewable energy companies founded by Brian Caffyn of UPC Energy Group, a company with over 750MW of operational renewable energy assets and more than 3,000MW in development worldwide, UPC Solar currently manages the U.S. Army's largest solar installation in Fort Carson, Colorado and the fourth-largest solar PV project in the U.S., a 3MW plant in Bucks County, Pennsylvania.

The pipeline acquisition follows a recently proposed series of renewable energy measures from Canada's Ontario Power Authority. In the Green Energy Act, 2009, a solar feed-in tariff secures stability and competitive electricity rates for renewable energy providers, while also representing North America's first step in becoming more like Spain and Germany in terms of substantial solar power development.

1.8MW solar installation dedicated by enXco

enXco, an EDF Energies Nouvelles Company, has officially dedicated the Hall's Warehouse Corp. Solar Project marking the completion of the 1.8MW solar installation, bringing the Hall's total solar output to 3.2MW and making it New Jersey's largest private commercial roof-top solar system.

The 501 Kentile Road and 601 Kentile Road facilities features 20,184 First Solar panels and 2,190 UNI-SOLAR laminates installed on the roofs. The system will be operated by enXco, who will also supply the project's output to Hall's Corporation under a Power Purchase Agreement on a net-metering basis. The project had been co-developed by Infinite Energy and Clean Energy Holdings, while Vanguard Energy Partners, LLC was the installer.

First Solar confirms rumoured Sempra PV plant extension

Just a few months after Pacific Crest financial analyst Mark Bachman revealed that First Solar had been selected for a massive extension to Sempra Generation's 10MW solar power plant in Boulder City, Nevada, First Solar has confirmed the deal. First Solar is to design, engineer and construct a 48MW plant at the same location, with the project expected to be completed sometime in 2010, subject to Sempra obtaining a power purchase agreement (PPA) with a utility.

SunPower and Xcel Energy sign up for 17MW power plant in Colorado

Alamosa County in south Colorado is the planned location of what will be the second-largest high-efficiency solar PV power plant in North America, once SunPower and Xcel Energy construct their new 17MW solar power plant. The companies have signed up for the construction of a 17MW AC photovoltaic solar power plant that will utilise SunPower's Tracker systems.

This Alamosa plant is subject to approval by the Colorado Public Utility Commission, as well as the availability of project financing.

Satcon signs three-year 330MW supply deal with Ecostream

Satcon Technology Corporation has entered into a supply agreement with Ecostream, a solar system provider and part of sustainable energy company Econcern, for 330MW of solar power products and solutions. The three-year agreement will include delivery of Satcon's PowerGate Plus line of solar inverters.

News

Evergreen Solar targets utility-scale projects

Evergreen Solar has entered into an agreement with RMT, Inc., a renewable energy projects firm, to boost sales of its String Ribbon modules into the utility-scale solar plant market. The new agreement will see RMT handle all engineering, procurement and construction functions while Evergreen Solar will provide the solar panels.

The companies said that they have already submitted bids for more than 400MW of solar installations, which could be implemented over the next five years.

Solar thermal comes to Nevada with BrightSource's potential 600MW development

In a land agreement that could potentially see the establishment of a solar thermal development up to 600MW in Lincoln County, Nevada, BrightSource Energy, Inc. has revealed that it has reached an agreement on the principal terms of a private land contract with Nevada's Coyote Springs Land Company, a planned community developer.

The location of the planned project is a six-square-mile area within the larger Coyote Springs development in Lincoln County, just northeast of Las Vegas. Necessary environmental permits from the Bureau of Land Management, U.S. have been secured.

Energy Innovations creates spin-off for RayTracker products

Energy Innovations has announced that its RayTracker product group has been spun off to form RayTracker, Inc. The new company will allow the team to take advantage of the growing demand for its RayTracker GC product line. The GC line was made to be cost-effective while boasting high efficiency and reliability. The RayTracker was included in over 2MW of installations in 2008.

The company claims that PV panels mounted on a RayTracker system yield up to 38% more energy than fixed flat PV systems annually and up to 23% more than fixed-tilt systems.

SMA and Sunetric team up for Hawaii solar farm

SMA America, Inc.'s Sunny Central 250U solar inverters have been used for the second-largest solar farm in Hawaii. The design/build alternative energy company and Hawaii's largest locally-owned solar integrator, Sunetric, installed a 500kW system at Wilcox Memorial Hospital on the island of Kauai.

The solar farm, which is the first such installation at a Hawaii hospital, generates 740,000kWh a year, enough electricity to power 85 homes, and spans 1.4 acres. 2,190 SunPower solar panels combine with three SMA Sunny Central 250U inverters to convert energy for the hospital. The project saves the hospital US$250,000 a year by cutting 52% of its electricity costs.

Sunetric's Vice President of Business Development, Todd Georgopapadakos said, "In 2008, we installed more PV than anyone else in Hawaii, and we choose SMA inverters because their strong track record for success, reliability and sealed design gives us confidence."

National Semi claims tests show 57% power pop in PV panel performance

As much as 57% of the power lost because of temporary or partial shading of solar PV panels can be recouped with the use of a new optimization technology, according to test results released by National Semiconductor. The company said that its SolarMagic power optimizers (which will be available this spring) improve the energy harvesting of solar panels in real-world conditions, where shading and other issues can significantly reduce the performance of solar systems.

The tests, conducted at National's Santa Clara, CA, facility, used a screen representing typical rooftop obstructions to replicate shade on a portion of a conventionally wired solar PV system. Although 8-16% of the array was shaded over the course of a day, it resulted in average power losses of 35-40%.

However, an identical solar array fitted with the SolarMagic devices produced an average of 30-37% more electricity in the same conditions – effectively recouping up to 57% of the lost power, according to the company.

The test and reference arrays were each made up of 2 strings with 12 PV panels per string, with both strings attached to a Xantrex inverter. The performance data were collected using the inverter company's software and had a measuring accuracy of ±5%.

European Region News Focus

ACCIONA commences work on 50MW CSP plant

ACCIONA Energy has begun work on its third concentrating solar power plant in Spain, which will boast a capacity of 50MW on completion in the second half of 2010. The plant, located in Majadas de Tiétar in the Cáceres province of southwest Spain, is expected to create between 300 and 400 jobs during the construction phase.

The €237 million investment in the plant will see the implementation of 76 kilometres of solar trough collectors on the 135 hectare solar field. The 800 solar collectors will feature a total of 192,000 mirrors, borrowing experience from the solar trough collector technology used in ACCIONA's "Nevada Solar One" plant.

This plant is the third such established in Spain by the company, with plans for a fourth in Spain by the end of 2010.

Plans for the fourth plant will see construction start in June 2009 on Palma del Río, another 50MW CSP facility. The company has also initiated administrative procedures for a fifth CSP plant in Spain, to be named Alvarado II.

Mitsubishi takes 34% share of ACCIONA's Amareleja plant in Portugal

In an investment amounting to €261 million, Mitsubishi Corporation has claimed a 34% stake in ACCIONA's Amareleja (Moura) PV solar plant in Portugal. At 45.8MWp, the Moura plant is on track to become the world´s largest grid-connected photovoltaic solar plants on completion of all phases. Both companies are aiming to extend their collaboration in renewable energy and other sustainable development projects worldwide.

Mitsubishi takes a 34% stake in Amper Central Solar, the developer of the Moura plant, which is 100% owned by ACCIONA. Situated on a 250 hectare site, the plant has an estimated annual production of 93 million kWh of electricity.

Q-Cells, LDK Solar form joint venture for large-scale solar energy plants

Recent rumours of a business tie-up between Q-Cells and LDK Solar have come to fruition with the official formation of a Joint Venture (JV) to promote and supply PV systems for large-scale solar power plants in both Europe and China. The new business partners said that a 40MW project located in Europe had already been secured, which will see the use of solar wafers from LDK Solar and solar cells from Q-Cells, though no details were given in respect to modules.

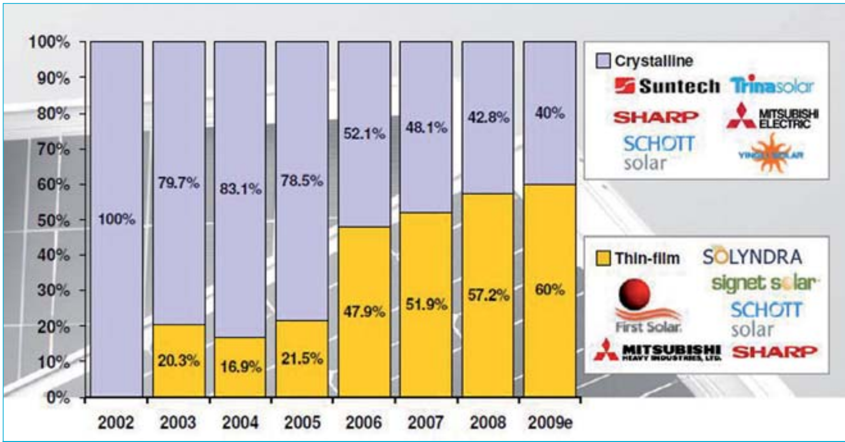
The JV is intended to reduce system costs through the supply chain and leverage market presence in the two regions, according to the companies.

"This joint venture will strengthen our position in the crucial business area of large-scale PV power plants," noted Anton Milner, CEO of Q-Cells SE.

Other projects were said to be in the planning stage including projects in China.

Phoenix Solar expects further growth in 2009; targets 60% thin-film installation

Despite a major fall-off in installations in the fourth quarter of 2008 due to the early onset of winter in Germany, a complete end of projects in Spain and large-scale project finance difficulties due to the financial crisis, Phoenix Solar AG posted record sales for 2008, reaching €402 million, compared to €260 million in 2007. Based on its current backlog, the PV systems integrator expects sales to reach approximately €520 million in 2009.



Phoenix Solar's product mix projections.

Phoenix Solar has experienced a CAGR of 78% since 2000 and expects to increase its business outside of Germany to more than 35% of revenues in 2009 and 50% by the end of 2010. In the long term, Phoenix Solar plans overseas sales to reach approximately 65% by the end of 2013.

A key part of the growth strategy would seem to be the emphasis on thin-film technologies. Phoenix Solar was one of the first integrators to offer thin-film modules from First Solar, which has seen its thin-film product mix grow from 21.5% of installations to 57.2% in 2008. Phoenix Solar's thin-film product mix is expected to further increase to approximately 60% in 2009.

Thin-film technology agnostic Phoenix Solar has secured long-term supply contracts with a host of players that include start-ups such as Signet Solar (50MW, 2008-2011), which uses Applied Materials' 'SunFab' technology, and Solyndra in a deal worth €450 million in the same timeframe.

The company expects power plant projects to resume growth in 2Q09 and installations to peak in 4Q09, returning to normal seasonal trends after the disruption in Spain, which caused an installation peak in 3Q08 due to feed-in tariff changes and a new MW cap being imposed.

Grupo Ibereolica starts work on two 50MW CSP solar thermal plants

Grupo Ibereolica has strengthened its foray into the solar thermal industry with its involvement with a dual project that will see an additional 100MW of capacity on Spain's solar portfolio. Grupo Ibereolica has signed an agreement with Inveravante, a private energy, finance and real estate conglomerate, for the joint construction of two 50MW CSP solar thermal plants, one in Seville, Andalucia, the other in Badajoz, Extremadura.

Construction on the two 50MW plants will start immediately, as all permits and authorisations have been granted. The projects will use parabolic trough technology, and future additions such as upgrading to salt storage and biomass hybridisation in order to increase nightime production have been discussed.

Siemens targets dominant position in solar thermal technology

Siemens has acquired a 28% share in Italian solar thermal specialist Archimede Solar Energy for an undisclosed sum, using the purchase to claim that the German engineering conglomerate was intending to become the leading global company for solar thermal power plants. Siemens believes that solar thermal power market would experience double-digit growth rates per annum, reaching more than €10 billion in sector revenue by 2015.

Siemens said it would provide the capital necessary for a rapid expansion of production capacity at Archimede, with the option to acquire a majority stake in the solar company in the 'mid-term.' Archimede only had revenue in single-digit million euro range in 2008.

Archimede uses molten salt as heat transfer fluid in its solar receivers for parabolic-trough power plants.

Asia Region News Focus

Jordan's solar future looks bright with US$13.2 million funding from EU Commission

Jordan's solar industry looks to be on the up as reports have emerged of a US$13.2 million funding package for the establishment of a solar plant and renewable energy research facility. According to the news site UPI.com, the ~5MW plant will be located in Fujeij, near Shobak in the southwest of Jordan.

The National Energy Research Center, as it will be called, will comprise the 5MW solar power plant as well as a renewable energy training centre for local and regional workers. Construction of the plant will contribute towards the country's national energy strategy that is striving to establish 600MW of solar power installations by the year 2020.

P2 Solar gets approval for 25MW Punjab solar power plant

P2 Solar, Inc. has received approval from the Indian State of Punjab for the construction of a 25MW solar power plant, which will include a 33-year power purchase agreement. Further details of the project were unavailable.

The company will create a written agreement detailing the terms of the project after May 20, 2009.

Canadian Solar to supply PV systems to 80,000 rural households in Sichuan, China

Canadian Solar has been selected to supply 1.6MW of photovoltaic panels for 80,000 solar home systems for rural households in the Chinese province of Sichuan. The project was initiated and financed by China's Ministry of Agriculture and the Sichuan provincial government.

The solar home systems, rated at a peak capacity of 20W each, can power two lights and a small TV. Delivery of the PV units is slated for completion this month.

"A solar home system makes a real impact on the lives of these rural households," said Shawn Qu, President and CEO of Canadian Solar. "In many cases it will be the first electrical power source these rural families have ever had." "We are very proud to be part of this project," he continued. "Canadian Solar has a business division devoted to the designing, manufacturing, and installing solar home and solar village systems for rural electrification and has been actively involved in rural electrification projects in China since 2004."

eSolar names India's ACME as exclusive licensee for up to 1GW of plants

Solar thermal power company eSolar has entered into an exclusive licensing agreement with ACME Group, an India-based infrastructure solutions company that allows for the construction of up to 1GW of solar power plants in the country over the next 10 years. As a licensee of eSolar's technology, ACME is granted the exclusive rights to represent eSolar in the construction of solar thermal plants in India.

The US$30 million agreement allows for ACME to participate in solar thermal plant construction and operations in India using eSolar's technology over the next 10 years, as well as activities such as technology development and component manufacturing.

ACME has already signed power purchase MOUs for 250MW worth of power plants, of which 100MW will begin construction later this year.

Marking eSolar's first such international licensing agreement, the deal is further to the recent US$10 million collaborative move with NRG Energy, Inc., which will see up to 500MW of solar power plants in the U.S. being constructed by NRG using eSolar's modular and scalable technology.

Product Briefings

SMP

SMP now offers energy-efficient chokes for photovoltaic power plants

Product Briefing Outline: SMP Sintermetalle Prometheus (SMP) is offering chokes for power inverters, featuring low losses, very low stray fields and a highly compact design as well as energy efficiency advantages for power inverters that are based on these chokes.

Problem: Power inverters in photovoltaic plants convert the direct current originating from the solar cells into alternating current. It is desirable that plants yield a maximum of energy at as low a cost as possible from the sun's radiation on the connected photovoltaic modules. The direct current from the modules must be converted into a sinusoidal waveform and thus into the values required by the grid. So-called filters consisting of capacitors and filter chokes ensure that the current being fed into the grid exhibits a sinusoidal waveform.

Solution: SMP has designed high-performance, low-loss chokes that meet the constantly increasing requirements of solar technology. The materials used have low magnetostriction and exceptionally low eddy current and hysteresis losses; as a result, the inverters in which they are used are highly efficient, and with a larger proportion of the generated power being fed back into the grid, a faster return on investment is achieved. Compact choke design is another important aspect. In comparison to conventional designs, SMP chokes are claimed to occupy 25% less volume.

Applications: Power inverters in photovoltaic plants.

Platform: SMP manufactures all components to customer specifications using in-house-developed powder composites. All products are RoHS- and REACH-compliant and the materials used are UL-listed. To allow for a wide range of requirements, components can be made to all common standards.

Availability: Currently available.

LINAK and LORENTZ

LA36 actuator from LINAK designed for harsh environments

Product Briefing Outline: LINAK and LORENTZ have collaborated to produce a new linear actuator, the LA36, specifically designed for solar utility plants and harsh environments requiring solar tracking systems. The LA36 actuator is very sturdy, enabling the LORENTZ to apply to $18m^2$ to $22m^2$ solar panels, increasing the solar panel surface area by just over one quarter.

Problem: An actuator is the unit that converts low DC voltage from the control box into a linear movement. The LINAK actuator consists of three main elements: a motor, gear and spindle including a nut. LORENTZ's aim was to minimise the demand for maintenance of their solar tracking system, which they built to withstand all weathers. The size of solar panels produced depends on the strength of the solar tracking system.

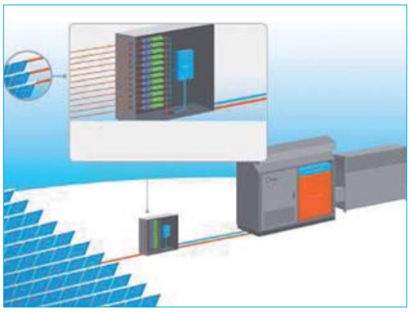
Solution: Together with LINAK, a special solution, the LA36 actuator, was developed. The actuator employs a heavy-duty aluminium housing specifically designed for harsh conditions, and can be washed down by a high pressure cleaner, reducing maintenance time. A highly efficient acme thread spindle is also used. It has a duty cycle with a maximum load of 20% (up to 600mm stroke; for strokes between 601-999mm the maximum duty cycle is 15%) at ambient temperature of 25°C. The actuator's ambient operating temperature is -30°C to +65°C, and it provides full performance from 5 - 40°C.

Applications: Harsh environments that require solar trackers for large-scale utility PV power plants.

Platform: The LA36 actuator uses 12, 24 or 36V DC Permanent magnetic motors with re-settable thermal overload protection. Maximum speed up to 160mm/sec., depending on load and spindle pitch. Hand crank for manual operation. Potentiometer full scale at 333mm stroke with 8mm pitch; 500mm stroke with 12mm pitch; and 833mm stroke with 20mm pitch.

Availability: Currently available.

Satcon Technology Corporation



Satcon's 'Solstice' distributed energy management system designed for large-scale PV power plants

Product Briefing Outline: Satcon Technology Corporation has introduced the 'Satcon Solstice,' a utility-grade DC architecture solution for highly efficient power conversion for large-scale solar power plants. It delivers fine-grained power harvesting and control with critical utility-ready grid interconnection, and it is claimed to boost total power production by 5-12% over designs using standard inverters.

Problem: As solar installations have continued to increase in scale, so too have the complexities of harvesting and managing power. In order for large-scale installations to achieve a sustainable and profitable levelized cost of energy, a fundamental shift in array design parameters and energy management is required. This shift is brought into play by using a management system that is smart enough to monitor and control the entire PV system, agile enough to optimize constantly changing variables, and flexible enough to take advantage of new, more affordable technologies throughout its lifespan.

Solution: Building on Satcon's solar PV inverter technologies, Solstice is the next generation of solar PV energy harvesting. Coupling string-level power conversion with a new smaller footprint central inverter design, Solstice is a complete power solution that will provide high efficiency, localized command and control, and higher kilowatt hours per day. By converting power at each individual string, the solution virtually eliminates typical array losses from shading, soiling and panel mismatching. By conditioning power, monitoring performance, and controlling variables at the string level, Solstice keeps even the largest PV plants running smoothly and enables them to achieve maximum throughput.

Applications: Large-scale solar power plants.

Platform: 30kW, 60kW, 100kW, 150kW, 200kW, 250kW, 500kW, and 1MW DC-to-AC Converter. Integrated Transformer (internal or external; model dependent) System-Wide Command and Control Center.

Availability: Available in 4Q09.

Utility-scale PV systems: grid connection requirements, test procedures and European harmonisation

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ABSTRACT

New interconnections requirements for utility-connected photovoltaic systems are coming into force in several European countries, armed with the task of supporting the grid operation and stability. This approach to better integration of photovoltaic systems into the electric power system enables a larger dissemination of renewable energies. This paper presents the new grid code in Germany as an example for improved integration, complemented by a brief report regarding activities currently being undertaken to ensure European harmonisation of interconnection requirements.

Introduction

Facing the enormous growth of decentralised generation connected to the distribution systems, the year 2009 brings fundamental changes for new PV systems in a number of European countries. While in the past, generators connected to the distribution system were commonly not permitted to take over an active role and had to "disconnect at the first sign of trouble", the new guidelines now require the units to actively support the grid during normal as well as disturbed conditions. This step is being regarded more and more as absolutely necessary to guarantee reliability and quality of supply in the mid- to long-term.

"National laws, standards and recommendations in different countries have naturally different characteristics as practises have grown and developed from local needs and conditions."

This new approach has already been adopted in France (April 2008 [1, 2]) and Germany (June 2008 [3]) using the latest revisions of the national guidelines for the connection of generators to the low- (LV) or medium-voltage (MV) networks. Consequently, the change has also been recognised by other countries as being trend-setting for the new role that PV and other distributed energy resources (DERs) are going to play in the future. Among these, Austria recently (January 2009) adopted the new approach and incorporated a number of key requirements into its guidelines for the connection of generators to the distribution networks [4].

While the new guidelines are currently mainly relevant for MV connections and thus PV systems in the 100kW+ range, the same approach is already being incorporated into the recent drafts for the upcoming new low voltage interconnection specifications. All new PV installations will from then on be directly concerned and will have to fulfil the new requirements.

European harmonisation

National laws, standards and recommendations in different countries have naturally different characteristics as practises have grown and developed from local needs and conditions. The absence of harmonised interconnection specifications is one of the most severe obstacles to the wide deployment of DERs and the subsequent inclination towards active electricity networks in Europe. The objective of addressing this diversity has been taken on board by the research community and is also one of the key objectives of DERlab, the European

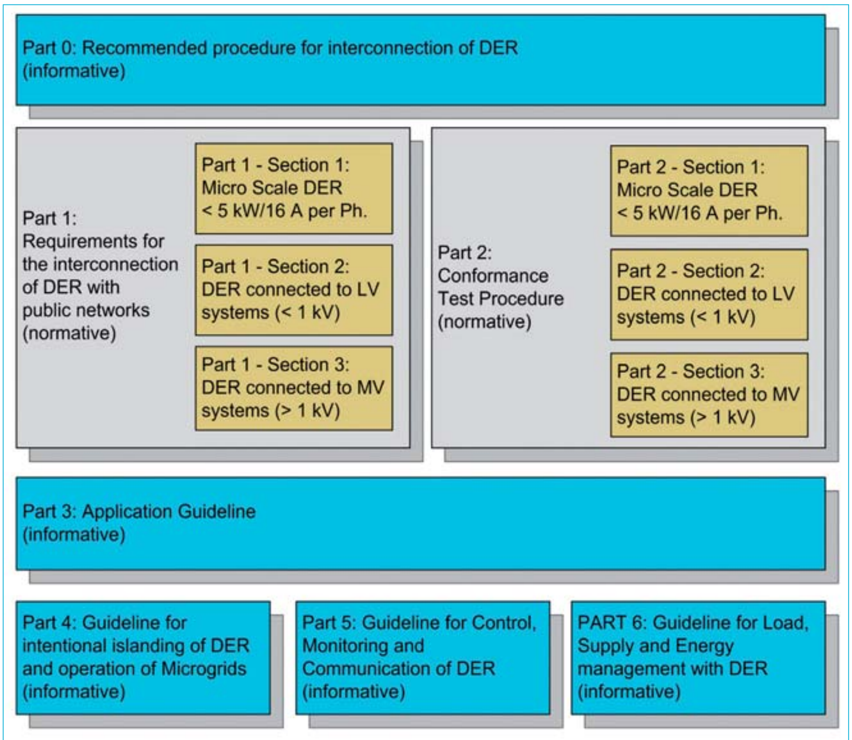

Figure 1. Proposed structure of Technical Specifications by DERlab to CENELEC TC8X WG03 working group [7].

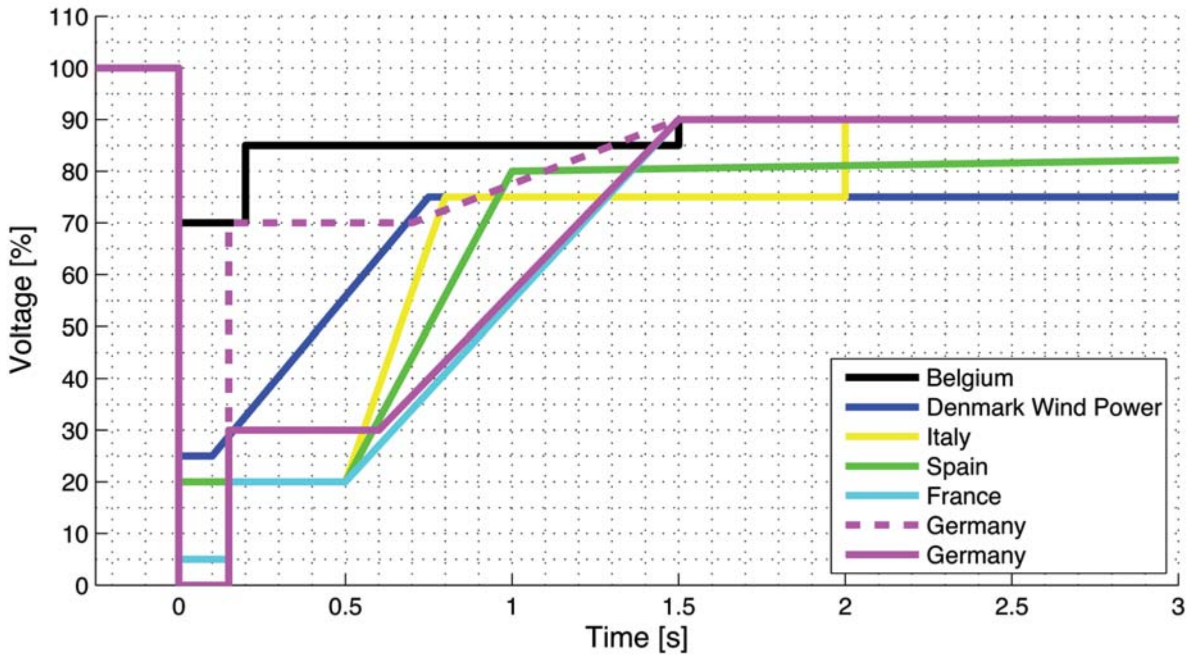

Figure 2. Requirements in national grid codes for decentralised generators connected to the distribution system during a grid fault.

Network of Excellence of independent laboratories working on the integration of DER [5].

As part of the DISPOWER project, the interconnection specifications of nine European countries were compared to give recommendations and to investigate standardisation needs [6]. Since then, other research projects commenced investigations comparing the interconnection specifications of different countries and defining the gaps. Analysing these results, DERlab has presented to the relevant standardisation committees a solid structure for a future European Standard for Interconnection of DER (EDIS) [7], as shown in Figure 1. This European approach intends to overcome the current lack of standardisation and testing procedures in this area, resulting in additional costs for manufacturers and project developers. Two European DERlab workshops, one in May 2009 in Salzburg, Austria, the second in September 2009 in Łódź, Poland will be performed in order to give additional support for the development of harmonised interconnection requirements.

For this purpose, DERlab has set up the "DEDIS - Database of European DER Interconnection Specifications" to create more transparency in the clutter of the different specifications and to support their European harmonisation. DEDIS is publicly available on the DERlab internet portal (www.der-lab.net) and is searchable by country, segment, or energy source. The survey given in DEDIS will be the basis for further investigations. Exemplary comparisons between interconnection specifications of different countries using DEDIS will help to clarify the current situation and illustrate the harmonisation needs. In addition, DEDIS users are given the opportunity to report on their own experiences, deviations from the national guidelines or other important feedback directly via a web-based interface. Based on this feedback, DEDIS will become a unique source of comprehensive information on DER implementation practise in Europe and thus make the complex interconnection issue more transparent.

European interconnection standard developments at CENELEC

Besides the aforementioned different national requirements, there is a European initiative at CENELEC, the European Standardisation organisation, in the field of electrical engineering to develop common European interconnection requirements. The CENELEC TC8X WG03 is charged with providing a Technical Specification for "Requirements for the connection of generators above 16A per phase to the LV distribution system or to the MV distribution system".

"Working group activities show that many challenges have been occurring due to the varying needs of European countries and their network systems."

It is important to harmonise these requirements in order to guarantee a common behaviour of all generators connected to the UCTE grid. Several DERlab members are actively participating in this working group.

A major working point within the TC8X WG03 is grid support of distributed generators. On the one hand, in the steady-state case, grid support should be provided by contributing to the voltage control through the injection of reactive power. In the transient case, on the other hand, grid support can be performed by staying connected (so called Fault-Ride-Through (FRT) behaviour) and by injection of short circuit current during a grid fault. Working group activities show that many challenges have been occurring due to the varying needs of European countries and their network systems. This can be exemplified inter alia by different FRT curves (see Figure 2) of existing European grid codes.

The Technical Specification also handles testing and commissioning. The intention is to describe common test procedures that can be carried out in European testing laboratories with comparable results. Therefore, DERlab is also carrying out Round-Robin-Tests with PV inverters with the aim of identifying differences in the interpretation of testing procedures as well as differences in test setups.

Interconnection requirements in Germany: the new medium voltage grid code

The developments in Germany are presented here as an example to illustrate new grid code requirements.

Based on the TransmissionCode 2007 and the "Guideline for connection and parallel operation of generators using renewable energy at the high voltage (HV) and extra high voltage (EHV) network", similar requirements concerning the

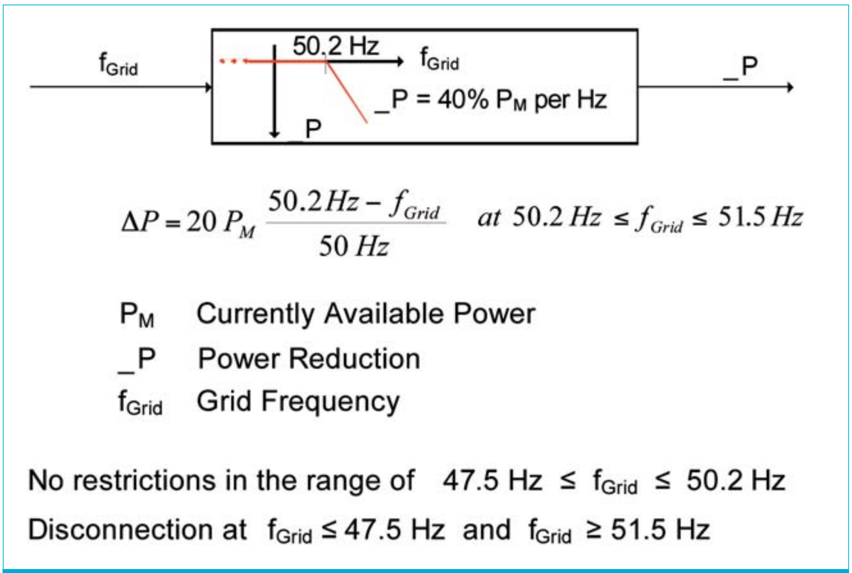

Figure 3. Active power droop characteristic in case of over frequency according to the German guideline for connection to the medium voltage distribution network [3].

grid-supporting electrical behaviour of distributed generators have been transferred to the Medium Voltage (MV) network [3]. PV systems that are installed after 1st January 2009 and grid-connected to the MV level are obliged to meet the following grid-supporting requirements in normal operation conditions:

- Limitation of power quality characteristic parameters
  - Limitation of steady-state voltage change of 2% of the nominal value
  - Limitation of voltage fluctuations due to switching operation
  - Limitation of long-term flicker
  - Limitation of current harmonics, interharmonics and higher frequency components up to 9kHz.
- Active power control (reduction)
  - Remote set point control by the DSO for power generation limitation in case of network congestions or danger of power system collapse
  - Automatic reduction of active power generation according to active power droop characteristic (Figure 3) in situations of over-frequency.
- Reactive power control
  - Set point control for voltage stability, also remotely by network operator
  - Minimum power factor of 0.95.

Figure 3 depicts the active power droop characteristic in case of over-frequency. All distributed generators must have the capability to reduce their power generation when the grid frequency exceeds the value of 50.2Hz. The reference value for the active power reduction ΔP is the currently available power generation value (PM) at the point in time when the grid frequency is equal to 50.2Hz. This active power reference value must be reduced at least with a coefficient of 40 %/Hz grid frequency deviation from 50.2Hz. If either the grid frequency increases to values equal to or higher than 51.5Hz or decreases to values equal to or less than 47.5Hz, the generation unit has to be disconnected.

Power Generation

"Distributed generators have to contribute to voltage stabilisation in order to avoid disconnection in the case of voltage dips."

The dynamic (transient) grid-supporting features are requested from January 1st 2010 in case of voltage dips at the MV level due to grid faults at the HV and EHV network. In detail, the requirements are:

- Fault-Ride-Through Capability, with:
  - No disconnection of the generation due to the voltage dip
  - No change of active power generation

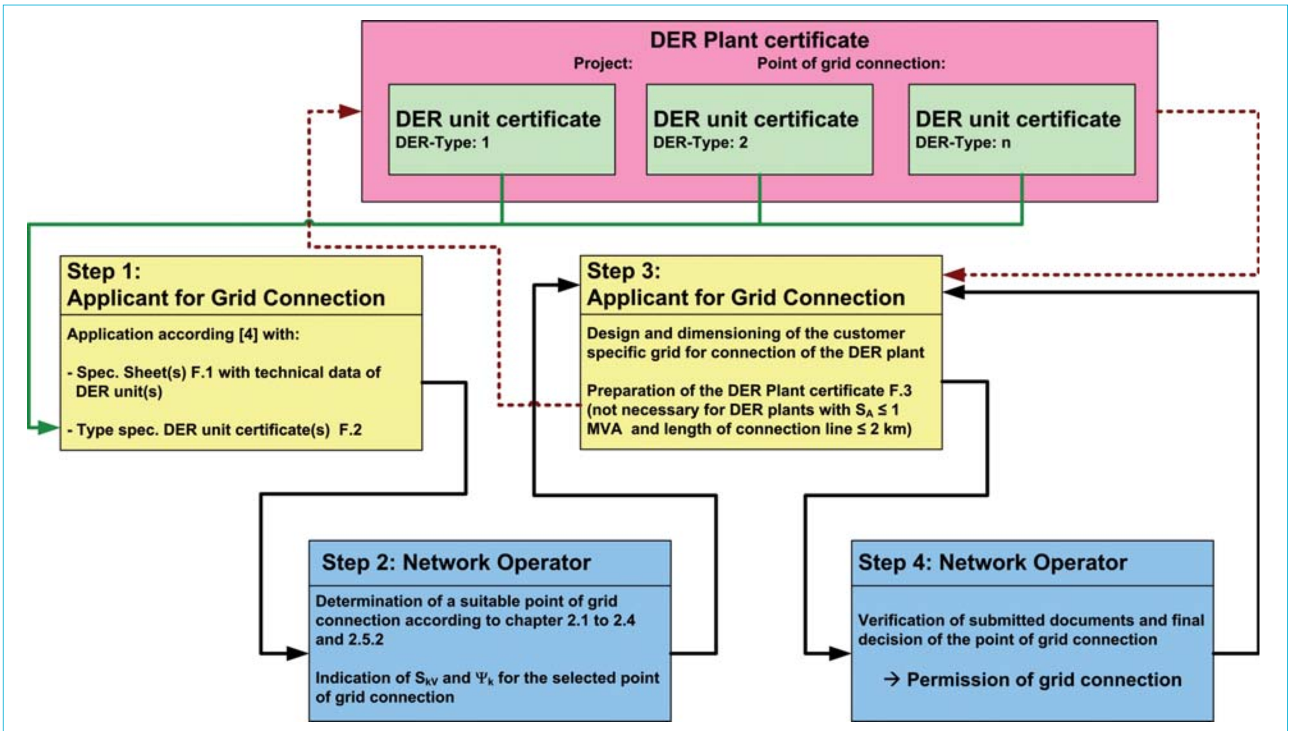

Figure 4. New procedure for the realisation of an interconnection of generators to the MV grid according to the German MV guideline.

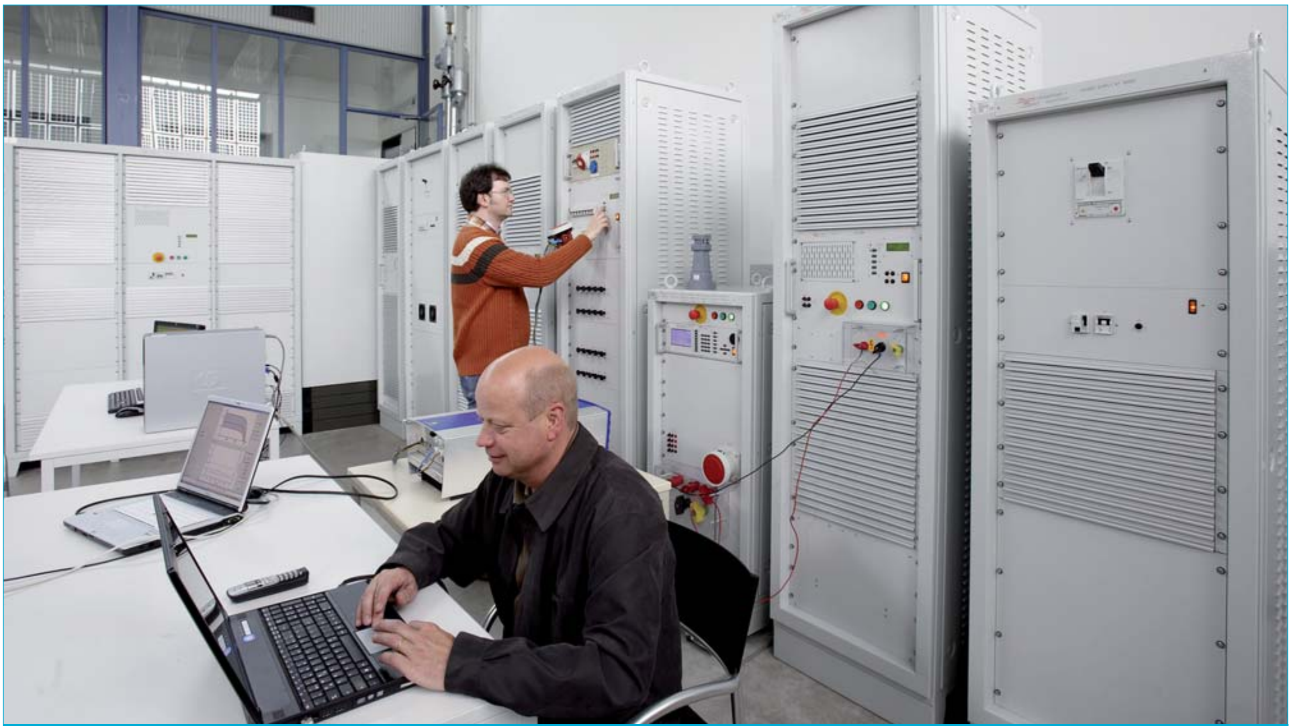

Figure 5. ISET's facility for PV inverters to test conformance with interconnection requirements.

before and after the fault for frequency stabilisation

- Feed-in of reactive power during the fault for voltage stabilisation

- Limitation of short-circuit current if necessary.

Thus, in addition to the stationary voltage support, distributed generators also have to contribute to voltage stabilisation in order to avoid disconnection in the case of voltage dips. The objective of this requirement is to prevent large power system collapse when a sudden power loss challenges the limited primary reserve for frequency stabilization. Depending on the fault conditions (voltage depth and fault duration), distributed generators are requested to "ride through the fault"; they are not allowed to disconnect from the grid and must feed in the same active power directly after the fault as before.

Proving compliance with the German grid code requirements

According to the BDEW guideline, a proof of compliance with the requirements is requested for all generating units versus generating plants. A "generating unit" is a single energy-generating unit, while a generating plant is the combination of several units including internal network and additional equipment to realise the grid connection.

For single generating units with rated power less than 1MVA and a connection line less than 2km, it is sufficient to show compliance with the requirements by a type-specific generating unit certificate. In the case of photovoltaic systems, this could be a certificate provided to the customer or by the manufacturer of the PV inverter. For systems consisting of several units, a site-dependent plant certificate is required that confirms the conformance of the plant with the requirements. Figure 4 shows the procedure to follow for a grid-connection request.

The German grid code requires testing according to 'FGW-TR3' procedures [8]. These were originally developed for wind generators and are currently being extended to be applicable to other generating technologies. In November 2008 a working group was founded to address photovoltaics-specific questions. A first finding of this group is that the test of a PV generating unit can be done independently of the type of modules used only by testing the PV inverters. The revision of two other FGW technical guidelines was recently finished and have been coming into effect from May 2009. In addition to FGW-TR3, there is an 'FGW-TR 4' guideline concerning simulations [9] – of importance for the plant certificate, which is partly based on simulation calculations. For these calculations, validated models of the generating units have to be used. Finally, the 'FGW-TR8' [10] describes the procedure of the certification process.

Beyond grid codes: the DERlab white book on static grid converters

Further to the new grid-code requirements, a DERlab initiative has been initiated to produce an "International White Book on the Grid Integration of Static Converters". The aim of the white book is to describe medium- to long-term harmonisation needs for the behaviour and technical interfaces of grid-connected static converters. The white book should support the preparation of international standards that describe controllable power units for:

- Grid operators to assure grid compatibility of the new power devices that might contribute with ancillary grid services;
- Manufacturers of static converters for producing products that are applicable for the world market; and
- Operators of such devices to have devices available that are of well-defined quality/compatibility and that can be used efficiently.

"The new requirements will in many cases require fundamental changes to the design of devices in order to realise the additionally required functionality."

The white book on static converters features the following three sections:

- Ancillary services
- Behaviour under fault conditions
- Communication and control

The draft of the white book is available for international discussion via the DERlab web site and open to further contributions.

Conclusions

New grid-code requirements recently introduced in some European countries are an important step towards a better integration of distributed power generation and renewables into the electric power system. However, for a wide deployment of distributed generation and renewables, it is also vital to harmonise DER interconnection requirements on a European level and to bring in line the different interests of manufacturers, decentralised power producers and network operators.

Further to the repercussions for PV systems and particularly for the inverters, which incorporate the interface to the network, the new requirements will in many cases require fundamental changes to the design of devices in order to realise the additionally required functionalities.

Acknowledgement

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References

[1] Décret no. 2008-386, April 2008 [available online at www.industrie.gouv.fr/energie/electric/se_ele_a6.htm].

[2] Arrêté du 23 avril 2008 relatif aux prescriptions techniques de conception et de fonctionnement pour le raccordement à un réseau public de distribution d'électricité en basse tension ou en moyenne tension d'une installation de production d'énergie électrique, Ministère De L'écologie, De L'énergie, Du Développement Durable Et De L'aménagement Du Territoire, Paris, April 2008.

[3] Bundesverband der Energie- und Wasserwirtschaft e.V. (BDEW) 2008, 'Technische Richtlinie für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Mittelspannungsnetz', Berlin, Germany.

[4] e-control GmbH 2009, 'TOR D4 – Parallelbetrieb von Erzeugungsanlagen mit Verteilernetzen.'

[5] Network of Excellence of DER Laboratories and Pre-Standardisation [available online at http://www.der-lab.net].

[6] Navarro, E. et al 2005, 'International standard situation concerning components of distributed power systems and recommendations of supplements', DISPOWER Project Deliverable D2.1 [available online at http://www.dispower.org].

[7] Bründlinger, R. & Bletterie, B. 2008, 'Key needs, priorities and framework for the development of a common European pre-standard on DER interconnection', DERlab Project Deliverable D2.1 [available online at http://www.der-lab.net].

[8] Technische Richtlinien für Erzeugungseinheiten - Teil 3: Bestimmung der Elektrischen Eigenschaften von Erzeugungseinheiten am Mittel-, Hoch-, und Höchstspannungsnetz, Rev. 19, Stand: 14.01.2009, Fördergesellschaft Windenergie e.V., Kiel, 2009.

[9] Technische Richtlinien für Erzeugungseinheiten – Teil 4: Anforderungen an Modellierung und Validierung von Simulationsmodellen der elektrischen Eigenschaften von Erzeugungseinheiten und –anlagen, Rev 3 – Stand: 07.04.2009, Fördergesellschaft Windenergie e.V., Kiel, 2009.

[10] Technische Richtlinien für Erzeugungseinheiten – Teil 8: Zertifizierung der elektrischen Eigenschaften von Erzeugungseinheiten und –anlagen am ittelspannungsnetz, Rev. 0-Entwurf, Stand: 30.04.2009, Fördergesellschaft Windenergie e.V., Kiel, 2009.

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Minimizing utility-scale PV power plant levelized cost of energy using high-capacity factor configurations

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ABSTRACT

Solar photovoltaic power plants have emerged in recent years as a viable means of large-scale renewable energy power generation. A critical question facing these PV plants at the utility scale remains the competitiveness of their energy generation cost with that of other sources. The relative cost of electricity from a generating source can be compared through the commonly used levelized cost of electricity (LCOE) calculation. The LCOE equation evaluates the life-cycle energy cost and production of a power plant, allowing alternative technologies – with different scales of operation, investment, or operating time periods – to be compared. This article reviews the LCOE drivers for a PV power plant and the impact of a plant's capacity factor on the system LCOE, as well as the effects of various factors such as capacity and geographical location. The economic tradeoffs between fixed and tracking systems are evaluated as well as a review of land use, plant operation and maintenance costs.

Introduction

From 2004 to 2008, the market for small (<50MW) distributed PV power plants took off around the world, particularly in Spain and Germany where more than 3GW of power plants were installed. PV power plants have also emerged in the United States where, as Table 1 shows, large installations have been built in recent years, or are under construction, including what will be one of the largest PV power plants in North America: Florida Power & Light's 25MW plant, featuring high-efficiency PV panels integrated onto tracking systems.

> "With LCOE falling rapidly for central station PV plants, their economic competiveness with other renewables and peaking power sources are driving adoption of the technology."

Pacific Gas & Electric Co. in California has announced more than 2GW of agreements involving both solar thermal and PV power plants, including more than 750MW of photovoltaics – the largest utility-scale PV contracts in the world. As part of this program, a 210MW high-efficiency PV, central station power plant will be built in the state's California Valley and could be the first to deliver utility-scale PV power to PG&E, beginning in 2010. With LCOE falling rapidly for central station PV plants, their economic competiveness with other renewables and peaking power sources are driving adoption of the technology.

System	Company	Technology	Year	Capacity (AC)
FPL Desoto	SunPower	Tracking xSi	2009	25MW
Nellis AFB	SunPower	Tracking xSi	2007	12MW
FPL Space Coast	SunPower	Fixed xSi	2009	10MW
Sempra Energy	First Solar	Fixed CdTe	2008	10MW
Alamosa	SunEdison	Tracking xSi	2007	7MW

Table 1. PV power plants operating or under construction in the United States.

LCOE of PV power plants

A key to the continued growth of utility-scale solar is the LCOE of a PV power plant. LCOE is one analytical tool that can be used to compare alternative technologies when different scales of operation, investment, or operating time periods exist. For example, LCOE could be used to compare the cost of energy generated by a PV power plant with that of a fossil fuel-generating unit or another renewable technology [1].

The LCOE calculation is the net present value of total life cycle costs of the project divided by the quantity of energy produced over the system life, as shown in the following equation:

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

The above LCOE equation can be disaggregated for solar generation as shown in the Box 1 below.

The following sections summarize the key LCOE input parameters, including their respective sub equations.

Initial investment

The initial investment in a PV system combines the total cost of the project plus the cost of construction financing. The capital cost is driven by:

- Area-related costs that scale with the physical size of the system, namely the panel, mounting system, land, site preparation, field wiring and system protection.
- Grid interconnection costs that scale with the peak power capacity of the system, including electrical infrastructure such as inverters, switching gear, transformers, interconnection relays and transmission upgrades.
- Project-related costs, such as general overhead, sales and marketing, and site design, which are generally fixed for similarly-sized projects.

1

$$= \frac{\text{Initial Investment} - \sum_{n=1}^{N} \frac{\text{Depreciation}^n}{(1+\text{Discount Rate})^n} \times (\text{Tax Rate}) + \sum_{n=1}^{N} \frac{\text{Annual Costs}^n}{(1+\text{Discount Rate})^n} \times (1-\text{Tax Rate}) - \frac{\text{Residual Value}}{(1+\text{Discount Rate})^n}}{\sum_{n=1}^{N} \frac{\text{Initial kWh/kWp} \times (1 - \text{System Degradation Rate})^n}{(1 + \text{Discount Rate})^n}}$$

Depreciation tax benefit

The depreciation tax benefit is the present value of that benefit over the financed life of the project asset. Public policy, which enables accelerated depreciation, directly benefits the system LCOE since faster depreciation translates to faster recognition of the depreciation benefit.

$$\sum_{n=1}^{N} \frac{\text{Depreciation}^{n}}{(1+\text{Discount Rate})^{n}} \times (\text{Tax Rate})$$

Annual costs

In the LCOE calculation, the present value of the annual system operating and maintenance costs is added to the total life-cycle cost. These costs include inverter maintenance, panel cleaning, site monitoring, insurance, land leases, financial reporting, general overheads and field repairs.

$$\sum_{n=1}^{N} \frac{\text{Annual Costs}^{n}}{(1+\text{Discount Rate})^{n}} \times (1-\text{Tax Rate})$$

System residual value

The present value of the end-of-life asset value is deducted from the total life cycle cost in the LCOE calculation. Silicon solar panels carry performance warranties for 25 years and have a significantly longer useful life. Therefore, if a project is financed for a 10- or 15-year term, the project residual value can be significant.

$$\frac{\text{Residual Value}}{(1+\text{Discount Rate})^{n}}$$

(2)

$$\sum_{n=1}^{N} \frac{\text{Initial kWh/kWp} \times (1 - \text{System Degradation Rate})^{n}}{(1 + \text{Discount Rate})^{n}}$$

System energy production

The system lifetime energy production is calculated by determining the first-year energy generation as expressed in kWh (AC)/kWp (AC), then degrading output over the system life based on an annual performance degradation rate. System degradation (largely a function of PV panel type and manufacturing quality) and its predictability are important factors in life-cycle costs since they determine the probable level of future cash flows. This stream of energy produced is then discounted to derive a present value of the energy generated to make a levelized cost calculation. The first-year kWh/kWp is a function of:

- The amount of sunshine the project site receives in a year.
- The mounting and orientation of the system (i.e., flat, fixed-tilt, tracking, etc.).
- The spacing between PV panels as expressed in terms of system ground-coverage ratio (GCR).
- The energy harvest of the PV panel (i.e., performance sensitivity to high temperatures, sensitivity to low or diffuse light, etc.).
- System losses from soiling, transformers, inverters, and wiring inefficiencies.
- System availability largely driven by inverter downtime.

Finally, the system's financing term (n) will determine the duration of cash flows and affect the assessment of the system residual value (see Box 2 above).

When evaluating LCOE and comparing other commonly known \$/kWh benchmarks, it is important to remember that LCOE is an evaluation of levelized life-cycle energy costs. The price of energy established under power purchase agreements (PPAs) or by feed-in-tariffs (FITs) may differ substantially from the LCOE of a given PV technology, since PPAs and FITs may represent different

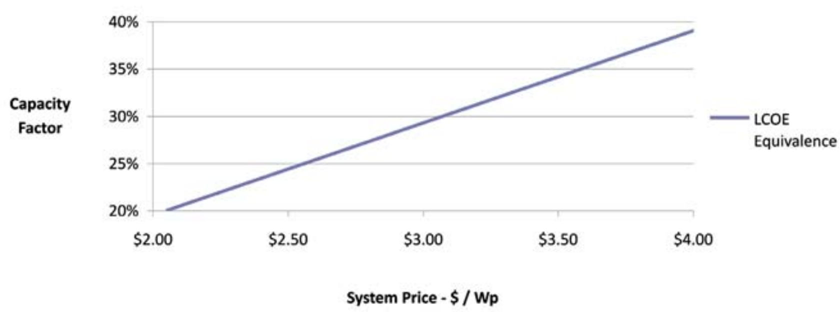

Figure 1. Associated capacity factors and system prices producing an identical LCOE.

contract or incentive durations, the inclusion of incentives such as tax benefits or accelerated depreciation, financing structures, and in some cases, the value of time-of-day production tariffs.

PV power plant capacity factor

The capacity factor, a standard methodology used in the utility industry to measure the productivity of energy-generating assets, is a key driver of a solar power plant's economics [2]. Since the majority of the expense of a PV power plant is fixed capital cost, LCOE is strongly correlated to the power plant's utilization. The net capacity factor for a PV power plant (after inverter and other plant power consumption) over a given period can be calculated (see Box 3 below).

A PV power plant's capacity factor is a function of the insolation at the project location, the performance of the PV panel (primarily as it relates to high-temperature performance), the orientation of the PV panel to the sun, the system electrical efficiencies, and the availability of the power plant to produce power.

The capacity factor's economic impact can be substantial. Figure 1 illustrates a range of identical LCOE values, expressed in $/kWh, for a given PV power plant system price as expressed in $/Wp and the associated capacity factor. (The capacity factor is generally expressed as a function of the AC rating of a plant, so the kWh/kWp calculation is based on the kWh per AC watt peak as opposed to the DC watt peak.)

3

$$\text{Net Capacity Factor (NCF)} = \frac{\text{Net Actual Generation}}{\text{Period Hours} \times \text{Net Maximum Capacity}} \times 100\%$$

As the capacity factor declines, the required installed system price must also substantially decline to maintain system economics. For example, a $2.50/Wp system with a 24% capacity factor (such as with a fixed-tilt configuration) delivers the same LCOE as a $3.50/Wp system with a 34% capacity factor (such as with a tracker).

The highest capacity factors (CF) are generated with trackers that follow the sun throughout the day to keep the panel optimally oriented toward the sun. Tracking also has the benefit of generating more energy in the peak electricity demand periods during the afternoon. Two patented single-axis tracking systems have been developed to optimize the capacity factor of a PV power plant: the T0 tracker (Figure 2), a horizontal one-axis tracker optimized for space-constrained sites; and the T20 tracker (Figure 3), a titled one-axis tracker optimized for maximum energy production.

A tracker's benefit to a PV power plant's annual and summer capacity factors can be substantial. Figure 4 illustrates the annual and summer (June 1-Aug 31) capacity factors achievable for a power plant located in southern Nevada and built with a fixed system, horizontal one-axis tracker, or tilted one-axis tracker. It is clear that the tilted one-axis tracker can generate approximately 30% more energy than a fixed system on an annual basis. Additionally, during the summer peak season, capacity factors can exceed 38% with a horizontal one-axis unit, providing energy when the utility experiences maximum seasonal demand.

The LCOE model assigns an equal value to electricity generated throughout the year; however, electricity generated at peak periods is more valuable to the utility. The use of a solar tracking system can

Figure 2. Horizontal single-axis trackers optimized for space-constrained sites.

Figure 3. Tilted single-axis trackers optimized for maximum energy production.

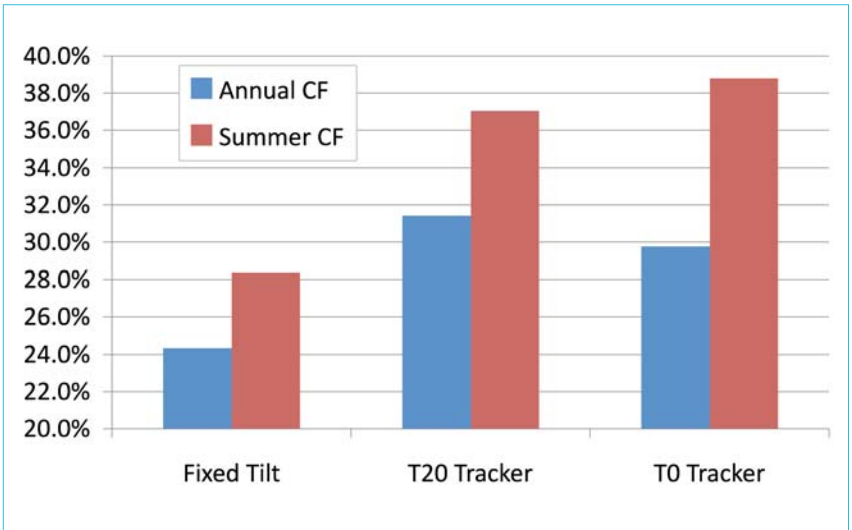

Figure 4. Annual and summer capacity factors (CF) for a southern Nevada PV power plant.

increase the output of a plant after 4 p.m. in the summer by more than 40%, which is often a peak demand period when energy is highly valued.

Figure 5 provides a comparison of the summer energy output of fixed and tracking PV power plants compared with the California ISO grid load, showing this improvement in afternoon production relative to peak demand. Figure 6 illustrates the point further, showing PV power plant capacity factors achievable during the peak 1 p.m. - 8 p.m. periods in the summer. During this peak period, capacity factors from trackers can exceed 70%, directly offsetting the need for natural gas peaking plants and other alternative peaking power resources.

Land use and capacity factor

Land for solar power plants has been readily available and inexpensive in the past, largely because it had little economic value other than in some low-yielding agricultural activities. As solar power plant developers began buying land in South Korea, southern Europe, and the southwest United States, prices for prime land conducive to a solar power plant rapidly increased in cost and general land availability became an issue. South Korea and southern Europe have seen solar-suitable land prices increase more than 300%, and southwest U.S. desert land has sold for prices as high as a reported US$23,000 per acre for flat land with high insolation located near electrical transmission lines, a roughly 15,000% increase over historical values for the same parcels [3].

There are two fundamental drivers for the land consumed by a solar power plant: solar panel efficiency and system ground-coverage ratio. System GCR represents the ratio of solar panel area to land area. Flat-mounted PV panels use the minimum land area based on system rating in MW and have the maximum GCR but have the lowest capacity factor and thus lower utilization of fixed plant costs. Conversely, a two-axis tracker has the maximum possible capacity factor but requires up to 10 times more land than flat configurations. To put it simply, the better the orientation to the sun (thus capacity factor), the longer the shadows created and therefore the further apart the panels must be placed to avoid panel-to-panel shading.

To deliver the best utility-scale PV LCOE, land use must be balanced with the system capacity factor. One way of addressing the optimization problem combines high-efficiency PV panels and tracking systems that efficiently use land while increasing energy production. A tilted single-axis tracker can maximize the capacity factor in an efficient land footprint, and a horizontal single-axis tracker helps optimize land use for constrained sites while still providing a high capacity factor.

Figure 7 illustrates the land consumption versus capacity factor for a central power plant producing 1TWh/year in a high insolation location. (Note that the listed capacity factors are based on the AC rating of the power plant at the point of grid interconnection; the DC nameplate capacity of the PV power plant will be approximately 20% higher than the AC rating, depending on the PV panel type and system configuration.) This example shows that:

- With high-efficiency PV panels, up to 75% less land is needed for a given capacity factor configuration.
- With high-efficiency PV panels mounted on trackers, up to 30% higher capacity factors can be attained while using a similar or lower amount of land than low- and medium-efficiency panels mounted on fixed-tilt systems. This means that lower LCOE, high-capacity factor configurations can be achieved without prohibitively increasing the amount of land required.

Cost effectiveness of tracking

Although the capacity factor benefit of tracking is clear, the decline in PV power plant prices raises a question about the continued cost effectiveness of tracking systems. One could argue that low-cost PV panels mounted on fixed structures would yield superior economics to a high-capacity factor tracking system during a new era of low-cost PV. This question on tracking cost effectiveness can be answered with an application of the LCOE equation. As with any change that improves the capacity factor of the system, the increase in performance must be weighed against the incremental cost, if any. In the case of tracking, the change to capital cost divided by the change in capacity factor can be seen in the following equation.

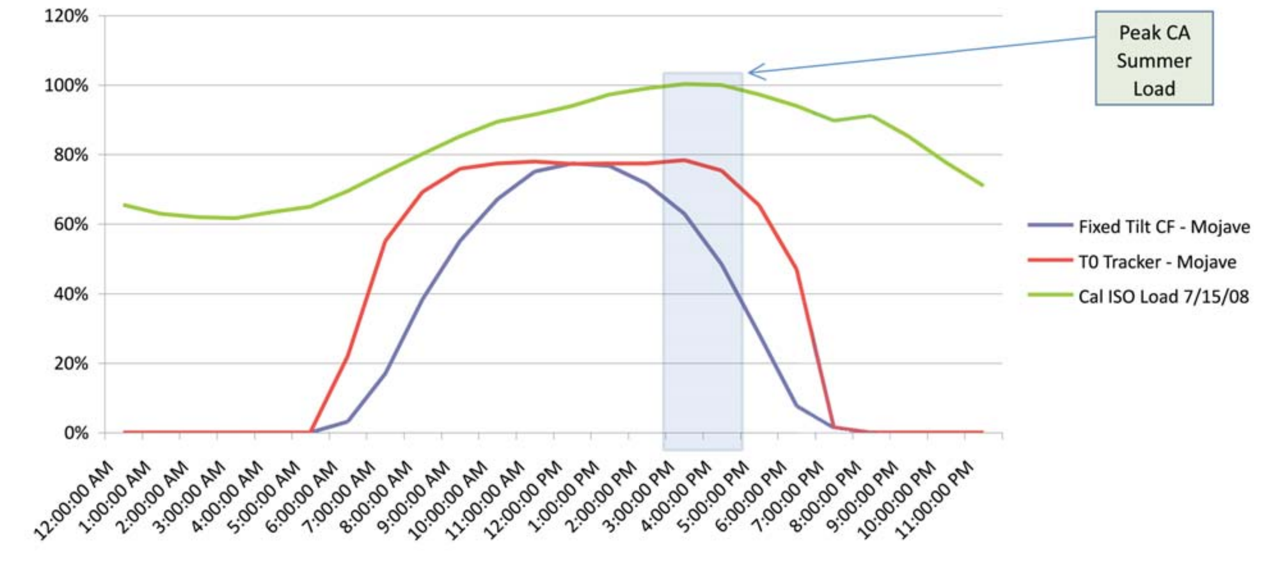

Figure 5. Comparison of California summer load requirements with fixed and tracking PV systems.

If the absolute change in capital cost is less than the absolute change in capacity factor, then economics suggest the implementation of the system that best improves the capacity factor. If this analysis is applied to a PV power plant located in the U.S. desert (southwest), even at a low system price of ~$4/Wp DC, the value of the tracker's 30% capacity factor improvement would be $1.20/Wp DC, far above the incremental capital cost of the tracker motor and control system.

Environmental conditions and capacity factor

In addition to sun tracking, local weather conditions – such as the amount of sunshine that a site receives – are the major drivers of high capacity factors. Desert sites can achieve capacity factors up to twice as high as those seen in less sunny northern states. Less obvious impacts on the capacity factor include ambient temperature, wind, solar cell technology, and soiling. Of these parameters, operating temperature and panel performance are key capacity factor drivers.

Typical solar panels experience a performance reduction of 0.5% per degree Celsius above 25°C. On a hot desert day, panel temperatures can exceed 60°C, resulting in a loss of power output of more than 15% over a panel's standard test condition rating. Some PV technologies, such as the back-contact monocrystalline silicon-cell design, perform better in high operating temperature conditions. Higher-efficiency panels can also benefit from a lower module operating temperature, owing largely to the conversion of more solar energy to electricity instead of heat.

Independent studies jointly conducted by the universities of Cyprus and Stuttgart in Nicosia, Cyprus, in 2006-07 confirmed the impact of excellent high-temperature performance on energy yield (and the resultant capacity factor). In other test comparisons of the output of high-efficiency modules with those of standard monocrystalline silicon panels, the Arizona State University Photovoltaics Testing Laboratory found that the modules demonstrated a 7.2% improvement to capacity factor during the summer test period, owing to the superior high-temperature performance of the cells (Figure 8). This extra energy provides a direct reduction in LCOE since the energy leverages all of the installed system plant costs.

Capacity factor and operations and maintenance costs

Improving the capacity factor of a system directly reduces operation and maintenance (O&M) costs through higher utilization rates of fixed assets. Table 2 shows this correlation as it relates to the inverter requirements of generating 1 TWh of annual energy in a PV power plant. In this example, 1 TWh of energy would require 335 inverters, each rated at 1 MWp, with a single-axis tilt tracker versus 442 inverters with a fixed-tilt system at the same location. The use of a tracking system would therefore significantly reduce the inverter O&M costs, the most costly portion of annual system maintenance.

Significant power-related maintenance costs also exist with respect to transformers, switching gear, and grid interconnection, and all benefit from a high capacity factor system configuration.

Module cleaning, panel repair or replacement, mounting structure and wiring maintenance and vegetation control costs also scale down with such a system.

Although tracking systems add cost in terms of motor and controller maintenance, this cost is relatively small when compared with the other O&M cost savings that trackers provide. For example, the tracker's motor requires only annual lubrication and a single motor can control more than 300kWp of PV.

Also, the tracker bearings require no lubrication and are designed for more than 25 years of use. The O&M cost of a utility-scale tracking system ends up being less than US$0.001/kWh more than a fixed configuration, a calculation which does not factor in the O&M savings from increased energy production.

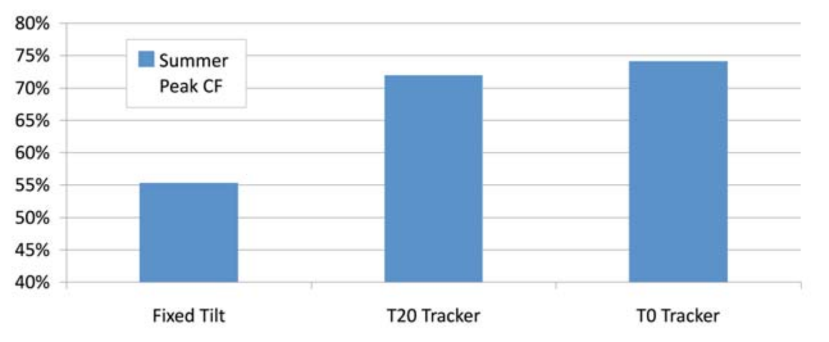

Figure 6. Summer peak period (1:00pm-8:00pm) CF for southern Nevada.

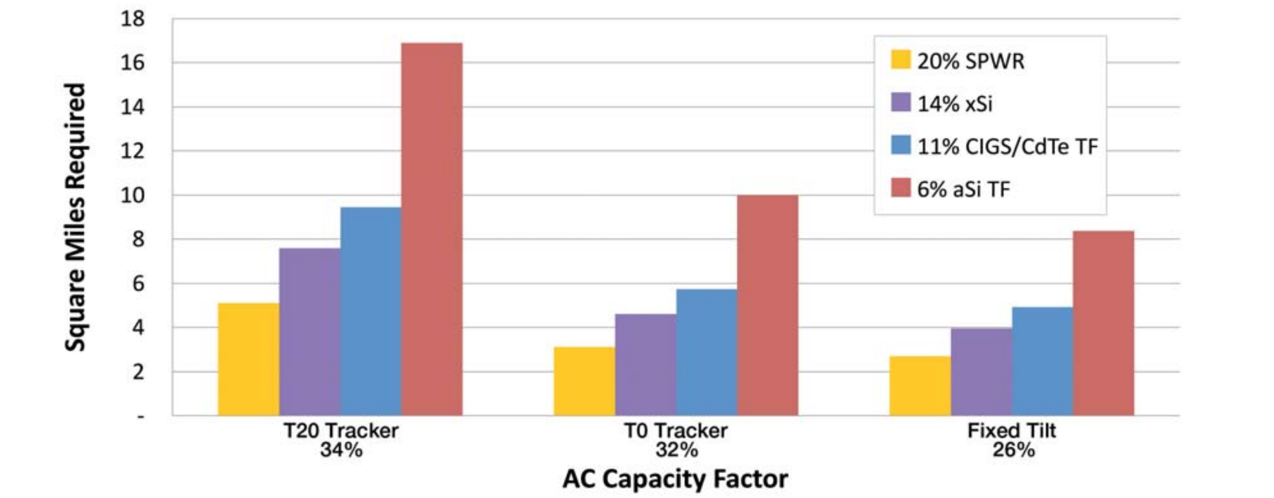

Figure 7. Land use and capacity factors for 1TWh production configurations.

Maintaining system capacity factor

Maintaining a high capacity factor throughout a system's life is critical in delivering the lowest cost of energy. PV power plant economics are maximized if the system capacity factor remains high throughout its 30- to 40-year lifetime.

A plant's capacity factor degradation largely depends on the PV panel technology and quality. Crystalline silicon has the longest operating history of any solar cell technology. Figure 9 shows a monocrystalline silicon panel that has gone through 20 years of outdoor exposure with no major visual degradation. Performance studies of silicon panels have shown only 4% total degradation after 22 years of outdoor exposure [4]. This experience provides a high level of confidence in making future performance predictions.

Most investors finance a solar system based on an assumed annual panel degradation rate of 0.5 to 1.0%, a faster rate than these historical data for silicon PV might indicate. Research on silicon PV historical performance suggests that panel life (and therefore power plant energy production) may extend much further than the 25-year design life [5]. This demonstrates that long-term performance may enable longer financeable system lives in the future.

Figure 10, which illustrates LCOE model sensitivity to financed system life based on a 7% discount rate, shows that extending the financed term of the project beyond today's 20- to 25-year values could materially impact the LCOE.

Conclusion

The levelized cost of energy is the net present value of total life cycle costs of the project divided by the quantity of energy produced over the system life. On the

	T20 Tracker	Fixed Tilt
Capacity Factor	34.1%	25.8%
1 MWp Inverters per annual TWh	335	442
Inverter O&M Cost	**100%**	**132%**

Table 2. Inverters required for 1TWh of energy production in the southwest U.S. desert.

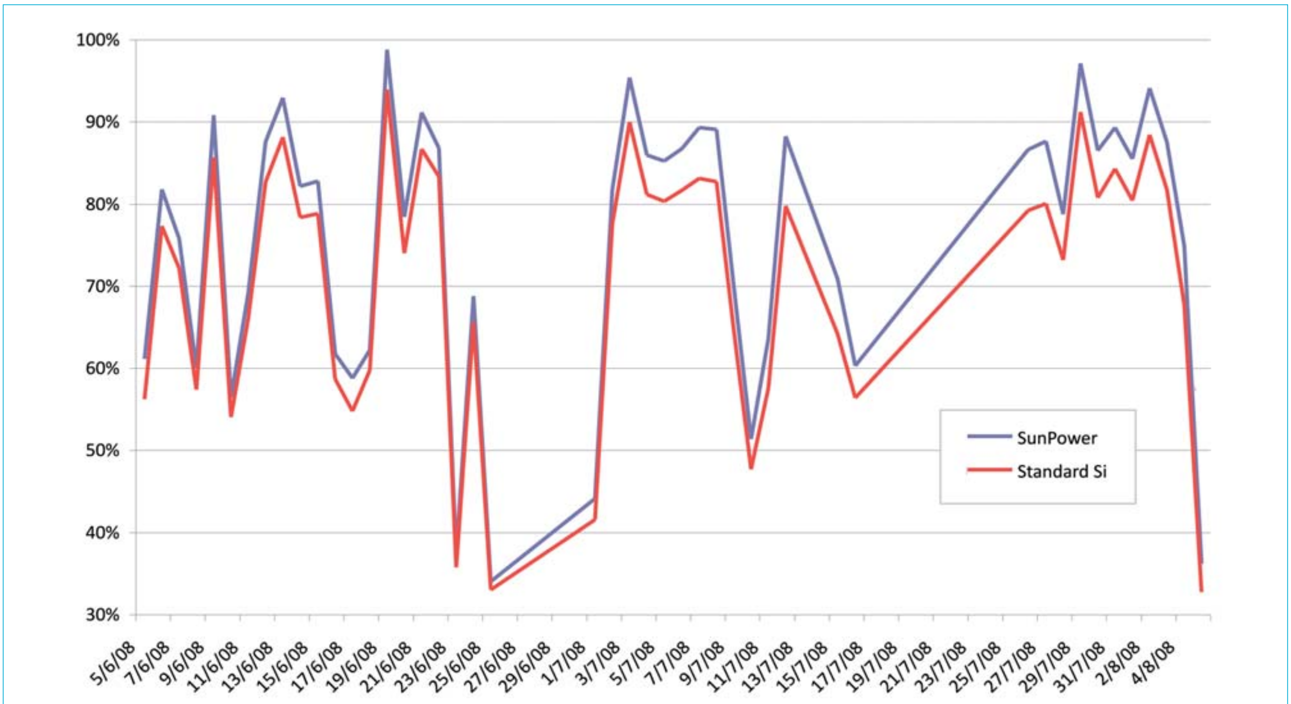

Figure 8. Performance of SunPower panels in high temperature conditions.

Figure 9. Monocrystalline silicon PV panel after 20 years of outdoor exposure.

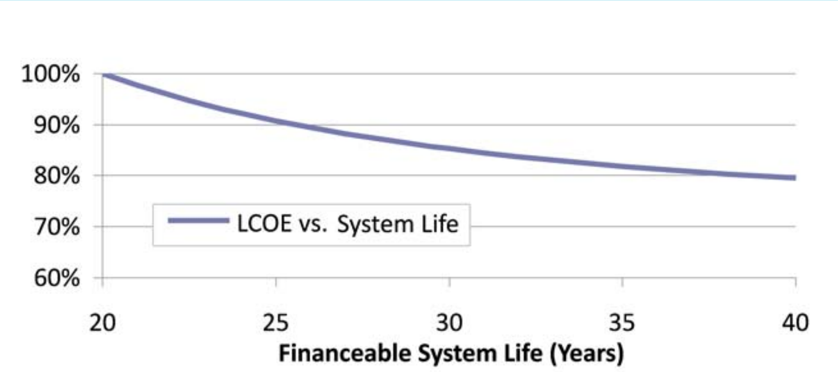

Figure 10. LCOE sensitivity to financeable system life.

many dimensions of cost and performance that underpin LCOE for a solar power plant, high-capacity factor tracking PV offers a compelling solution.

Key LCOE benefits for high-efficiency tracking PV power plants include the highest total lifetime energy production and system capacity factors; lower life-cycle operations and maintenance costs caused by up to four times the energy production per panel per year; lower power plant balance-of-system capital costs through the reduction in the number of modules and scale of the mounting system and land required to generate a given amount of energy; and the arguably the lowest long-term energy delivery risk, given that monocrystalline PV modules provide predictable capacity factor delivery, which reduces investor investment risk and enables longer financeable system lives.

The LCOE analysis detailed in this article shows how high-efficiency, monocrystalline silicon-based tracking PV power plants generate economic benefits to project investors and utilities alike. Single-axis tracking will continue to offer some of the best system economics, despite rapid reductions in panel and power plant costs.

References

[1] Short, W., Packey, D. & Holt, T. 1995, 'A manual for the economic evaluation of energy efficiency and renewable energy technologies', National Renewable Energy Laboratory.

[2] North American Electric Reliability Corp. (NERC) 2008, 'Generating availability data system instructions–implementation of IEEE 762,' p. F-10.

[3] Woody, T. 2008, 'The Southwest Desert's Real Estate Boom,' *Fortune*, July 11, 2008.

[4] De Lia, F., Castello, S. & Abenante, L. 2003, 'Efficiency degradation of c-silicon photovoltaic modules after 22-year continuous field exposure,' *Proceedings of 3rd World Conference on PV Energy Conversion*, Osaka, Japan.

[5] Dunlop, E., Halton, D. & Ossenbrink, H. 2005, '20 years of life and more: Where is the end of life of a PV module?' *IEEE Proceedings*, p. 1595.

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Considerations for selecting thin-film technologies for large-scale photovoltaic applications

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ABSTRACT

Thin-film or crystalline photovoltaic modules? One of the consequences of the rapid introduction of new photovoltaic technologies is the buzz generated in the industry. Large-scale photovoltaic applications are especially sensitive to any question connected with cost optimization. Therefore, stakeholders involved in photovoltaic project development are questioning whether the time has arrived to shift module technologies to large-scale applications. A great variety of opinions are exposed every time this question arises. This paper's aim is to uncover the key questions that should be taken into consideration in order to select the proper technology for large-scale photovoltaic applications and to provide the maximum amount of practical information for this decision.

Introduction

Photovoltaic technologies are extremely dynamic. The evolution of traditional crystalline solutions and the introduction of new materials are increasing the possibilities available for this market.

As new solutions appear on the scene, new questions are raised. The following section will concentrate on developing documented answers that may help to clear up the new market scenario, and will evaluate the feasibility of thin-film and crystalline modules in large-scale photovoltaic applications.

There are two main questions being posed by photovoltaic system developers, investors and system integrators:

1. Should we move to thin-film, or is it better to remain with crystalline-based modules for large-scale applications?
2. In case we decide to move to thin-film, what are this technology's key features for consideration?

Criteria for selecting photovoltaic modules

In order to select the optimum photovoltaic module to be implemented in an application, it is advisable to evaluate a mix of features, as outlined below. Each of these features may have a different weight, depending on the project characteristics and the investment profile.

Photovoltaic module technology

The industry currently has a range of options, from which we can select monocrystalline, polycrystalline, a-Si, Tandem or CdTe modules for large-scale applications. For ease of discussion, these options will be categorized into two groups: thin-film and crystalline.

The goal here is to simply state the main differences to be considered between the two technologies. For broader insights, please consult related specific literature of photovoltaic materials and technologies.

Thin-film photovoltaic modules are characterized by:

- Using a fraction of the material used by crystalline modules
- Implementing production lines that lower manufacturing costs
- Having a wider light spectrum sensibility
- Performing more independently of temperature variations
- Having a lesser relative power output in terms of Watt peak per square metre (Wp/m^2).

In contrast, crystalline technology features are well known among the community and are characterized by:

- Being a highly mature technology
- Being established in the market for any application size
- Broad experience; almost every large-scale system integrator has direct experience with this technology
- Having a long silicon supply chain. Margins along the chain are highly influenced by market positioning. Traditionally, the earlier the silicon stage, the higher the margin. There has recently been a sudden drop in prices (Q4 2008 – Q1 2009); this was more connected with the price negotiation of supplies than with production cost optimization.

Module power output

The previous section detailed the majority of all module features in terms of direct influence in project design and system costs. There is a power gap that separates crystalline modules from thin-film modules which, although expected to shorten in the near future, should be taken into consideration.

Standard-sized crystalline modules average 180Wp to 300Wp, while standard-sized thin-film modules average 60Wp to 120Wp. The following table shows the conversion of those absolute values into relative values.

In the case of thin-film modules, it is essential to get the power output referenced after the first degradation stage when the power output is stabilized.

It is important to understand the direct implications of one's choice of technology type. The following costs are directly influenced by the power output module decision, to a lesser or greater degree. These cost influences will be discussed in detail later in this paper.

- Cost of the land
- Fixing structure/tracking system
- Module installation
- Low tension
- Monitoring
- Security

	Wp/m^2
Crystalline	144 - 152
Thin-film	45 - 85*

Table 1. Relative photovoltaic module power output (Wp/m^2). (*At the present moment (Q1 2009), there exist CIGS thin-film modules that exceed these relative values, but for very specific applications. In this article a more general overview is presented.)

Product warranty

A minimum of 5 years' product warranty is advisable, despite the fact that some module manufacturers persist in offering 2 years' product warranty. The reason for their reluctance to extend their offer is simple: those manufacturers are already established in the market and are averse to competing by offering higher warranties. However, newly established manufacturers are pushing for change, so one might expect that a 5 year product warranty will become standard in the near future.

Yield warranty

The standard yield warranty has been set to guarantee 90% of module capacity from year 0 to 10, and 80% of module capacity from year 10 to 25. Again, it may be the case that some module manufacturers keep their position to guarantee yield for just 20 years. Market trends may push them to adapt those values to the new standard before long. This feature is a crucial one for the final investor, as it provides the required guarantees to make sure the module will perform as expected throughout the whole life of the investment considered in the financial simulation.

An interesting additional offer currently being promoted by newly established module manufacturers is a supplementary insurance policy that the module manufacturer signs with an insurance company. This guarantees that whatever occurs in the future with the manufacturer, the module yield is fully protected. It goes without saying that this is certainly a recommended feature to request from module suppliers.

Certificates

It is also important to check with the module supplier to ensure that they have passed all IEC and CE certification processes. Additional TÜV/UL/SGS certificates reinforce the quality perception.

However, there remains much more to uncover in the certificates field. For example, a buyer might be interested in knowing more about the technology used by the manufacturing line. It may be a turnkey proprietary solution, a self-engineered solution, or a mix of both, and for these reasons, it is worth asking for references.

Manufacturers' excellence and quality programs are another vein that should be investigated, bringing to mind terms such as EFQM, Malcolm Baldrige, Deming, ISO 9000, ISO 14000, Corporate Social Responsibility, Six Sigma and many other related methodologies. The adoption of some of those programs can give crucial hints complimentary to standard PV module certificates.

Lastly, due to the multiplication of manufacturers, we have identified a reinforced request coming from investors and financial institutions to perform on-site evaluations for module manufacturers in order to provide additional insights about production lines, site facilities, quality control programs and module performance.

These auditing processes are usually carried out for newly established module manufacturers, or in the case of a first-time local market entry. Once completed, both investors and financial institutions gain enough confidence to release their funds according to the project payment milestones.

> "The standard yield warranty has been set to guarantee 90% of module capacity from year 0 to 10, and 80% of module capacity from year 10 to 25."

Recycling policies

Public Administrations may be tempted to request higher tax fees and bank guarantees from those projects based on CIGS and CdTe module technologies as they may contain elements potentially dangerous to the environment. The truth is that these elements are present in a stable atomic state, but it remains an issue that must be negotiated with certain Public Administrations. In response to this concern, those affected module manufacturers have established recycling programs that show support for projects that implement their technology.

In the event that such module technologies are to be used, it is essential to have a clear understanding of the specific recycling policy in order to achieve a stronger position to negotiate with the Public Administration regarding tax fees and bank guarantees to cover potential environmental risks.

Payment terms

Module manufacturers are used to cashing their products before releasing them to their clients. As one might guess, the newly created scenario allows the buyer to have a stronger position in order to negotiate this area.

The following is a list of the indicative ranges to be negotiated:

1. Down payment: 5-15%
2. Product release: 60-75%
3. Net-90 days: 10-25% (depending on the country, the standard may go from Net-15 to Net-180 days).

Traditionally, module manufacturers only accepted discussions about payments #1 and #2, with payment #3 rarely being touched on. Payment #3 usually corresponds to the partial net margin of the module manufacturer. Consequently, module manufacturers already secure their production costs with payments #1 and #2, and once the modules are shipped, manufacturers end up just crediting part of their margin. Negotiations of module supply should include some discussion of these payment elements.

Module prices

Let's start analysing the first feature that you might consider in order to position a module supplier: price.

Location: Jaén, Spain
Nominal power: 2.1MWp
Trackers: 906
Ground area: Approx. 150,000m^2
Solar modules: Approx. 10,600 units
Electricity production: Approx. 4,000,000kWh per annum
Completion date: July 2008
Involvement: Concept, Detailed Engineering, Project Finance, Licensing, Negotiations with Public Administrations, Supply Chain, EPC, Optimization, O&M.

Figure 1. The Solar Park in Jaén, Spain. In an area of 150,000m^2, 4 million kilowatt hours of clean energy are produced annually.

Module Price Band	Crystalline (€/Wp)	Thin-film (€/Wp)
Low	1.70-2.10	1.45-1.60
Middle	2.15-2.40	1.65-1.80
High	2.45-2.85	1.85-2.10

Table 2. Indicative module prices for large-scale applications (Q1-Q2 2009).

BOS costs (€/Wp)	Fix Structure		1-axis tracking system		2-axis tracking system	
	Crystalline 230Wp	Thin-film 90Wp	Crystalline 230Wp	Thin-film 90Wp	Crystalline 230Wp	Thin-film 90Wp
Administrative [1]	0.0385	0.0385	0.0484	0.0484	0.0517	0.0517
Engineering [2]	0.2255	0.2255	0.2255	0.2255	0.2255	0.2255
Land [3]	0.0528	0.1194	0.0924	0.2090	0.1072	0.2424
Civil works [4]	0.0484	0.1095	0.0847	0.1916	0.0983	0.2222
Fix structure/ tracking system [5]	0.4070	0.9204	0.8987	2.0324	1.2650	2.8608
Module set-up [6]	0.0440	0.0995	0.0451	0.1020	0.0451	0.1020
High tension[7]	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200
Low tension [8]	0.4620	0.6966	0.4840	0.7297	0.4840	0.7297
Monitoring [9]	0.0264	0.0398	0.0374	0.0564	0.0374	0.0564
Security [10]	0.0660	0.0995	0.1122	0.1692	0.1164	0.1755
TOTAL BOS costs	1.5906	2.5687	2.2484	3.9841	2.6505	4.8862

[1] Administrative costs include those connected to the licensing process, due-diligences, legal consultants, etc.
[2] Engineering costs include concept and detailed engineering, technical consultants, project management, etc.
[3] For the purpose of this article we have considered acquisition of the land upon which our large-scale PV park will be installed. In the event of a land-renting scenario, this cost disappears from BOS and is integrated as a variable cost into ROI simulation.
[4] Civil works include site facilities and land preparation.
[5] Fix structure/tracking system includes material supply, foundations and installation costs.
[6] Module set-up includes installation costs (module supply costs are excluded).
[7] High tension includes any equipment, civil works, installation, and manpower needed to connect the PV park to the public grid.
[8] Low tension includes all materials (wires, protection devices, inverters, etc.), civil works and related installation costs.
[9] Monitoring includes all costs connected to data network, internet access, monitoring equipment and installation.
[10] Security includes all required equipment and installation costs needed to secure the site.
All of these BOS costs are taken directly from Bioinversiones' experience in building large-scale PV parks.

Table 3. Indicative BOS costs for large-scale applications (Q1-Q2 2009).

The trend during the last 24 months (Q1 2007 – Q1 2009) has been incredibly market driven. During 2007, crystalline modules for large-scale applications were quoted in a range of 2.80€/Wp to 3.40€/Wp. (At time of publishing, the exchange rate was 1€=1.32904 USD.) This price represented a relatively stable scenario and margins across the whole supply chain were well known.

A sudden market reaction appeared in Q2 2007 led by the changes in the Spanish PV legal frame. It generated massive global pressure across the module supply chain, creating a global scenario where module manufacturers could barely meet the demand.

This situation resulted in an escalation of module prices. In Q2-Q3 2008, module for large-scale applications reached quotes in the range of 3.30 to 3.50€/Wp.

Worldwide module manufacturers were able to sell their stocks and scheduled productions until Q3 2008 at a very high price. Customers applying directly to module sales managers meant that there was no need to seek out customers, leading to an easy sale and a resulting freedom of pricing. From then until now (Q1-Q2 2009), the scenario has altered drastically.

- Spanish demand suddenly ceased in Q4 2008 due to the introduction of year caps that limited the expansion of the PV market.
- Emerging PV countries offer promising perspectives, but are still in the early stages of project development (France, Italy, USA, Greece, Bulgaria, etc.).
- New players have jumped into the arena of PV module manufacturers, especially those connected with thin-film module technologies, and have set up new production lines that have reduced manufacturing costs considerably.
- Low-quality PV modules have been almost placed out of the market. It is widely known that the quality of the Asian module was a hot question. In a scenario where offer meets demand, quality is a must. Presently, most of the surviving Asian module manufacturers are those that took quality standards seriously and successfully implemented strict quality programs.

These points generated a new scenario where module sales managers started travelling to look for clients, as the queues for quotes have died down. Additionally, high competitiveness introduced by thin-film (a-Si, CdTe, CIGS...) module manufacturers has pushed down the excellent margins across the traditional crystalline (ingot, wafer, cell, module) supply chain.

"In Q2-Q3 2008, module for large-scale applications reached quotes in the range of 3.30 to 3.50€/Wp."

Table 2 illustrates an indicative breakdown of module prices available for large-scale applications during Q1-Q2 2009. For simplicity, we will consider an average 230Wp crystalline module and an average 90Wp thin-film module. Quotes referred to are Delivered Duty Paid (DDP) incoterm.

It should be noted that the table structure does not intend to assimilate price band to quality. The following examples illustrate this point.

1) High-band crystalline modules may correspond to certain manufacturers, usually positioned in the highest ranks for quality. However, this is not the

€/Wp	Fix Structure				1-axis tracking system				2-axis tracking system			
Module Price Band	Crystalline 230Wp		Thin-film 90Wp		Crystalline 230Wp		Thin-film 90Wp		Crystalline 230Wp		Thin-film 90Wp	
Low	3.2906	3.6906	4.0187	4.1687	3.9484	4.3484	5.4341	5.5841	4.3505	4.7505	6.3362	6.4862
Middle	3.7406	3.9906	4.2187	4.3687	4.3984	4.6484	5.6341	5.7841	4.8005	5.0505	6.5362	6.6862
High	4.0406	4.4406	4.4187	4.6687	4.6984	5.0984	5.8341	6.0841	5.1005	5.5005	6.7362	6.9862

Table 4. Indicative integrated photovoltaic system costs for large-scale applications (Q1-Q2 2009).

only real fact that drives them to quote their modules so high: certain supply constraints with their cell supplier can have a major effect on the price. In the past, these manufacturers had signed long-term cell supply contracts and as a result, cannot adjust their prices down to follow the market trend simply because they are buying cells at much higher prices than the market standard.

2) Many of the module manufacturers included in the low price band insisted that their clients should audit their products, manufacturing site and quality control program. It should be taken as a positive sign when manufacturers are so confident of their quality that they encourage their clients to check it.

The above examples suggest that there is no direct correlation between price and quality; but rather that many other factors have a relevant weight.

Balance-of-system costs

Balance-of-System (BOS) costs include the rest of the costs that one might find while developing photovoltaic systems.

Table 3 includes indicative prices for each of the BOS items during Q1-Q2 2009. As before, we will consider an average 230Wp crystalline module and a 90Wp thin-film module. Quotes referred to are Delivered Duty Paid (DDP) incoterm.

"High-band crystalline modules may correspond to certain manufacturers, usually positioned in the highest ranks for quality."

Table 4 shows BOS costs integrated with module prices, and reveals some points of interest. While a vague idea of costs can be garnered from a focus on photovoltaic module prices or BOS costs alone, Table 4 allows the prospective buyer to observe how the photovoltaic system costs are balanced when all the costs are considered.

Conclusions

In the months and years to come, the photovoltaic market will perform a self-regulation of prices. As emerging photovoltaic countries increase their demand for modules, the down-pricing trend may freeze for some time. Nevertheless, global module manufacturing capacity is increasing at a fast rate, which is bound to decrease the likelihood of seeing module shortage and scarcity for some time.

Location: Almería, Spain
Nominal power: Phase 1: 2.1MWp; Phase 2: 1.1MWp
Free-standing
Ground area: Approx. 50,000m^2
Solar modules: Approx. 8,000 units
Electricity production: Approx. 2,600,000kWh per annum
Completion date: September 2008
Involvement: Concept, Detailed Engineering, Project Finance, Licensing, Negotiations with Public Administrations, Supply Chain, EPC, Optimization, O&M.

Figure 2. The Solar Park in Almería, Spain. In an area of 5,000m^2, 2.6 million kilowatt hours of clean energy are produced annually.

Returning to the questions asked earlier in the paper, we can now review and answer them based on the lessons learned from our findings.

1) *Should we move to thin-film, or is it better to remain with crystalline-based modules for large-scale applications?*

There is no definitive answer to this question.

Due to the lesser relative power output, perhaps thin-film module technology should be considered for mounting in free-standing PV parks where land availability is not a constraint, and land costs have a minor influence on the overall system price. Highly cost-optimized foundations and supporting metallic structures can also prove profitable in lowering related costs as much as possible and bringing costs closer to those associated with crystalline BOS costs. From a cost-effectiveness perspective, tracking solutions remain the only available option as a reserved application for crystalline modules.

2) *And in case we decide to move to thin-film, what are this technology's key features for consideration?*

One should definitely consider the highest relatively powered thin-film modules available in the market. The higher the relative photovoltaic module power output (Wp/m^2), the lesser the BOS costs associated with that particular solution.

Regardless of the application, it is advisable to check all of the key features exposed in this article. BioInversiones develops tailor-made photovoltaic systems, which are fully optimized to run under their specific environments, and designed to generate the highest returns to investors and the local community. Consequently, please take note that the above guidelines and costs must be properly evaluated for each individual project.

About the Author

Pedro M. Fernández, founder of BioInversiones, is an experienced photovoltaic business developer committed to providing conscious profitable green business solutions. Pedro has successfully led a vertical integration from module manufacturing towards investments in turnkey PV power plants. He has also held technical and management positions in Gas Natural SDG. He graduated with a degree in electricity engineering and an M.B.A. from Universitat Rovira i Virgili in Tarragona, Spain.

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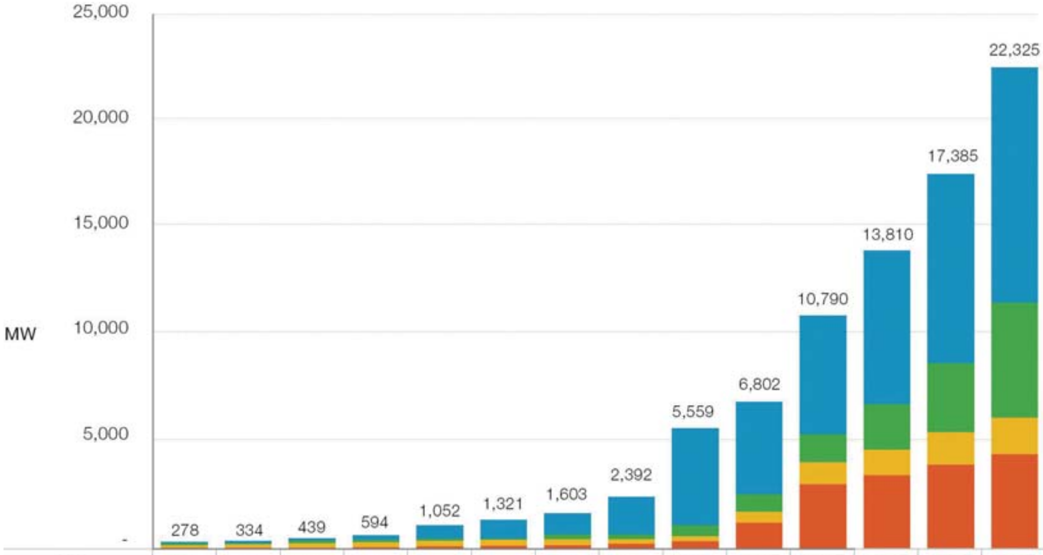
Power Generation

Market Watch



MW	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Europe	50	96	106	210	637	906	975	1,768	4,503	4,302	5,490	7,110	8,785	10,925
Rest of the world	94	75	104	98	53	12	196	207	485	800	1,300	2,100	3,200	5,200
Japan	112	135	185	223	272	290	287	210	230	500	1,000	1,200	1,500	1,700
USA	22	29	44	63	90	114	145	207	342	1,200	3,000	3,400	3,900	4,500
TOTAL	278	334	439	594	1,052	1,321	1,603	2,392	5,559	6,802	10,790	13,810	17,385	22,325

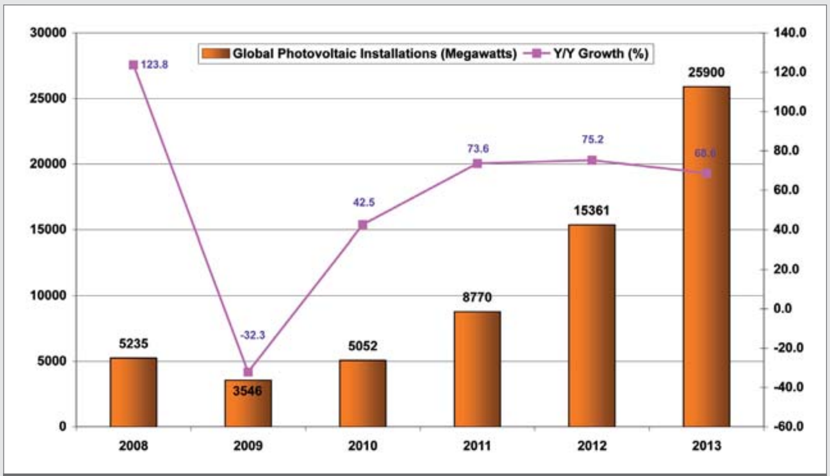
160

News

Major market decline forecasted for the solar industry in 2009, according to iSuppli

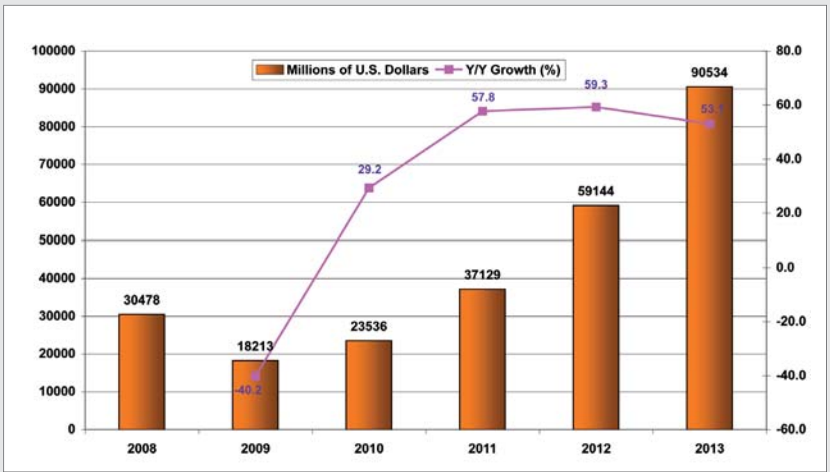
Market research firm iSuppli Corp. expects a major decline in the photovoltaics industry in 2009, due to massive overcapacity, plunging prices and weak demand for solar as a consequence of the global economic recession. Worldwide PV system installations are forecasted to decline to 3.5GW in 2009, down 32% from 5.2GW in 2008. A 12% reduction in the average price per solar watt will also impact global PV revenues, which will drop by a massive 40.2% to US$18.2 billion, down from US$30.5 billion in 2008.

The 500MW-cap imposed in Spain, prompted by the massive 2.5GW plus growth seen in the country last year, is a key contributor to the decline in installations as emerging markets are not expected to fill the void for 2009. Indeed, according to Dr. Henning Wicht, Senior Director and Principal Analyst for iSuppli, believes the impact will continue into 2010, limiting global revenue growth to 29.2% for the year.



iSuppli Corp: Global Photovoltaic System Installation.

Source: Photovoltaics International



iSuppli Corp: Global revenues generated by photovoltaic installations 2008-2013.

Source: Photovoltaics International

"For years, the PV industry enjoyed vigorous double-digit annual growth in the 40% range, spurring a wild-west mentality among market participants," said Dr. Henning Wicht, senior director and principal analyst for iSuppli. "An ever-rising flood of market participants attempted to capitalize on this growth, all hoping to claim a 10% share of market revenue by throwing more production capacity into the market. This overproduction situation, along with a decline in demand, will lead to the sharp, unprecedented fall in PV industry revenue in 2009."

The good times are expected to return, but not until 2011 and beyond. Revenue growth of 57.8% is expected in 2011, followed by similar levels through 2013 as both demand and supply become more balanced. Wicht noted that there would be fewer new entrants into the market place and a slowdown in new capacity coming on stream.

"PV remains attractive because it continues to demonstrate a favorable Return on Investment (RoI)," noted Wicht. "Furthermore, government incentives in the form of above-market feed-in-tariffs and tax breaks will remain in place, making the RoI equations viable through 2012. Cost reductions will lead to attractive RoI and payback periods even without governmental help after 2012."

Lower prices due to productivity drives will contribute to overall cost-per-watt reductions, further opening new markets, Wicht said.

Overall, the shakeout would be good for the industry, in that it would result in a more mature and orderly supply chain.

Study shows decline in installed costs of solar PV power systems in U.S.

A new study on the installed costs of solar photovoltaic power systems in the U.S. shows that the average cost of these systems declined significantly from 1998 to 2007, but remained relatively flat during the last two years of this period.

"Tracking the Sun: The Installed Cost of Photovoltaics in the U.S. from 1998-2007" was written by Ryan Wiser, Galen Barbose, and Carla Peterman, researchers at the Department of Energy's Lawrence Berkeley National Laboratory. They say that the overall decline in the installed cost of solar PV systems is mostly the result of decreases in nonmodule costs, such as the cost of labour, marketing, overhead, inverters, and the balance of systems.

"This suggests that state and local PV deployment programs – which likely have a greater impact on nonmodule costs than on module prices – have been at least somewhat successful in spurring cost reductions," according to the authors, who work at the lab's Environmental Energy Technologies Division.

Installations of solar PV systems have grown at a rapid rate in the U.S., and governments have offered various incentives to expand the solar market. "A goal of government incentive programs is to help drive the cost of PV systems lower. One purpose of this study is to provide reliable information about the costs of installed systems over time," said Wiser.

The study examined 37,000 grid-connected PV systems installed between 1998 and 2007 in 12 states. It found that average installed costs, in terms of real 2007 dollars per installed watt, declined from US$10.50 per watt in 1998 to US$7.60 per watt in 2007, equivalent to an average annual reduction of 30 cents per watt, or 3.5% per year in real dollars.

Because incentives for residential PV systems decreased over this period, the net installed cost of residential PV has stayed relatively flat since 2001. At the same time, the net installed cost of commercial PV has dropped – it was US$3.90 per watt in 2007, compared to US$5.90 per watt in 2001, a drop of 3%, due in large part to the federal ITC.

VLSI Research: photovoltaic equipment sales topped US$4.4 billion in 2008

Specialist market research firm VLSI Research has said that the photovoltaic cell and module manufacturing equipment market, which includes the thin-film equipment sector, reached US$4.4 billion in sales in 2008 as the solar industry continued to expand and add new manufacturing capacity. The equipment market was also boosted by the emergence of various thin-film technologies that entered production for the first time in 2008, enabling suppliers to record new revenue streams.

However, John West, VLSI Research's Europe Managing Director, cautioned that growth in the market would slow down in 2009, projecting growth of 8% compared to 2008, reaching approximately US$4.75 billion in sales. The cautionary note was due to an expected decline in conventional c-Si cell equipment sales in 2009 as overcapacity and tight financial markets curtail expansion plans. West noted that there was a halt to capacity expansions in 2009 as PV cell and module manufacturers absorbed several years of aggressive capacity expansions.

Overall growth in 2009 is expected to come from the continued roll-out of thin-film manufacturing due in part to the equipment lead-times and large order backlogs held by thin-film equipment suppliers.

India is on the rise in the PV industry

SEMI India has summarized a vision for the Indian solar industry in a white paper called "The Solar PV Landscape in India – An Industry Perspective." CEO of Tata BP Solar, K. Subramanya, released the report during a special media briefing.

The paper was developed by the SEMI India PV Advisory Committee and represented by global photovoltaics industry leaders. It includes growth opportunities and details on how India could possibly become a global leader in photovoltaics for years to come, in addition to the current state of the solar market. The paper notes the country's energy needs and its energy dependence on fossil fuels.

India, a country which experiences over 300 sunny days annually, has 9 photovoltaic cell manufacturers with close to 20 module manufacturers. Less dependence on fossil fuels and more on PV manufacturing could promote many socio-economic advantages.

Solar subsidies failing to attract applicants in Japan

Subsidies in Japan for home solar panels are having a difficult time luring applicants. This may imply that the government could soon step in to promote the solar power industry.

A new stimulus plan is expected to spend more money on solar projects. This is the fourth such package in the last year and is predicted to include fiscal spending of up to US$150 billion. Last January, the Japanese Government introduced a ¥70,000 subsidy per kW of solar panel equipment, hoping 35,000 users would apply from January-March. So far, there have been just 21,653 applications, according to the Japan Photovoltaic Energy Association. Reuters says this subsidy would come out to close to ¥245,000 for 3.5kW of equipment per household, nearly a tenth of the cost.

Analysts believe the credit crisis may lead to customers feeling uneasy about big investments, especially since solar energy will become cheaper in the future.

Etsuko Akiba, head of media relations at the Nippon Association of Consumer Specialists, commented, "People say they would rather wait until the cost halves in three to five years, which is what the Government has forecast."

¥9 billion has been budgeted for the subsidies for a three-month period in addition to ¥20 billion for the fiscal year, starting April 1, aiming for 120,000 applicants in 15 months. Local governments have also been giving subsidies to aid the move for solar energy.

Demand for solar panels had disappeared after the Japanese Government stopped giving subsidies in March of 2006.

China's new subsidies plan: suggests decline in annual allowance

With the introduction of a solar subsidy system for the Chinese market, Barclays Capital Solar has published an update, with details garnered from the Chinese Ministry of Finance's announcement on March 31st. The reviewed announcement includes news of an annual decline in subsidies.

The Barclays report states that contrary to the original release, the program covers both non-BIPV rooftop applications as well as BIPV, but that the incentive for the non-BIPV applications will be lower than the US$2.90/W announced for BIPV.

Stimulus package

China's 4 trillion yuan stimulus package (announced in early March) included 210 billion yuan (US$30 billion) for green energy programs, but there are rumours that there is an additional US$30 billion green stimulus package on the cards – this has been disputed by Barclays' research.

ACT feed-in tariff to benefit Canberra's solar industry

The Australian Federal Government has initiated a new feed-in tariff in the ACT (Australian Capital Territories) that will ensure homeowners in the region will receive a premium of 3.88 times the current market rate for their solar-generated electricity for 20 years. The new ACT scheme will pay between 50.05$c/kWh for electricity produced by grid connected solar systems up to 10kW and 40.04$c/kWh for systems up to 30kW capacity.

This news is a major boon for the ACT region, as compared to other regions where there is a significantly lower rebate, or none at all.

Australia's Energy Matters site points out that there is a major difference between ACT's program and others. This particular feed-in tariff program is based on a gross model, under the terms of which all electricity generated benefits from the premium rate. In other states, the net model applies, whereby only electricity generated surplus to the consumption of the particular building being supplied is eligible for the rebate.

Frost & Sullivan pushes for more attention to solar energy in South Africa

In response to the Royal Danish government's plans to donate R60 million toward renewable energy projects at the local government level in South Africa, which will help fund a number of projects including wind energy and methane gas capture at landfills, Frost & Sullivan stated that some of these funds should be put toward the support of solar energy. The company noted that there is great potential for solar energy in Africa; however, response has been limited due to high equipment costs.

Although the National Energy Regulator of South Africa (NERSA) has proposed incentives, there is no indication as to when they will be implemented. It has been said that the suggested feed-in tariffs may not be high enough to inspire substantial interest. The government has set a target of 3% of all power to be generated by renewable sources by 2013, though this has been criticized as too weak.

Photovoltaic industry 2009: a journey into uncertainty

Paula Mints, Navigant Consulting, Inc., Palo Alto, California, USA

ABSTRACT

Despite over 30 years of unprofitability, being viewed as too expensive and in many cases, unattractive, the PV industry has also enjoyed over 30 years of strong growth. Though granted, in the past, this growth was often from a much smaller base than the gigawatt levels experienced today, it is still an impressive achievement. Table 1 provides a history of PV industry growth from 1978 to the present. The data in Table 1 is based on what was sold into the global market to the first point of sale, eliminating double shipment (sales) of technology.

During most of its >30-year history, the industry has experienced the sort of accelerated growth expected from emerging industries; for example, the internet boom. In the 30 years from 1978 to 2008, the PV industry had two years of >100% growth (1978 at 100% and 1980 at 120%); and six years of growth >50% (1979 at 50%, 1981 at 61%, 1983 at 88%, 2004 at 55%, 2007 at 55% and 2008 at 79%). It has not all been good times though: in 1985 industry sales (demand) grew by 11% over 1984; in 1986 industry growth was 8%; in 1993 industry growth was 3% and in 1994 industry growth was 10%.

In the early days when the industry saw <25MWp in yearly sales, most demand was for the remote applications (remote homes, villages, telecommunications, battery charging, etc.). In the late 1990s, Japan and Germany implemented incentive structures that drove demand for grid-connected installations. From 2000 through 2008, industry growth has consistently been >30%. It is important to remember, however, that despite extraordinary growth, on the manufacturing side (supply) the industry first turned a profit in 2004. Table 2 offers data on the major applications for the photovoltaic industry from 1998 through 2008, with a forecast to 2013. In 1998 the grid-connected application was still only 31% of total demand. The first year that saw demand for grid-connected systems take a major share of sales was in 2000, when the grid-connected application was 51% of demand and sales. In 2008, grid-connected sales were 94%.

The photovoltaic industry has suffered from unprofitability, from the high capital expense required to develop the technology – in part because of the long timeline from R&D through pilot-scale to commercial production, from the stigma of its continuing need for subsidies (even though all energy technologies are subsidized at some point in the chain), and early on, from the perception that the technology was new and different and those who invested in it were similarly new and different. This is a lot for any industry to overcome, and through it all – the bad unprofitable days and the recent profitable ones – the industry has persevered, continuing to develop the best distributed generation technology currently available. Figure 1 shows the industry's 30-year climb to gigawatt sales.

Year	MWp	% Chg
1978	1.0	100%
1979	1.5	50%
1980	3.3	120%
1981	5.3	61%
1982	7.7	45%
1983	14.5	88%
1984	17.5	21%
1985	19.4	11%
1986	21.0	8%
1987	24.9	19%
1988	31.5	27%
1989	37.9	20%
1990	42.7	13%
1991	48.2	13%
1992	54.1	12%
1993	55.7	3%
1994	61.0	10%
1995	71.5	17%
1996	82.6	16%
1997	114.1	38%
1998	134.8	18%
1999	175.5	30%
2000	252.0	44%
2001	352.9	40%
2002	504.9	43%
2003	675.3	34%
2004	1049.8	55%
2005	1407.7	34%
2006	1984.6	41%
2007	3073.0	55%
2008	5491.8	79%

Table 1. PV industry growth (1978 – 2008).

The rise of thin films

The silicon shortage that hampered growth from 2004 through 2007 was not new; indeed, it had concerned the industry for many years and many discussions were had, and consortiums formed to address it. In 1995, when industry sales were 71.5MWp and the industry's primary silicon supply was scrap, there was panic over a silicon shortage and higher prices when the price of scrap remelt nearly doubled from US$7 to US$8.00 per kilogram to US$13.00 per kilogram. Crystalline manufacturers responded by announcing potential price increases. In fact, in 1995 average prices decreased by an average of 5% for all categories of buyers. The same year saw thin-film technologies represent 14% of total shipments, though thin film's share of global sales decreased for several years thereafter.

The silicon shortage that began (in earnest) in 2004 and continued through the beginning of 2008 was more severe than earlier shortages because the volume of demand had increased significantly. The PV industry had waited years for this strong demand, and the constraints to meeting it were frustrating. This increase in demand, driven by Europe's feed-in tariff incentive model, led directly to growth of large-field (often referred to as utility-scale) installations of >1MWp. As silicon became more costly (>US$400 per kilogram in some cases) and more scarce, and as demand climbed, crystalline modules became more costly and a case was made for thin films, which are theoretically less expensive to manufacture.

During this period, thin film's share of total sales increased from a 5% share in 2004, to a 7% share in 2006, to an 11% share in 2007 and to a 14% share in 2008. Previously viewed as a risky technology choice by system integrators and installers, thin-film technologies (in particular CdTe and a-Si) were able to overcome market resistance and make real, perhaps long-term, gains. Figure 2 presents thin films' contributions to total shipments from 1980 through 2008. The relative strength of thin films in the mid- to late-1980s was due to strong sales into the consumer indoor application (calculators, watches, etc.). During the mid- to late-1980 period, total shipments (sales) were <50MWp annually.

"High levels of inventory and soft demand are driving the cost of crystalline technologies down, and thin films are experiencing difficulties competing with the higher efficiency of crystalline."

Currently, high levels of inventory and soft demand are driving the cost of crystalline technologies down, and thin films are experiencing difficulties competing with the higher efficiency of crystalline. Despite this, thin films have made real gains in the market and are expected to have a 16% share of 2009 sales.

The good times screech to a halt

In the early days, PV manufacturers were unprofitable; research and development was (and still is) extremely capital expensive, and the market was either remote (off-grid) or demonstration (grid-connected). In 2004, the industry entered a stage of supply-constrained profitability, where strong demand was unquestioned and was assumed to be everlasting. Debt and equity financing were reasonably easy to come by. Particularly in markets with strong feed-in tariffs (Spain and Germany), systems sprang up seemingly overnight, and modules were bought under the belief that growth would continue at >40% a year for the foreseeable, and even unforeseeable, future. During this time industry quality standards and performance guarantee

	1998	2003	2008	2013		CAGR	CAGR	CAGR 2008-2013	
Grid Sub-Application	MWp	MWp	MWp	Conservative MWp	Accelerated MWp	1998-2003	2003-2008	Conserv.	ACC.
Grid-Residential	32.8	426.1	1544.0	4587.3	8514.9	67%	29%	24%	41%
Grid-Commercial	6.7	51.3	2727.7	7492.5	13907.7	50%	121%	22%	39%
Grid-Utility	2.5	6.8	874.9	3211.1	5960.5	22%	164%	30%	47%
Total Grid	42.0	484.2	5146.6	15290.9	28383.1	63%	60%	24%	41%
Total Demand	134.8	675.3	5491.8	15839.8	28994.4	38%	52%	24%	39%
Grid % Total	31%	72%	94%	97%	98%				

Table 2. PV industry application split (1998 – 2008).

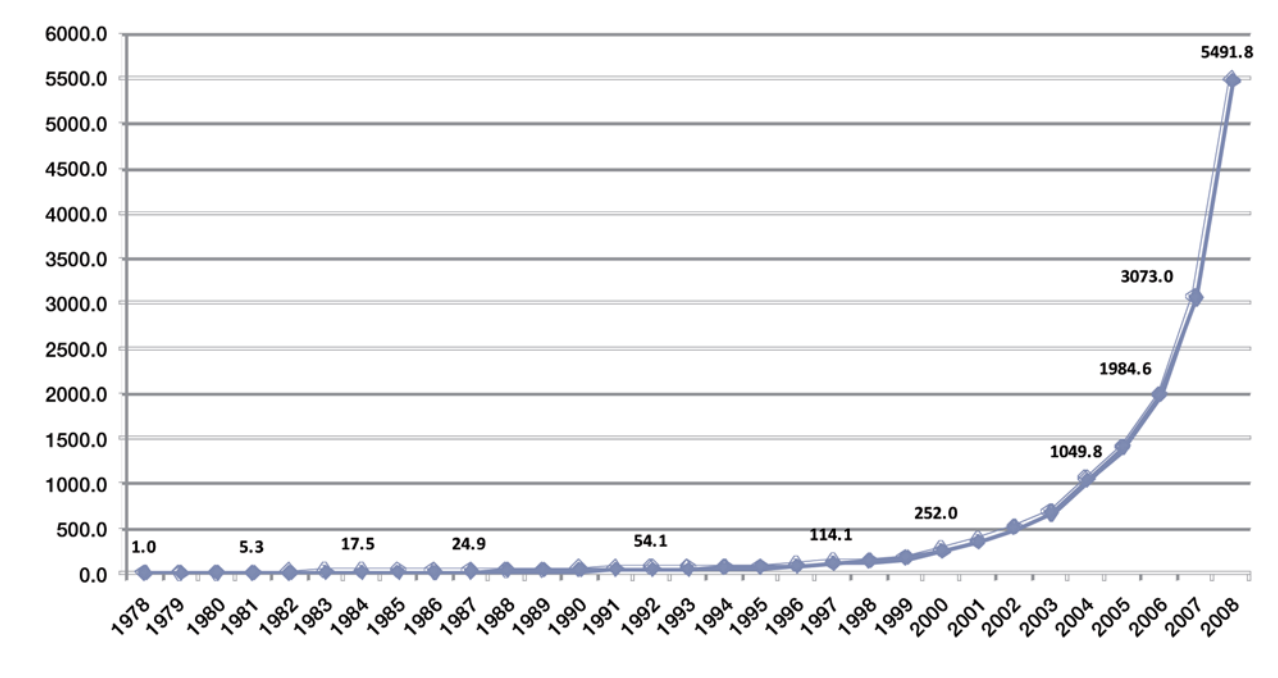


Figure 1. PV industry shipments (1978 – 2008).

requirements were relaxed (primarily by investors, who have now learned how important these standards were and are to industry sustainability). New entrants, though well-meaning but also lacking the experience of 30 unprofitable years, did not understand that the potential of lower-cost manufacturing is not the entire story, and that grid parity is a far more complex concept than it appears.

During this period strong demand drove up prices, even for thin films in certain markets. In 2008, technology revenues increased by 80% to US$20.4 billion.

"Photovoltaic technologies still have to prove economic sustainability without subsidies. This leaves the industry a one- to two-year period to retrench, mature its business models and to continue developing its technologies."

Unfortunately, in 2008 the market in Spain was significantly oversold, and has since collapsed. Even more unfortunate, worldwide economies were driven into recession by a global financial collapse that has almost frozen debt and equity availability into 2009. Regarding the markets in Europe, Spain and Germany consumed 74% of total module sales in 2008, with the rest of Europe taking another 5%. In particular, with the collapse of the market in Spain, there is simply no other global market that can consume 42% of sales. Figure 3 presents supply (sales)

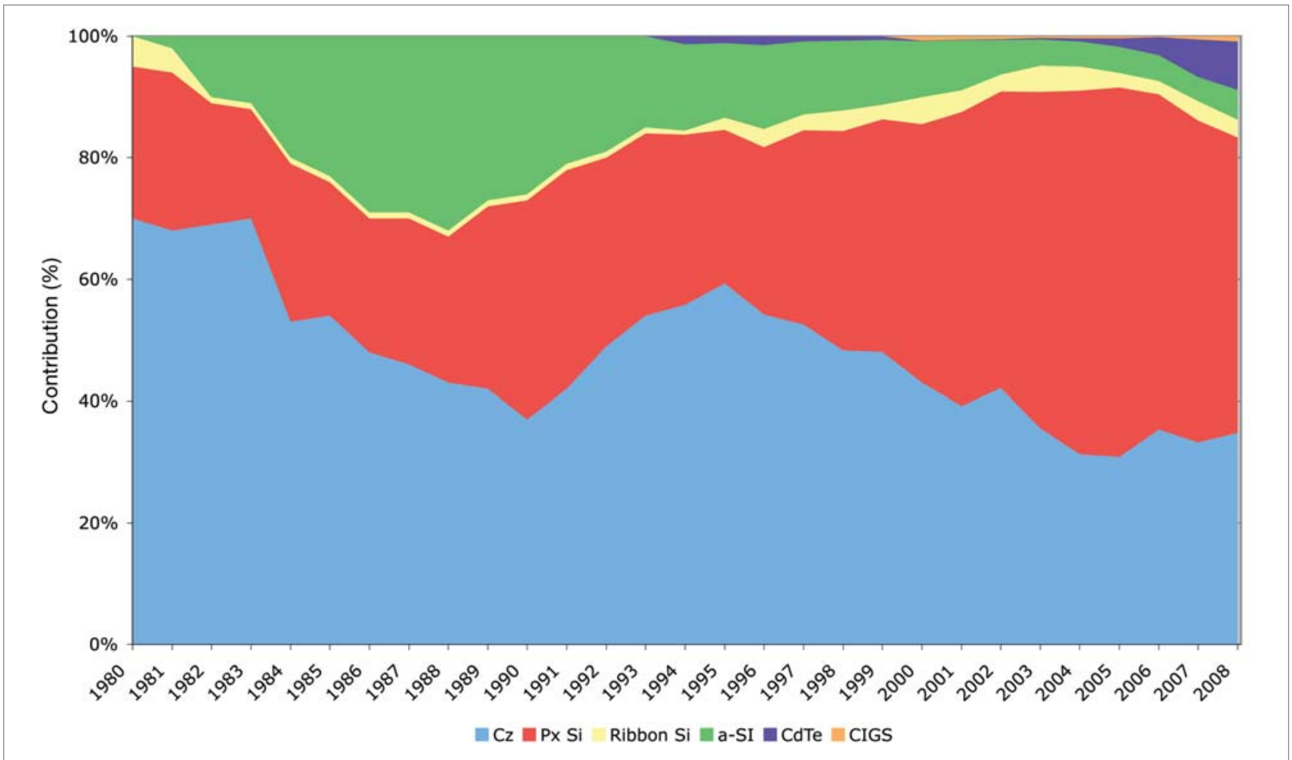


Figure 2. Thin film contribution to total industry shipments (1980 – 2008).

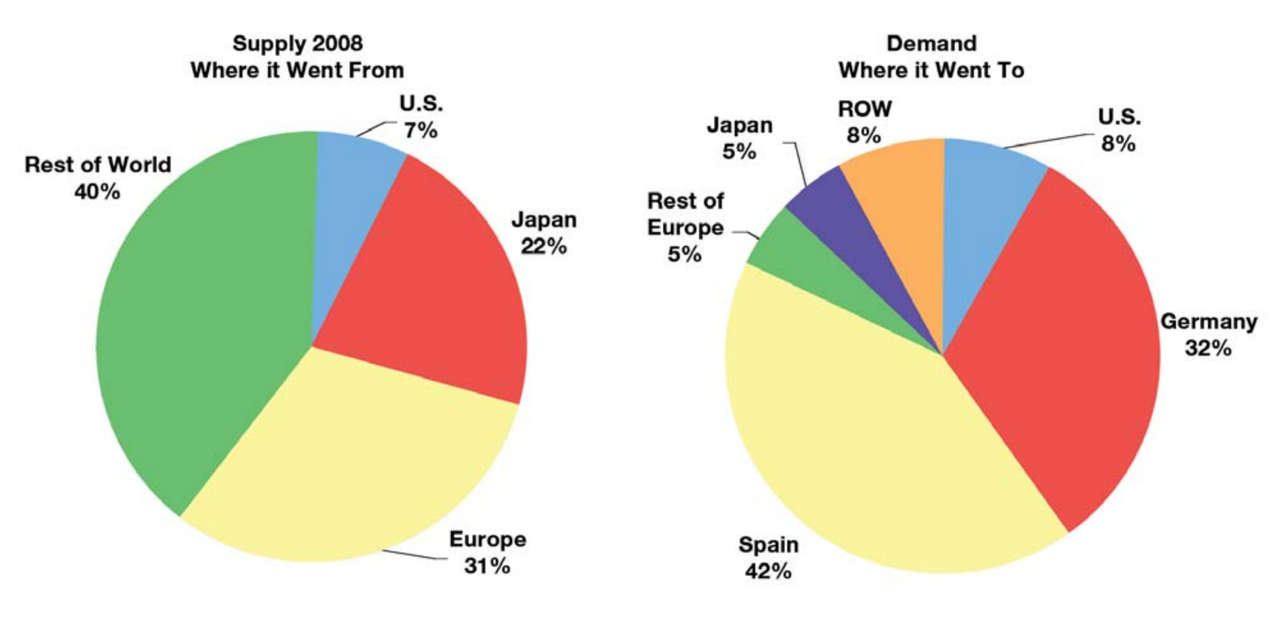


Figure 3. Supply and demand 2008 (based on a 5491.8MWp total).

and demand (market) share information for 2008.

Long-term industry participants remember the struggles of the past, but new entrants are in for a shock. With current levels of inventory, lower prices and softer demand, revenues are expected to decline significantly in 2008 anywhere from 12% to 26%, depending on the overall volume of sales. The reason for the decline in revenues is, again, falling prices for module and cell products. When demand softens and inventories rise, any industry will lower its prices to and beyond the point of pain. It also follows that an industry that has endured more than 30 profitless years will raise prices until the market balks.

Figure 4 presents a picture of pricing trends over time, including the recent 2009 decreases. The prices used to prepare this figure are averages, and so, for every year there is a low and high, along with a range. A weighted average that takes into account volumes and regions is used annually to arrive at the global average selling price. In the 2004 through 2008 period, cell prices were in many cases the same as module prices.

Particularly as there are several reasons for the current slow demand (collapse of Spain, global recession, frozen credit and securitization markets, among other causes), the industry can expect at least one, perhaps two difficult years. During this time, lower module and system prices may have the effect of lowering margins for the long term. That is, this new market reality we are entering may have a long memory and new expectations as to what it will pay for a photovoltaic system of any size, and the electricity generated from a system. The industry is therefore encouraged to continue lowering costs so that there is enough of a buffer in the margin to ensure profitability.

Photovoltaic systems come with a high upfront capital cost, low running costs, and a long lifetime. The end user, however, is buying electricity, and they want the stability in electricity prices that solar can provide, but at a price close to or lower than that paid for conventional energy. In some cases, when economic times

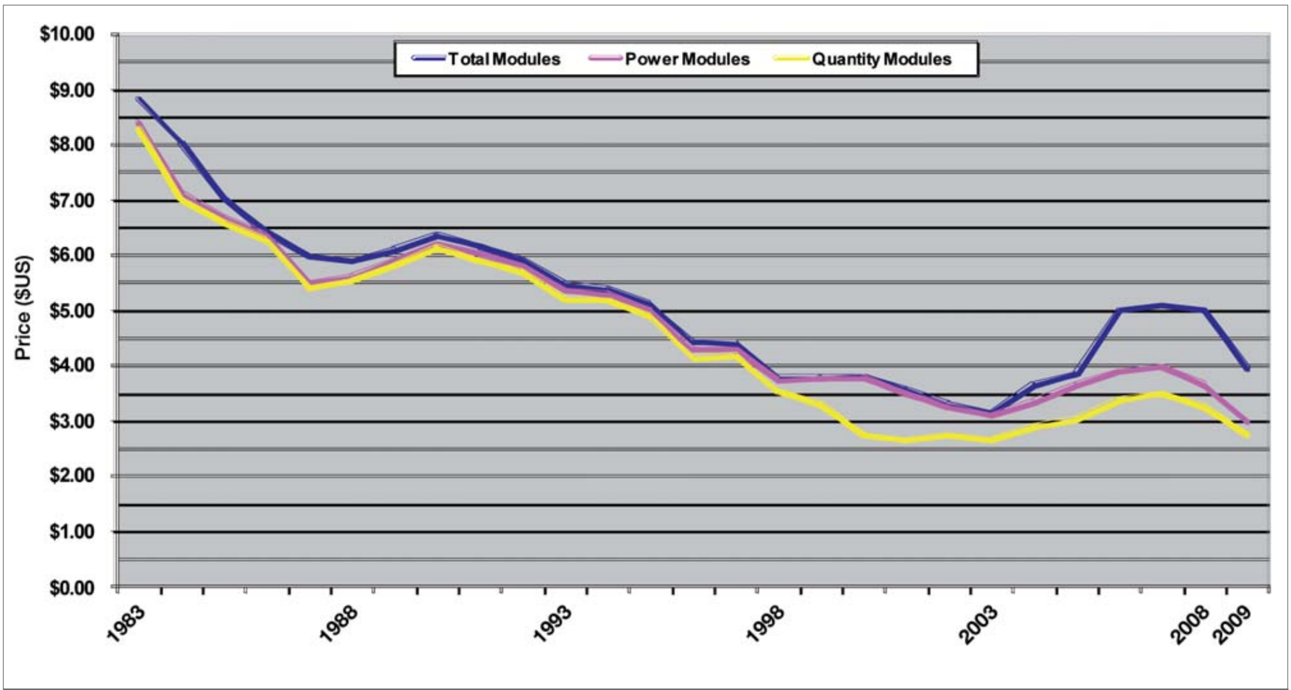


Figure 4. Average module prices (1983-2009).

are good, customers are willing to pay a premium for renewable energy, but when times are difficult, these same customers are driven to economize, whether or not these economies are short-sighted. Like it or not, humans are a short-sighted bunch, and governments (who legislate for or against incentives) will pay attention to their constituents.

Call it grid parity if you will, it is crucial that the industry continue to work towards demand that not driven by incentives, but again, is sustainable on its own. The grid-parity concept is, as previously stated, complex, differing by market (U.S. state, country, sometimes city). Complicating the grid parity concept is the fact that all energy technologies are subsidized somewhere along their value chain. However, photovoltaic technologies still have to prove economic sustainability without subsidies. This leaves the industry a one- to two-year period to retrench, mature its business models and to continue developing its technologies. The latter technology development is something that the industry does very well. The technologies are all following their development timelines towards lower costs and increasing conversion efficiencies. Hard times tend to bring on great technological gains, out of necessity if for no other reason.

During the silicon shortage, great gains were made in the use of silicon for crystalline technologies. Strong demand and effective incentives (particularly in Europe) also encouraged the development of new business models for the implementation of solar systems. With the current downturn and low availability of financing, the industry will continue maturing these business models so that when demand returns it can be met on all levels of the business value chain. Certainly the capacity will be in place to meet future volumes, but available capacity alone is not enough to mature an industry. Some of the new entrants will likely be absorbed, or possibly disappear. Lastly, the PV industry has time to open new markets, which is crucial for its future. Europe alone cannot continue to support an entire industry.

The developing world continues to offer potential for business, though a method of meeting this need profitably is still a work in progress. Figure 5 provides a short-term forecast through 2013 under three scenarios: recession, conservative, and accelerated. It is assumed that 2009 will be closer to the recession forecast, and 2010 will likely be conservative. However, 2011 and 2012 have the potential of returning to the accelerated forecast. Long-term accelerated forecast is an outlier, that is, an indication of an industry that is still maturing.

In the future, demand will settle at some sustainable point if again, the industry continues to mature its business models, lower its costs so that it can price profitably at a sustainable (for the market) level, and continue maturing its technologies.

About the Author

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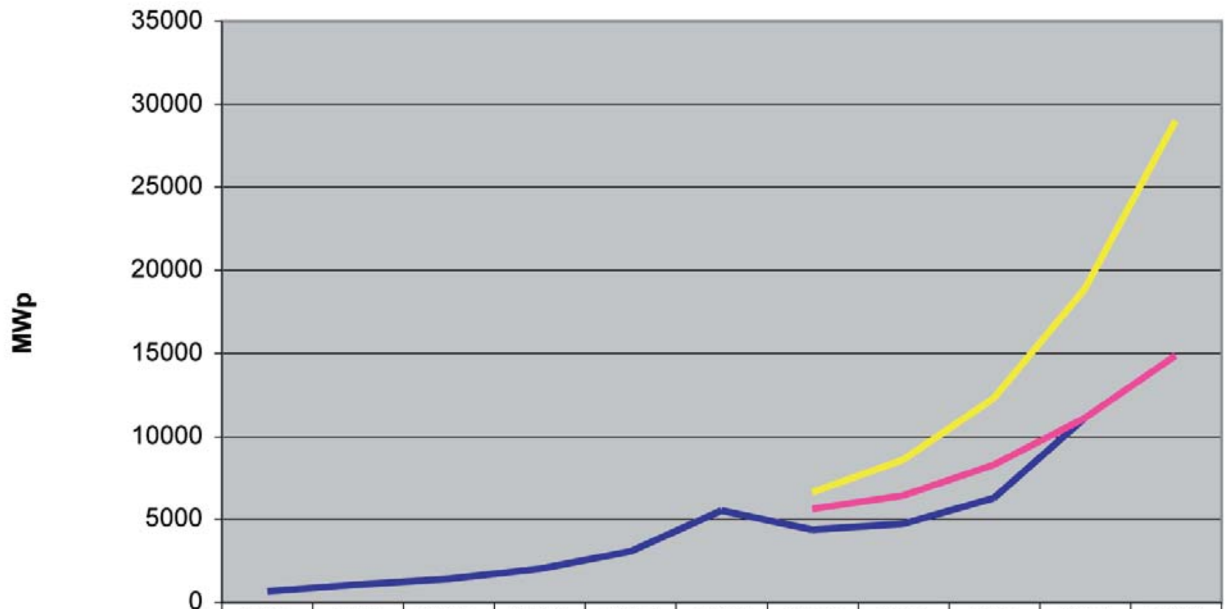
Market Watch



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Recession	675.4	1049.8	1407.7	1984.6	3073.0	5491.8	4373.4	4710.7	6248.6	11079.7	14852.1
Conservative							5618.2	6436.4	8285.9	11079.7	14852.1
Accelerated							6598.8	8564.3	12283.7	18846.5	28994.4

Figure 5. Photovoltaic industry forecast scenarios: recession, conservative, accelerated (2003-2013).

EPIA market outlook until 2013: a promising future for the PV industry

Denis Thomas, European Photovoltaic Industry Association (EPIA), Brussels, Belgium

ABSTRACT

In 2008, the global PV market reached 5.6GW and the cumulative PV power installed totalled almost 15GW compared to 9GW in 2007. Spain represented almost half of the new installations in 2008 with about 2.5GW, followed by Germany with 1.5GW additional connected systems. USA confirmed its trend with 342MW newly installed PV systems, followed by South Korea which registered 274MW of PV installations over the year. Italy connected almost 260MW while France, Portugal, Belgium and the Czech Republic made good scores confirming Europe's global leadership in the deployment of solar PV energy. A diversification of the market is taking place with countries adopting appropriate support policies.

EPIA's market forecast to 2013

Given the current crisis context, high uncertainties exist regarding the 2009 market. This year, experts believe the market could reach up to 7GW, with each individual country's development influencing the final figure. Spain, in particular, recently changed its support scheme, setting up a cap which will limit the development of the global market in 2009. The PV sector is hoping other markets such as the US, Germany, France and Italy will pull the demand. Favourable policy frameworks are expected to further accelerate PV deployment in these countries. In 2013, the global PV market could reach 22GW if appropriate policies, such as feed-in tariffs, are in place.

> "In 2013, the global PV market could reach 22GW if appropriate policies, such as feed-in tariffs, are in place."

Global historical PV market development

The solar PV market has been booming over the last decade and is forecast to confirm this trend in the coming years. By the end of 2008, the global cumulative PV power installed was approaching 15GW. Today, Europe is leading the way with more than 9GW representing over 65% of the global cumulative PV power installed. Japan (2.1GW) and the US (1.2 GW) are following behind, representing 15% and 8%, respectively.

Global PV market outlook

PV market deployment is, to a large extent, dependent on the political framework of any given country. Support mechanisms are defined in national laws. The introduction, modification or fading out of such support

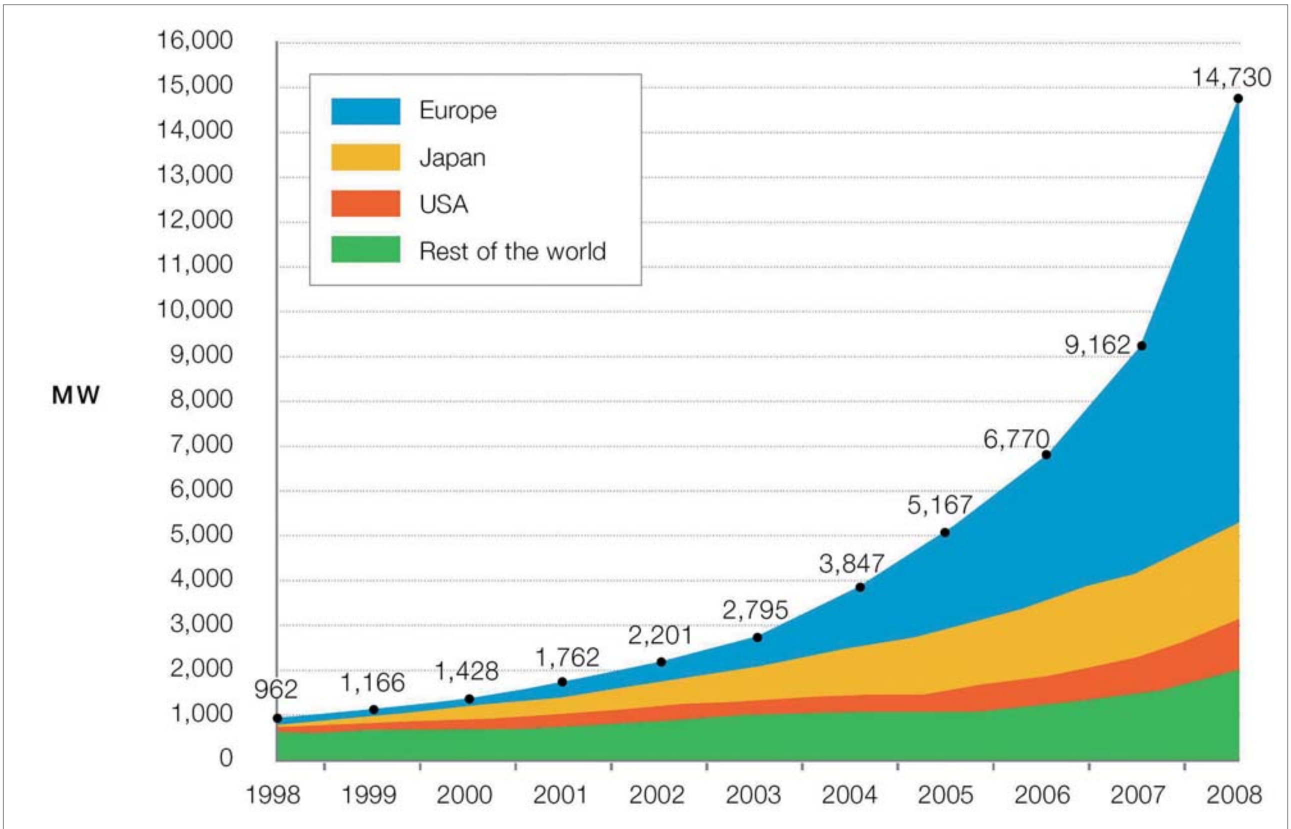


Figure 1. Historical development of global cumulative PV power installed per region.

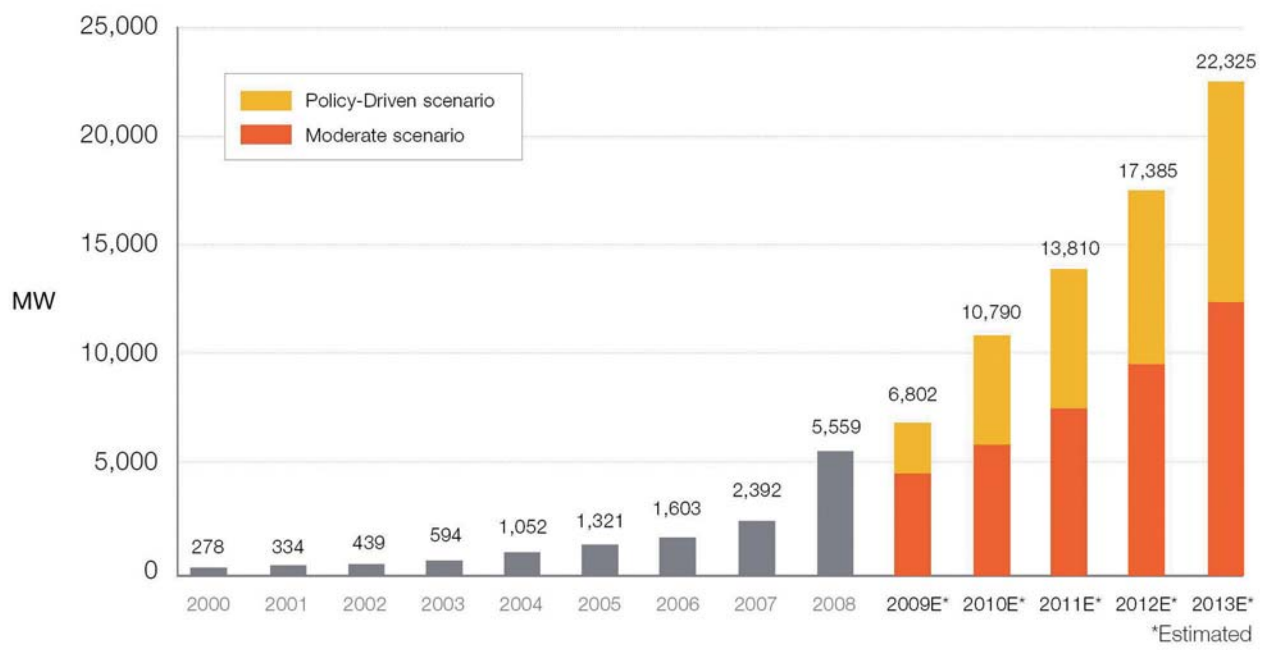


Figure 2. Global annual PV market outlook to 2013.

schemes can have profound consequences on PV industries, requiring that PV market forecasts have a deep understanding of the political framework. EPIA puts a great deal of effort into analysing PV markets. Due to its close contact with key players in the industry, with national PV associations and its knowledge of PV policy and support schemes, EPIA market scenarios are a credible and well-known source of short-term market forecasts as well as long-term scenarios.

In March 2009, EPIA went through an extensive data-gathering exercise among a highly representative sample of the PV industry, national associations and energy agencies. Based on the cross-checking of data and the consolidation of complementary market projection methods, EPIA has derived two representative scenarios for the future development of the PV industry.

The **Moderate scenario** is based on the assumption of a 'business as usual' situation that does not assume any major enforcement of existing support mechanisms.

The **Policy-Driven scenario** is based on the assumption of the follow-up and introduction of support mechanisms, namely feed-in tariffs, in a large number of countries.

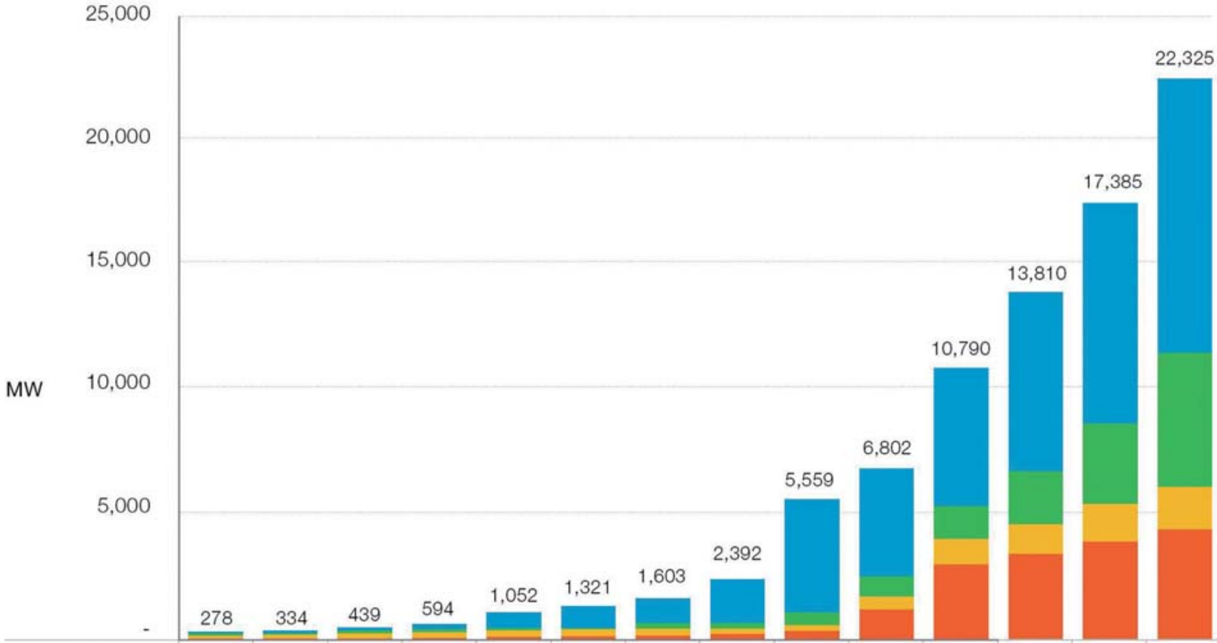
These two scenarios analyse, on a country basis, the historical development of the PV market, existing support policies, their attractiveness and expected developments, administrative procedures in place, national renewable energy objectives and the potential for solar PV.

For 2009, EPIA expects the global PV market to grow to around 6.8GW under the Policy-Driven scenario. Under the Moderate scenario, the anticipation is that the global PV market will stagnate at around 4.6GW.

By 2013, EPIA foresees the market reaching 22GW under the Policy-Driven scenario, which would mean a Compound Annual Growth Rate (CAGR) of 32% from 2008 to 2013. For the Moderate scenario, the annual market is expected to reach just above 12GW with a CAGR of 17% over the period from 2008 to 2013.

Country	Type	2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Belgium	EPIA Moderate	2	18	48	100	70	80	90	100
	EPIA Policy-Driven				175	125	130	140	160
Czech Republic	EPIA Moderate	0	3	51	80	90	110	140	170
	EPIA Policy-Driven				100	160	200	220	240
France	EPIA Moderate	8	11	46	250	340	600	900	1,000
	EPIA Policy-Driven				300	500	850	1,200	1,400
Germany	EPIA Moderate	850	1,100	1,500	2,000	2,000	2,300	2,600	3,000
	EPIA Policy-Driven				2,500	2,800	3,200	3,600	4,000
Greece	EPIA Moderate	1	2	11	35	100	100	100	100
	EPIA Policy-Driven				52	200	450	700	900
Italy	EPIA Moderate	13	42	258	400	600	750	950	1,250
	EPIA Policy-Driven				500	800	1,100	1,400	1,600
Portugal	EPIA Moderate	0	14	50	40	50	100	160	230
	EPIA Policy-Driven				50	80	180	350	500
Spain	EPIA Moderate	88	560	2,511	375	500	500	550	800
	EPIA Policy-Driven				375	500	600	650	1,500
Rest of Europe	EPIA Moderate	12	17	28	120	140	200	300	450
	EPIA Policy-Driven				250	325	400	525	625
Japan	EPIA Moderate	287	210	230	400	500	700	1,000	1,100
	EPIA Policy-Driven				500	1,000	1,200	1,500	1,700
USA	EPIA Moderate	145	207	342	340	1,000	1,200	1,500	2,000
	EPIA Policy-Driven				1,200	3,000	3,400	3,900	4,500
China	EPIA Moderate	12	20	45	80	100	300	600	1,000
	EPIA Policy-Driven				100	150	600	1,200	2,000
India	EPIA Moderate	12	20	40	50	60	80	120	300
	EPIA Policy-Driven				100	200	250	300	600
South Korea	EPIA Moderate	20	43	274	100	150	220	300	400
	EPIA Policy-Driven				200	350	450	700	1,000
Rest of the world	EPIA Moderate	153	125	126	250	300	300	300	350
	EPIA Policy-Driven				400	600	800	1,000	1,600
TOTAL	EPIA Moderate	1,603	2,392	5,559	4,620	6,000	7,540	9,610	12,250
	EPIA Policy-Driven				6,802	10,790	13,810	17,385	22,325

Table 1. Global annual PV market outlook to 2013 (MW).



MW	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009E	2010E	2011E	2012E	2013E
Europe	50	96	106	210	637	906	975	1,768	4,503	4,302	5,490	7,110	8,785	10,925
Rest of the world	94	75	104	98	53	12	196	207	485	800	1,300	2,100	3,200	5,200
Japan	112	135	185	223	272	290	287	210	230	500	1,000	1,200	1,500	1,700
USA	22	29	44	63	90	114	145	207	342	1,200	3,000	3,400	3,900	4,500
TOTAL	278	334	439	594	1,052	1,321	1,603	2,392	5,559	6,802	10,790	13,810	17,385	22,325

Figure 3. Global annual PV market outlook by region (Policy-Driven scenario).

Regional distribution of global PV markets

Considering the regional distribution of the global market outlook under the Policy-Driven scenario, EPIA foresees the EU PV market to grow from 4.5GW in 2008 to 11GW by 2013; US from 0.3GW to 4.5GW; Japan from 0.23GW to 1.7GW and the rest of the world (including China and South Korea) to grow from 0.5GW to more than 5GW by 2013.

Europe: the global PV market leader

Since 2004, Europe has been leading the global market for PV applications. In 2008, Europe represented over 80% of the global PV market. Among European countries, Germany has been leading the way for several years, but 2008 saw Spain take over the number one position worldwide with around 45% of the global market and 56% of the EU market.

Numerous countries are developing excellent support schemes for PV, of which Italy and France are emerging as the new high-potential markets. Some, such as the Czech Republic, Belgium, Bulgaria, Portugal and Greece, are following with promising support schemes.

In its Policy-Driven forecast for Europe, EPIA expects Germany to remain as the major PV market in Europe with increasing participation from France and Italy. If the cap is removed in Spain, EPIA expects these four countries to represent more than 75% of the European market by 2013.

Production capacity outlook

According to a survey conducted among EPIA members, production capacities along the PV value chain are expected to grow with a CAGR of 20% to 30% in the short-term (during the period 2009-2013).

> "Over the last three years, established polysilicon producers have more than doubled their total production capacity."

It is important to note that 'end-of-year production capacities' along the value chain (from silicon to modules) are always larger than actual production and much larger than installed systems in the field. This is because, firstly, a considerable part of the capacity is added during the year while capacities are always stated as end-of-year capacities. Secondly, as capacities are often stated by assuming a 365-day 24-hour operation, maintenance periods and periods of lower capacity usage have to be considered when comparing actual production and capacity figures. Thirdly, one should consider the delay (up to several weeks) between the production of the modules and their effective installation in the field.

Due to a strong continuous growth of the global PV market, as well as the slower process for establishing new silicon production facilities than for downstream processes in the supply chain, polysilicon supply has represented the main bottleneck of the PV industry since 2005. Over the last three years, established polysilicon producers have more than doubled their total production capacity and many new players have entered the polysilicon business. Due to this impressive increase in polysilicon production, EPIA expects the silicon shortage to end most probably by the end of 2009 or beginning of 2010.

Ramping-up processes for wafer, cell and module production is much faster than for polysilicon, which explains why the difference between cell and polysilicon capacities was relatively high in the past and is expected to narrow in the near future. Upstream processes like polysilicon production are characterised by a higher concentration of actors due to the high level of investments, and by a lower flexibility of equipment than downstream processes (cell or module production), characterised by a large number of actors due to the limited level of investment and a higher flexibility to adapt to the demand. As a result, utilisation rates in upstream processes are generally higher than in downstream processes.

This polysilicon shortage, which has limited the growth of crystalline technologies in the last few years, has offered a great opportunity for the PV thin-film industry to grow and establish

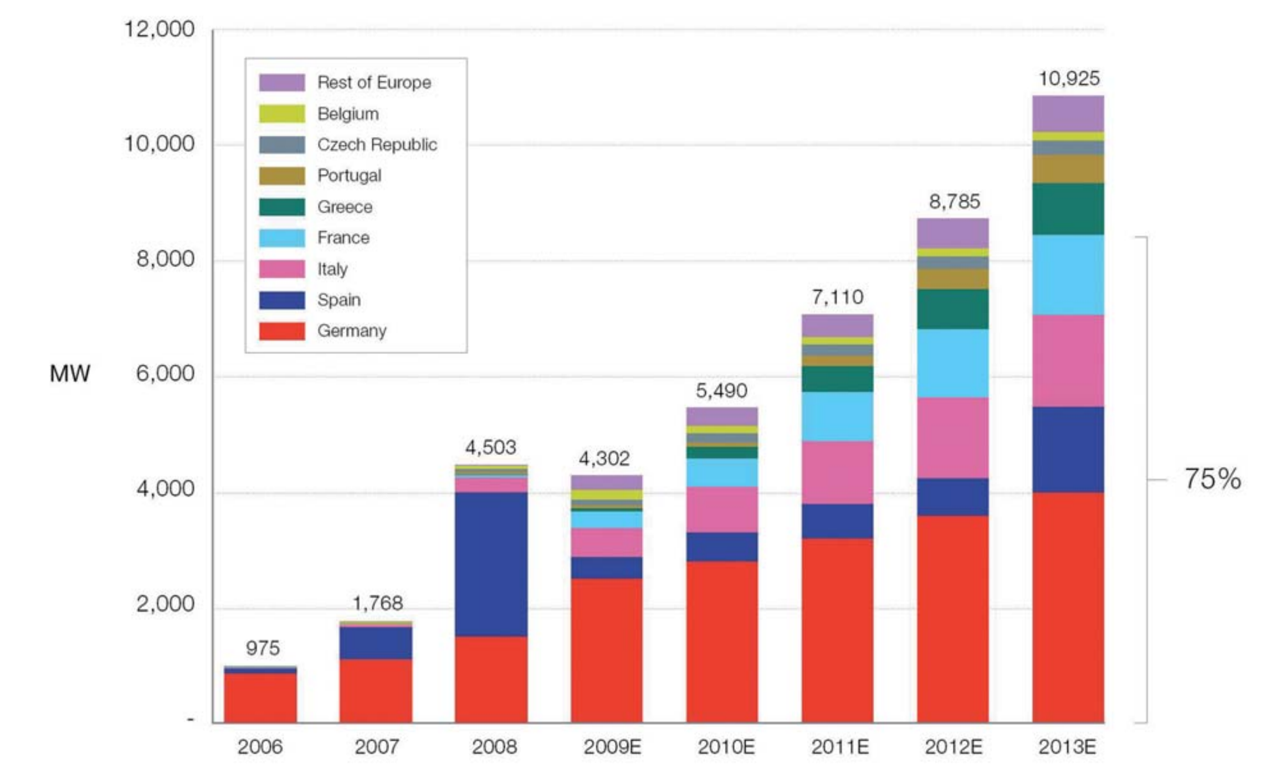


Figure 4. European annual PV market outlook to 2013 (Policy-Driven scenario).

thin film as a major PV technology solution. Whereas thin-film shares represented less than 5% of the total production capacity in 2005 with around 90MW, these shares will reach more than 20% in 2010 with little more than 4GW, and will represent around 25% in 2013 with about 9GW.

Global outlook: production capacity meets demand

As outlined earlier, effective module production during the year is lower than the module production capacity expressed at the end of the year. Comparing the expected module production with the expected demand, EPIA foresees that the PV industry is prepared to deliver large quantities (GW-scale) of modules and to follow the future PV demand in the short-term.

Nevertheless, these results should be handled with care as investments in new production capacities will only take place if the PV demand increases as expected by the industry. This supposes, among others factors, the putting in place of appropriate policy frameworks for PV, low administrative barriers and easy procedures to connect PV to the grid.

With an end to the polysilicon shortage in sight, EPIA expects that module prices will fall back on their historical learning curve which showed over the last three decades a 20% module price reduction each time the cumulative PV power installed was doubled. The first signs of this price decrease have become visible during the first quarter of 2009. If the module price decrease is passed on to the final customer and leads to a decrease in PV system prices (which is not always the case today in every market), the generation cost (€/kWh) of PV electricity will compete sooner with conventional retail electricity prices from the grid. If grid parity (the point at which the generation cost of PV electricity equals the retail price of electricity) is reached sooner, EPIA believes that the global PV market will grow even faster than expected in its Policy-Driven scenario and that the PV industry will be able to grow accordingly.

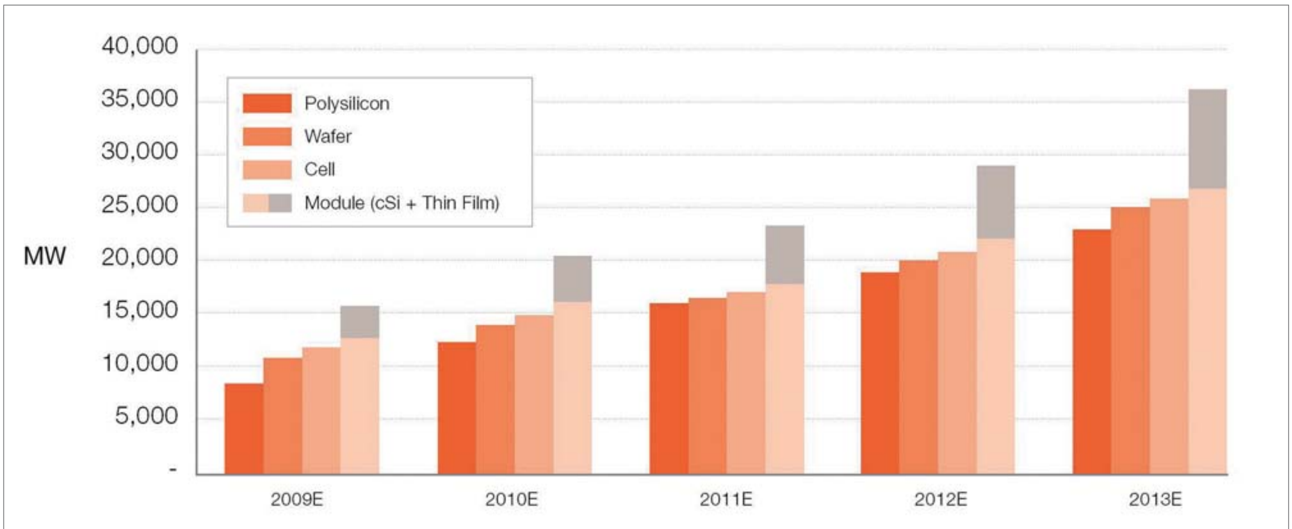


Figure 5. Production capacity outlook to 2013.

Market Watch

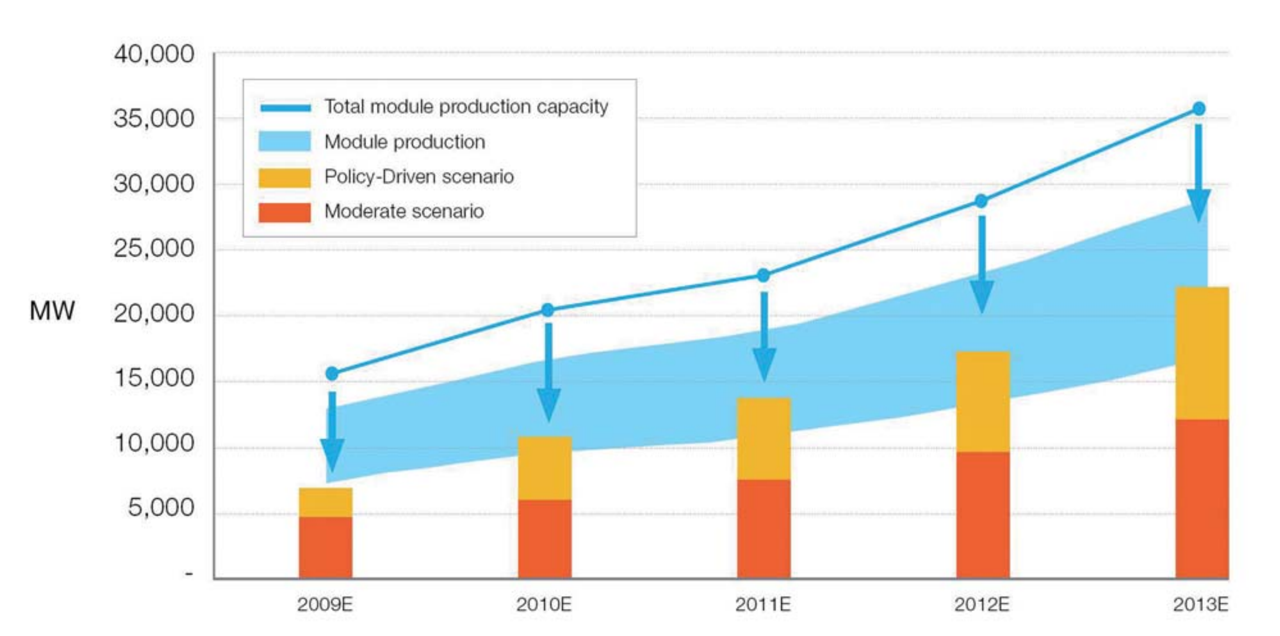


Figure 6. Global outlook – production capacity vs. market.

Further growth for the PV industry

Like all industries, the solar PV sector has not been spared by the credit crunch. Medium- to large-scale PV plants are taking longer to be financed than ever before. However, the fundamentals of the PV sector remain intact, if not better than before, considering the price decrease of PV modules of between 10% and 20% since the beginning of 2009.

Finance availability – a major growth factor

Given the current world uncertainties, all banks have strongly reduced their credit loans and the solar PV sector is no exception to this trend. Project financing thus appears as a challenge for the industry; while obtaining debt financing in 2008 required about a four-week wait, today it takes eight to 10 weeks, on average.

The perceived risk is higher, fewer banks are engaged and these lenders prefer to consider smaller projects (less than €50 million), if any. PV pricing is crucial, as the lending situation differs in most countries. Technology leaders and companies that are capable of reducing their prices will likely be the most successful in this situation. Experts also confirm that high-quality PV projects meeting all legal requirements, from the planning to the operating phase, will be financed.

Financing is possible, but project promoters need to be realistic. Investors are very selective due to the low finance availability, but they still see PV as an excellent sector for investment, both in PV projects and PV companies.

A reliable, calculable and low-risk investment

Given the government support programmes (mainly in the form of feed-in tariffs) providing investor security in the long-term and warranties from module manufacturers, solar PV represents a low-risk investment. It is a proven technology with a module lifetime well above thirty years, based on the 20-25-year warranty given, whereas the economic payback time of the investment is generally from eight to twelve years. As we know how much energy we produce for at least a 25-year period, we know how much we will receive from the feed-in tariff and can calculate our revenues over this period.

PV modules back on the learning curve

Due to the polysilicon shortage, PV has been above its historical price experience curve over the last three to four years. Seeing a major increase in polysilicon production, average polysilicon prices have decreased significantly and are driving general costs for silicon-based technologies downward.

In addition to this, the industry has unanimously recognised the module oversupply situation in today's PV market. As a result, module prices have dropped by 10% to 20% since the beginning of the year – very good news for the PV sector in general, and an indicator that PV technology is now back on its learning curve.

Conclusion: a strong commitment from the industry

The PV industry hopes finance availability will improve in the coming months. In any case, PV fundamentals remain strong and the industry is committed to accelerating price decreases. We can also look forward to further penetration of the existing PV markets and an accelerated market development in new and emerging PV markets. In this context, the European PV industry has unanimously agreed that photovoltaic energy could provide up to 12% of European electricity demand by 2020 if important boundary conditions in the way electricity is used in households and effective storage can be provided, and is strongly committed to becoming a significant energy supplier in Europe.

With this commitment and under the right framework conditions, it is possible to reduce PV generation costs by 8% every year, or a decrease of 50% every eight years. Investors can easily keep confidence with the solar photovoltaic technology.

About the Author

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Shakin' all over: Move over world, the solar leader may soon be the USA

What country is the "great hope for the global solar industry"? Not Germany, although it still has something left in the tank before its recent torrid – and subsidized – growth rate hits the wall. Certainly not policy-challenged Spain, whose incentive program about-face has left a gigawatt or so of modules originally designated for Iberian installations sitting in warehouses with no pipeline to fill. Italy or Greece? Sure, they'll grow at a nice clip, but can't be counted on for any drastic scaling or consistency of governmental attention. China perhaps? Although its manufacturing chops will continue to feed the international market, the PRC's own domestic demand curve isn't steep enough to gobble up all of that capacity, despite the leadership's helping-hands policies.

No, the saviour of solar is the USA, opined the Prometheus Institute's Travis Bradford during Greentech Media's recent "Surviving the Shakeout" solar industry summit.

After going over the state of the industry – which has flipped from a supply-constrained sector to one where demand contingencies call the shots and PV module ASPs have plummeted since late 2008 – Bradford focused on the current state and future promise of the U.S. market. Given the massive insolation enjoyed in the States, solar patriots have long touted the country's great potential for PV and thermal. If Bradford is correct, that potential will become reality over the next decade.

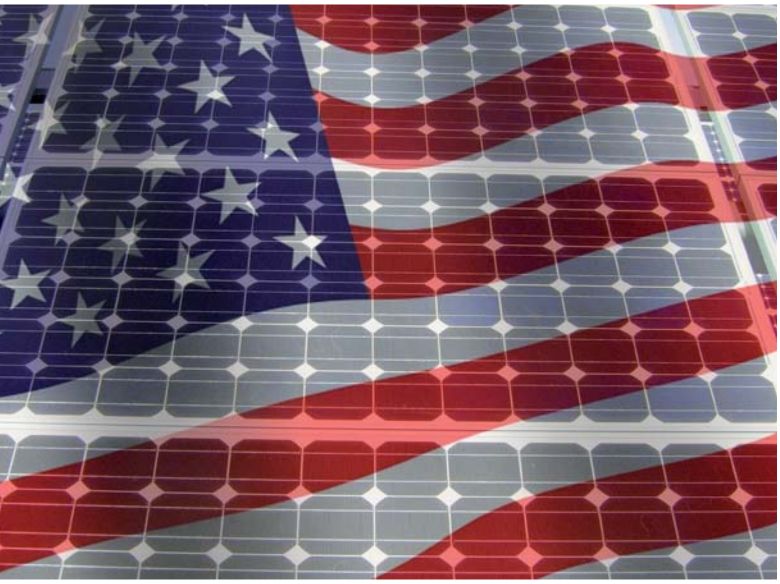

Photo collage: Tom Cheyney

He showed data comparing the total annual sunlight measured in kilowatt-hour per square metre compared to average electricity rates tabbed in cents per kilowatt-hour, which revealed that many U.S. population centres are or will soon become cost-effective for solar and reach grid parity – *even without subsidies*. The U.S. numbers are better than any other market in the industrialized world, Bradford says.

Given the recent about-face of U.S. policy regarding solar and other renewables, he characterized the combination of healthy federal and state incentives – including their positive impact on the equity and debt parts of the financial equation – with the drop in module prices, as a nirvana-like situation.

Bradford showed NREL map charts that depict electrical rate differences in various parts of the country. Two projections for 2015 – one factoring in a 0.5% annual rate hike, the other a 1% raise – predict that either half or two-thirds of the U.S. market can get below grid parity with solar power. Put another way, 98% or 99% of the country will be within 5 cents per kilowatt-hour.

This confluence of factors leads to what he calls a "near-term windfall in the U.S. industry," one that will strengthen when the "financing lynchpin" is ameliorated.

Another photovoltaic patriot, Spire's Roger Little, echoed Bradford's bullishness, claiming the U.S. "will become the world's largest solar energy market." Citing positives like the federal stimulus package, the growing call for huge utility projects, state incentives that could be worth up to 250GW in 10 years, the enactment of renewable portfolio standards in most states and a federal one in the works, and the push for creating green jobs, Little said it's time "to get into this business and take advantage of the opportunities."

He believes the best way to kick-start the lagging U.S. PV manufacturing base is not to build vertically-integrated gigawatt factories but to adopt what he calls "distributed module assembly," a kinder, gentler plan for building relatively modest 50MW automated, mostly crystalline-silicon-based panel plants throughout the country, positioning them to feed the growing solar demand.

If one of these plants were built in each state, the cumulative production would cover what Little believes will be a nearly 2.5GW shortfall in the U.S. capacity to meet its own demand by 2012.

The Little Plan's basic assumptions include a 219W module with 15.5% efficient cells costing US$1.80 per watt, seven-year depreciation, and a 20,000 square-foot factory at US$10 per square foot per year. He puts the non-cell-related module costs at 54 cents per watt and the total module cost, including the cell, at US$2.34.

He offered an example that showed an upfront investment of US$10 million, from which the federal ITC slices out US$3 million and the state tax break removes another US$5 million, resulting in a net cost for a 50MW module fab of a mere US$2 million.

The annual profit and loss for such a factory? With annual revenues at US$140 million (at US$2.80 per watt times 50MW), after working through the costs of goods sold and general/administrative expenses, the EDITDA is a not-measly US$14.9 million.

Little's model also posits the creation of more than 10,000 jobs in the module assembly and module tool businesses by 2012. He thinks that building "utility solar farm factories," where super-size, 1kW modules are fabricated close to where they will be deployed, could maximize cost reductions to the tune of US$2.96 per watt in utility system costs.

Although his plan is a tad self-serving given Spire's business model to sell turnkey module production lines, the Little Plan is intriguing – and well worth including in the conversation about approaches to bulking up the U.S. solar manufacturing base to service burgeoning domestic demand and be more competitive globally.

This column is an edited version of a blog that originally appeared on PV-Tech.org

Tom Cheyney is Senior Contributing Editor (U.S.) for the Photovoltaics International journal and writes blogs for PV-Tech.org.