Taking thin-film technology closer to the lowest possible manufacturing cost

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ABSTRACT

It is widely acknowledged that, without government subsidies, solar power still cannot compete effectively with conventional sources of electrical energy. As the industry strives to make solar electricity affordable and as a viable alternative to fossil fuels, solar power technology companies are diligently moving towards reducing the manufacturing cost for solar modules. In the case of thin-film solar cells in particular, as a benchmark, the cost of for solar power must be reduced for it to be competitive or to attain grid parity. This paper presents a number of opinions from industry leaders on how best to decrease this vital cost.

In terms of progress, First Solar continues to maintain the lowest manufacturing cost in the industry and was the first company to break the $1/watt price barrier last year. In its third quarter results released in October 2009, the company shared that the combination of higher watt throughput and a number of other operational improvements drove manufacturing cost reduction to $0.85 per watt. This was down 2% quarter-over-quarter, 21% year-over-year.

The long-term financial models which the company has previously discussed suggest manufacturing cost targets of $0.65 to $0.70 a watt by 2012. Its manufacturing costs have declined two-thirds from over $3 per watt to less than $1 per watt since First Solar began full commercial operation of its initial manufacturing line in late 2004.

Trends

Jim Cushing, managing director of Applied Materials' SunFab Products Group says industry costs are coming down due to three major trends: line integration, selection, cost and optimisation of direct materials, and efficiency gains.

"Over the last 30 years, solar technology has consistently been driving towards lower costs and higher efficiencies and closer to direct competitiveness with grid sourced electricity. Over the last 18 months, this trend has been accelerated as poly costs have dropped, thin-film companies have scaled, and larger, more capable equipment manufacturers have entered the market. Given the increased levels of investment in this industry, we see these trends continuing as factory productivity increases, economies of scale drive cost, and efficiencies improve", Cushing explained.

Cushing shared that the three main focus areas for Applied Materials are factory operation (primarily throughput, uptime, and yield), technology (efficiency), and direct materials costs.

"Our factory metrics are up across the board, and we have continued to deliver efficiency improvements to our factories. For direct materials, we recently had our second generation module IEC Certified. The approach to this module was to engineer lower cost. We changed the front glass, thinned the PVB [laminate], developed low gas flow processes, and negotiated lower direct material prices. The overall module material cost saving was 22%", Cushing added.

From the industry's perspective, **Dr. Harin Ullal** (pictured right), who works for the National Center for Photovoltaics at NREL, says First Solar has done an outstanding job in demonstrating how a PV company can systematically drive down the cost of PV modules over the years.

"One of the strategies they adopted very early in the game is the concept of 'smart copy'. At the same time, they improved the name plate rating of their individual manufacturing line, which was rated at 25MW a few years ago. Today, the same line is rated at 53MW without any replacement of hardware, but improving on the variables. So this is an excellent model for the other thin-film PV industry companies to follow if they would like to be a successful PV company in the future. Going forward, cost reductions will be more challenging in the future", said Dr. Ullal.

Rival companies acknowledge First Solar's performance and attribute its cost reduction-related results to the volume of manufacturing.

For instance, United Solar Ovonic's president **Subhendu Guha** (pictured right) mentioned that First Solar produces very large volumes, and has done an excellent job in lowering the module cost.

"We believe we can substantially reduce our costs from the current $1.76/watt to about a dollar/watt. This will be achieved through material cost savings, improved manufacturing throughput and yields, and improved conversion efficiency for our product", Guha said.

NREL's Dr. Harin Ullal.

Manfred Bächler, CTO, Phoenix Solar, underlined that the cost reduction roadmaps are still on track. "We as a company were focused on BOS (balance-of-system) cost reductions. However, for the second half of 2009 and probably also for 2010, we will suffer from increasing material prices", he said.

United Solar Ovonic president Subhendu Guha.

Critical factors

Direct materials account for around 50% of the total production cost, which explains why a company such as Applied Materials has dedicated teams focusing on engineering lower-cost solutions.

"We achieved over 22% reduction to date, and are currently working on another 20%-30% reduction. Additionally, we have an aggressive efficiency roadmap to 10% which will reduce our overall production cost to <$1/W. For a fully automated factory, labour cost is not a major factor, enabling more flexibility on factory location", continued Cushing.

In a thin-film product, the active material cost is very low. The encapsulants and the substrate dominate the cost, and prices decrease as the volume increases.

Last year, a study indicated that paying attention to lesser-known non-active materials can yield positive results. According to Lux Research, while active semiconductor materials garner wide attention in solar technologies, the lesser-known non-active materials significantly impact module efficiency, and account for 15% to 48% of module manufacturing costs. It was revealed that new non-active materials that can lower the overall cost per watt ($/W) of module manufacturing costs will be required. It added that thin-film modules see greater margin potential, but longer development cycles. Non-active materials comprise 36% to 48% of standard thin-film module manufacturing costs. New entrants with improved non-active technologies will have a greater edge in thin-film than in x-Si. The caveat: longer development cycles.

With the rapid growth in the PV industry, many companies are now coming up with fresh ideas and evaluating new materials.

> "Non-active materials comprise 36% to 48% of standard thin-film module manufacturing costs."

"Encapsulation is one where we feel there are a number of excellent potential solutions in the works. The key issue is proving reliability. Panels need to last 25-30 years under a wide range of environmental conditions and so a significant amount of data must be generated before a new technology can be adopted. That is why Applied built the SunFab Module Reliability and Test lab in Xi'An, China. This lab enables us to screen a variety of new materials and device designs under highly accelerated environmental conditions", said Cushing.

NREL's Dr. Ullal agreed that non-active materials are an important component of the cost structure for all PV technologies, such as encapsulations/packaging, Al frames and mounting structures. A lot of the future cost reduction for PV modules will come from the non-active materials, he said.

According to Dr. Ullal, PV companies that do not make a reliable PV product that will last 25 years in the field and meet the companies' warranties of 80% of rated module performance at the end of 25 years may not survive in the long term. There is a huge amount of development work underway to reduce the cost of non-active materials that contributes directly to cost-reduction of PV modules, he said.

Progress

For some time now, it has been highlighted that thin films must be less expensive at the module level to compensate for lower efficiency as more area, be it on the ground or on the roof, and more balance-of-system (BOS) is required to attain the same efficiency reached by most crystalline technologies. For instance, the costs for the supporting structures, DC cabling and inverters (power conditioning units – PCU) are higher than for c-Si modules.

> "Thin films must be less expensive at the module level to compensate for lower efficiency."

Efficiency is one of several components that affect total system cost, says Cushing. He also shared that his company has taken an integrated system-level approach to driving down these costs. One example of this approach is the module architecture including size, mounting and technology. The 5.7m^2 size of the panel maximises the number of watts installed per module, which significantly decreases labour time and cabling requirements. In addition,

Figure 1. Solarion AG's foil-based solar cells.

a back rail is bonded directly to the module in the factory. This further saves installation time in the field and reduces the number of BOS components required. The technology, thin-film silicon, has the added value of generating more energy-kWh per rated kW compared to c-Si due to the lower temperature coefficient. This integrated solution lowers total BOS costs and increases energy out which effectively offsets the 'penalty' due to the lower efficiency.

Phoenix Solar's Bächler mentioned that due to the significant price reductions in c-Si modules, thin-film module prices came under pressure. For some of the thin-film module manufacturers, the price reductions required by the market had been higher than the cost savings they could achieve due to improvements in manufacturing process and efficiency increase – i.e. they are facing lower than expected gross margins. But the same is also true for many c-Si manufacturers, he added.

Thin-film technology companies acknowledge that customers and project developers are getting more sophisticated, and are increasingly looking beyond cost-per-watt of solar modules to LCOE as a key buying criterion.

"This is a better measurement of the cost of energy from a particular system, measured by the energy yield and all the costs over its lifetime. We can compete on LCOE, even with low-priced Chinese poly", said Guha. Citing an example, he said, "When applied to an existing rooftop, our costs can be anywhere from 30-70c/watt below most polysilicon systems, and compared to our competition, our laminates have a proven capability to generate more energy per rated watt in real-world conditions. Having lower total installed costs and higher energy yield makes us competitive on an LCOE basis while continuing to offer features and benefits that glass panel products can't match".

Leipzig, Germany-based Solarion's sales and marketing director **Stefan Nitzsche** pointed out that there has been a reduction in BOS costs but that this rate was not as extensive as the module price decrease.

> "Customers and project developers are getting more sophisticated, and are increasingly looking beyond cost-per-watt of solar modules to LCOE.

"But the component suppliers are doing a good job and they are continuously improving that. A lot of potential is also in the mechanical and electrical design of the module. Considering the larger area required for less efficient [thin-film] modules the system price per installed kW has to be somewhat lower than for c-Si systems. Especially for large PV installations, the valuation of the system is not done by the module power alone; the trend is going to a performance ratio valuation of the entire system", said Nitzsche.

Manufacturing

Some companies highlight that although a-Si, like CIGS, can be deposited on a flexible substrate, its conversion efficiency, which already is generally much lower than that of CIGS, measurably degrades when it is exposed to ultraviolet light, including natural sunlight. To mitigate such degradation, manufacturers of a-Si solar cells are required to implement measures that add cost and complexity to their manufacturing processes.

According to United Solar Ovonic's Guha, this is really a myth. He says while amorphous silicon products show initial degradation on exposure to light, the efficiency stabilises after only a few hundred hours.

"Most manufacturers rate their product at the stable value, that is after the product has 'settled in' and is producing electricity at a consistent rate," commented Guha. "Regarding deposition of CIGS on flexible substrates, apart from demonstrating good production yield using the roll-to-roll deposition, degradation

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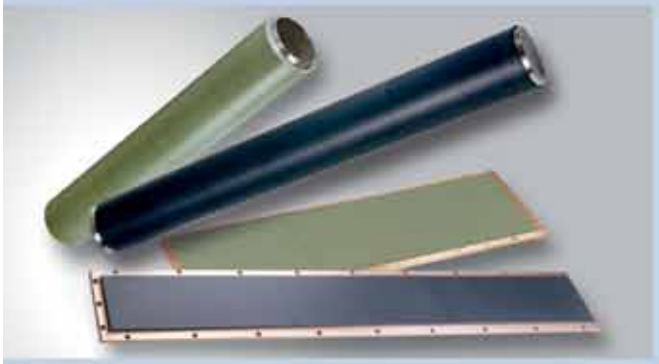

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Figure 2. Solarion's low-cost roll-to-roll manufacturing technology.

caused by moisture ingress is a big issue. Many companies are working to develop a moisture-barrier coating, but price and availability are not yet clear".

In order to further reduce the manufacturing cost of PV modules, Guha's company has pioneered the development of and has the fundamental patents on a unique approach utilizing proprietary continuous roll-to-roll solar cell deposition processes.

Elaborating on this development, Guha said: "We deposit the triple-junction amorphous silicon solar cell using an automated processor that takes six rolls of stainless steel, each 1.5 miles long, and deposits nine miles of solar cells on 6 rolls of stainless steel in 60 hours. We have built several generations of roll-to-roll processors, and have now perfected the process to obtain great uniformity, consistency and yield. Looking ahead, we are working on new manufacturing advancements that could substantially improve the product throughput from our existing lines and decrease our costs".

It is said that historically, manufacturers have formed PV modules by manufacturing individual solar cells and then interconnecting them.

In the roll-to-roll approach, manufacturers typically cuts cells from the finished substrate, complete thermal processing, and then cells are then assembled together, says Cushing. Further work is being done to come up with fully-automated roll-to-roll manufacturing solutions. "Thin-film technology deposited on glass already has the advantage of fully integrated processing. The manufacturing process uses laser scribe lines to create interconnected cells from the absorber and metal layers. This means that there is no extra interconnection step", added Cushing.

Solarion is using a proprietary coating technology for the deposition of the CIGS absorber based on a low-cost roll-to-roll process (see Fig. 2). Nitzsche declined to give details of the cost structure. However, he shared that the company process is a very competitive one.

"We have less energy consumption, better materials usage, higher process speeds and better process control than conventional CIGS evaporation technologies. This enables us to achieve appropriate efficiencies at lower deposition temperatures while using a plastic substrate. The insulating substrate enables us in the future to make monolithically integrated devices which decreases costs and increases product reliability", said Nitzsche.

"Furthermore, our roll-to-roll process drives down our capex requirements to set up a plant. A big advantage will be to get rid of the glass. To make flexible modules with a conversion efficiency of about 10% drives costs down dramatically... A flexible product allows for a significant decrease in system costs because for certain applications separate subconstructions will not be necessary anymore", Nitzsche added.

Going forward

First Solar has already demonstrated that their thin-film manufacturing cost is down to $0.85/watt and NREL's Dr. Ullal is confident that other thin-film companies will follow once they have economies of scale of installed production, and comparable module performance. First Solar says most of the conversion efficiency and cost initiatives are event-driven rather than time-driven.

Dr. Ullal says this might be true to some extent. He explains that a good example of this is the oversupply of polysilicon feedstock material which has driven down the cost of silicon modules by almost 50% in the last year.

Dr. Ullal says there is a lot of price pressure on thin-film PV technologies to drive down the cost of their modules. These price reductions will come from improving performance (efficiency of the modules), yield (electrical and mechanical), up-time, throughput and capital expenditure in the manufacturing lines. Other factors that affect cost are standardisation of processing equipments, capability of equipment to produce state-of-the-art efficiency modules, long-term supply chain contracts with vendors, etc. In addition, it is also important to work with countries and states that give you preferential incentives in terms of land, taxes (extended period of tax holidays), etc.

> "The challenge is finding out how to drive down cost in the overall supply chain."

From Applied's perspective, Cushing says while many companies are focused only on how to reduce cost at the module level, his company is looking at it from the systems level. The challenge is finding out how to drive down cost in the overall supply chain – from raw materials to installation and ultimately energy out. Material choices, mounting methods, and energy yields are examples of ways to drive down cost beyond pure production cost.

Guha says his company has made excellent progress over the past two years, and still has a lot of opportunity to reduce costs further.

"Our manufacturing cost-per-watt declined 12% in the fiscal first quarter as compared to the average for the full fiscal year 2009. When we are operating at our 150MW nameplate capacity, we expect to get our cost-per-watt down to about $1.50, and we have a path to get to about a $1/watt," concluded Guha.

About the Author

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