This paper first appeared in the tenth print edition of *Photovoltaics International* journal, published in November 2010.

Despite multiple challenges, the maturing thin-film PV sector looks set to increase market share

Shyam Mehta, GTM Research, San Francisco, California, USA

ABSTRACT

The three most viable thin-film photovoltaic technologies – cadmium telluride (CdTe), copper-indium gallium (di) selenide (CIGS), and amorphous silicon (a-Si) – continue to mature and grow technologically and in market stature. But apart from the dominance shown by CdTe leader First Solar, the rest of the TFPV manufacturers have had a fairly difficult time making significant commercial inroads as the price of mainstream crystalline-silicon modules plummeted over the past couple of years. Other factors delaying the long-predicted age of thin film include bankability challenges and difficulties in reducing production and system costs. Yet entrants in all three thin-film categories have reason for optimism, as they push toward a competitive market position. This paper provides an overview of the current status of the thin-film PV sector and its players, offering insights into why certain companies might emerge successfully in the years ahead.

Introduction

With a few notable exceptions, there is little doubt that after the growth and promise shown in 2008, the past year or so has been difficult for thin-film PV companies. There are three main reasons for this: polysilicon/crystalline-silicon module price drops, bankability challenges, and cost reduction difficulties.

Crystalline silicon price drops

Much of the value proposition of thin-film technologies rests on the price and availability of polysilicon for PV, and it was in this context that thin-film technologies emerged as an attractive proposition. Near-term feedstock availability for thin films is not an issue, meaning they could be deployed to fill the supply-demand gap resulting from the lack of polysilicon. Moreover, the high cost of polysilicon has made thin-film economics all the more favourable. The relative abundance and cheapness of polysilicon through 2009 therefore reduced the value proposition of thin-film technologies by eroding their cost advantage significantly, making life especially difficult for many thin-film manufacturers that had not ramped up manufacturing sufficiently to achieve cost gains from economies of scale.

Figs. 1 and 2 illustrate the pace at which c-Si pricing changed and the pricing and cost pressure that thin-film PV faced in 2009 as a consequence. Asian c-Si module prices in the fourth quarter of 2008 were in the US$3.50/Wp range; based on efficiency and performance differences, this meant that fair prices for representative CIGS and CdTe efficiencies were over US$3.00/Wp, while single-junction a-Si could sell at US$2.05/Wp. In nine months, Asian c-Si compression to US$2.25/Wp necessitated a 35% drop in thin-film prices, a required reduction for

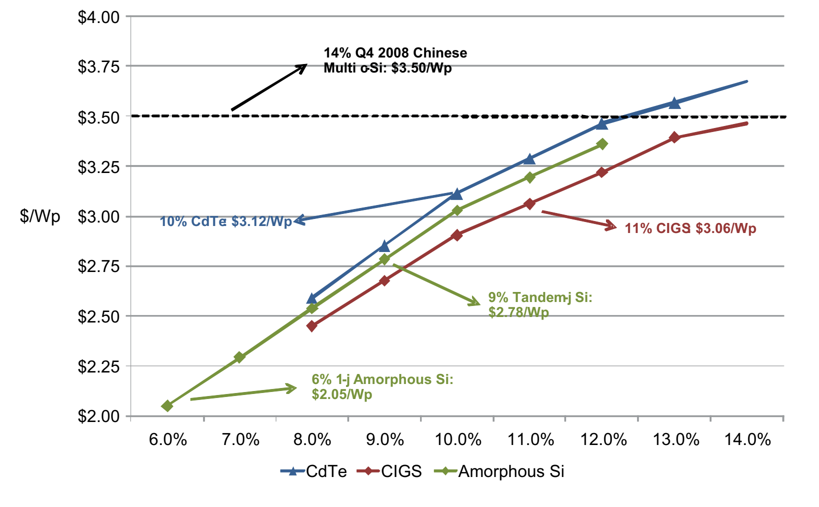

Figure 1. Effect of efficiency, BOS and performance on required module price (Q4 2008).

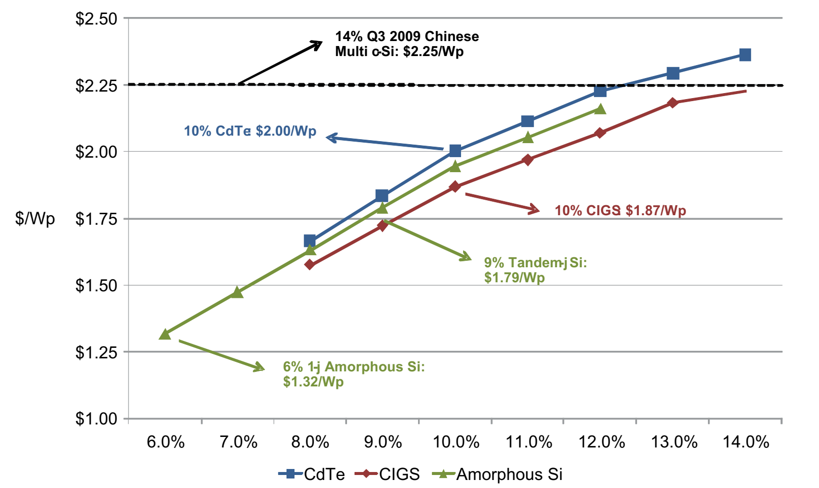

Figure 2. Effect of efficiency, BOS and performance on required module price (Q3 2009).

which most thin-film firms were completely unprepared. Single-junction amorphous silicon, for example, would have had to sell for US$1.32/Wp, at or below cost for most producers at that time. Even First Solar was not immune to crystalline-silicon price drops, as it was forced to introduce a rebate program in Germany for installed panels in order to preserve market share and maintain demand for its modules. To make matters worse, many less-established manufacturers were forced to offer further discounts to reflect the greater perceived risk associated with thin-film projects due to the bankability/risk factor.

Bankability challenges

The term 'bankability' refers to a project's ability to obtain financing. The credit crisis of 2007 and 2008 means that capital today is both scarce and expensive, which has forced lenders to be much more risk-averse than previously with respect to which projects they choose to finance. In other words, the projects that receive capital are those with the lowest risk profiles. Technology components comprise roughly 85% of a PV project's cost – of which the module comprises roughly 50%, which means that the module represents the largest cost component of a PV project. This has placed the module manufacturers under special scrutiny from banks, in two important respects:

- **Financial/balance sheet risk**. Since module warranties last for 20–25 years, it is essential that the module manufacturer be available during that time in order to honour its warranty. The long-term financial health of the company and the strength of its balance sheet come under the microscope here.
- **Technology/process risk.** Combining questions of risk with scarce, expensive capital means that banks have begun to exert their desire to control the technology. The long-term durability and performance (i.e., energy output) of the module in the field and the robustness of process flow of the manufacturer (to ensure consistent module quality) are of greatest concern in this respect.

The confluence of both these factors has resulted in many banks (particularly in Europe) passing on thin-film projects in favour of relatively less risky c-Si projects. On one hand, many thin-film manufacturers were formed relatively recently and have precious little to show in the way of sales and operating experience, meaning that their long-term financial viability is under question. Secondly, CdTe, CIGS and tandem-junction a-Si modules have not been deployed in the field for the full 20–25-year operating lifetime; in the case of CIGS, widespread operating data do not even exist for 5- or 10-year periods.

Consequently, banks have a perception of risk regarding the degradation (and thus the performance) characteristics of these modules, especially given the higher degradation rate of thin film as established by accelerated lifetime tests. Even single-junction amorphous Si, for which reliable system operating data exist, is not exempt, as lenders closely scrutinize the manufacturing process flow and control to ensure product consistency and durability. By contrast, c-Si generally offers a lower risk profile, since many companies in this space have been in business for more than a decade: the technology has a well-established manufacturing process, and field data are widely available. In fact, some c-Si projects built in the mid-1980s are still operating within their expected performance range.

The concern that thin-film companies may not be around to honour their warranties can be addressed using a simple solution: insurance can be offered for the warranty beyond the statutory warranty period (24 months in most of Europe and the U.S.), also known as a product guarantee cover. While this may add to module costs, the economic security obtained makes a huge difference when it comes to finding project financing, undercutting incumbents' advantage in this department. So far, Signet Solar, QS Solar, and NexPower (all a-Si companies) have been early adopters of this approach, and more are expected to follow. For all of these companies, insurance was provided through a combination of a regional industrial insurer (Marsh, in this instance), which is in turn reinsured by a globally established reinsurer (Munich Re). It must be stressed that by no means is the availability of a guarantee cover a given; the module vendor in question has to pass rigorous due diligence to qualify for the product.

Cost reduction issues

The challenges faced by thin-film players were also compounded by their limited ability to reduce costs during this time, largely for two reasons. One, the lack of bankability for most producers meant they were restricted to producing a few megawatts of product a month, which did not allow them to reach economies of scale and thus reduce their unit costs. It was not until late 2009, when bankable supply had been exhausted, that sufficient demand existed to help those players who had reached 30MW-plus scale to improve costs (and margins) meaningfully. Second, many new firms (especially CIGS and a-Si turnkey producers) continued to encounter technical snags in process control and optimization, particularly with yields and throughputs, which also restricted a meaningful commercial ramp.

"Overall, most thin-film players are still some distance away from being competitive with low-cost c-Si production on an efficiency-adjusted basis."

Overall, most thin-film players are still some distance away from being competitive with low-cost c-Si production on an efficiency-adjusted basis. With demand strength keeping utilizations high and continuous progress being made in terms of process optimization, 2010 and 2011 will be proving grounds for thin film, as it will become clear exactly which producers will have been able to execute on the more aggressive cost targets that a low-cost c-Si world dictates.

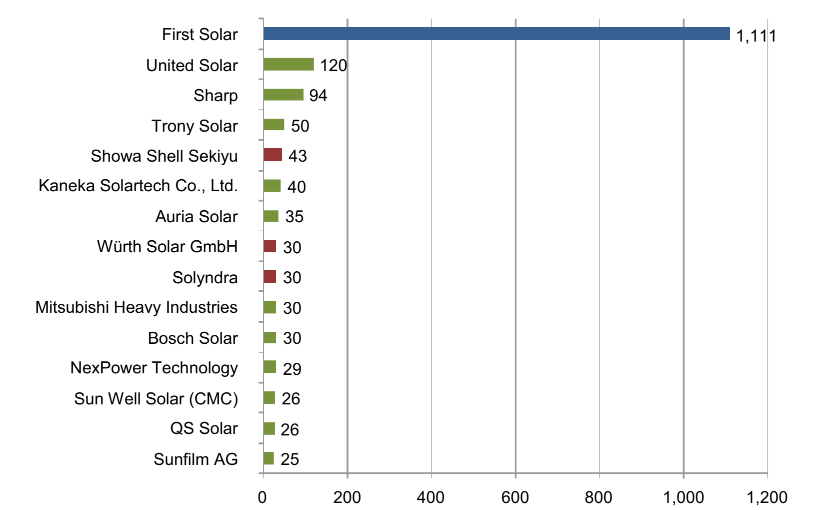

Figure 3. Top 20 thin-film firms by 2009 cell production (MW DC).

Top producers

Fig. 3 displays the top 15 thin-film producers in 2009. It should be noted that, with the exception of First Solar, less

Firm	Location	2009 Production (MW)	YE 2010 Capacity (MW)	Module Efficiency	Recent Developments
First Solar	Germany, US, Malaysia	1011	1341	11.2%	Reduced module cost to $0.76/Wp; expanding module capacity to 2.5 GW by YE2013; purchased U.S. developer NextLight in Apr 2010; U.S. project pipeline at 2.2 GW now
Abound Solar	US	4	100	10.0%	Obtained loan guarantee worth $400M from U.S. Dept. of Energy; will use to expand capacity
Calyxo GmbH	Germany	1	25	9.0%	Book value on Q-Cells balance sheet written down from EUR 77M to EUR 46M; looking to expand to 135 MW in 2011, but financing remains a question
Solexant	US	0	0	n/a	Competed 2 MW pilot line; raised $41.5M in Series C funding in June 2010; will receive further $44M from Oregon state; planning on constructing 100 MW facility in 2011
Primestar Solar	US	0	13	n/a	Plant to launch modules in 2011; GE is majority shareholder and public supporter of CdTe

Table 1. Key CdTe manufacturers and current status.

than 50% of thin-film production in 2009 was actually shipped and deployed in the field; this was indeed the case with the second-largest producer on the list, U.S.-based United Solar, with 120MW (actual shipments were around 71MW). United Solar is followed by Sharp (94MW), China-based Trony Solar (50MW), and CIGS-based Solar Frontier, formerly known as Show Shell Sekiyu K.K.

Eleven of the top 15 firms are amorphous silicon-based; most of them are small or midsized players that produced between 20-40MW in 2009. Three are CIGS firms (Solar Frontier, Würth, and Solyndra), and First Solar is the only CdTe name on the list. Notably, only five companies are Chinese or Taiwanese in origin, indicating that the region has yet to establish the kind of dominance it enjoys in c-Si manufacturing.

Cadmium telluride

Cadmium telluride is at once the most and least successful thin-film technology. It is the most successful because it is still the only technology to have been successfully commercialized at multi-hundred-megawatt scale, a feat accomplished by U.S.-based First Solar, which produced a world-record 1.111GW of modules in 2009. On the other hand, CdTe has by far the least representation in terms of the number of firms pursuing it as a preferred technology. As an indication of this skewed state of affairs, non First-Solar CdTe production in 2009 was only 5MW.

At this point, CdTe remains largely synonymous with First Solar. In terms of the company's recent progress, significant developments have been achieved on multiple fronts. These are summarized below:

- **Production and capacity.** With 1.1GW of modules sold in 2009 (compared to 504MW in 2008), First Solar emerged as the biggest selling module vendor

Firm	Location	Substrate	Manufacturing Process	2009 Production (MW)	YE 2010 Capacity (MW)	Module Efficiency	Target Market					Recent Developments
							Residential	Commercial	Utility	BIPV	Off-grid	
Avancis	Germany	Glass	sputtering and selenization	6	80	11.0%	v	v				Announced construction of second plant by BOY 2012, 100 MW capacity; achieved efficiency of 15.1% fully encapsulated module
Global Solar	US, Germany	Metal foil	coevaporation, roll-to-roll	10	76	10.0%	v	v		v	v	Dow to use Global's cells in development of CIGS solar shingles; product release in 2011. Already produces flexible modules for portable applications
Miasole	US	Metal foil	sputtering, PVD & roll-to-roll	4	60	10.5%		v	v			Supply agreements worth 12 MW signed with juwi, Phoenix Solar for 2010; expects to ship 22 MW in 2010
Nanosolar	US	Metal foil	printing, rapid thermal processing	5	80	9.0%			v			12 MW annual run-rate in 2009; shipping product to multiple customers in 2010; still in initial stages of commercial production
Odersun	Germany	Copper tape	roll-to-roll on copper tape	3	25	10.0%	v	v		v		Shifting focus to flexible modules for BIPV market and customized products
Solar Frontier	Japan	Glass	sputter & selenization	43	80	12.2%	v	v	v			Constructing 900 MW fab in Japan; expects to have 600 MW capacity online by EOY 2011
Solibro GmbH	Germany	Glass	coevaporation	14	135	12.6%	v	v	v			Expects to reach costs of EUR 0.80/Wp by EOY 2010; produced 25.5 MWp in H1 2010
Solyndra	US	Glass	coevaporation	30	110	9.7%		v				Canceled announced IPO but raised $175M in convertible debt; secured 16.2 MW in PPA sales to Southern California Edison in July 2010 Closed first factory in Q4 2010 citing lack of cost competitiveness, reduced 2013 capacity target from 610MW to 285–300MW
Stion	US	Glass	Two-stage sputtering process; pursuing double-junction CIGS/chalcopyrite module in 2011	0	10	11.8%	v	v	v		v	Received $70 MW in Series D round, $50M from Taiwan Semiconductor, who will also assemble modules; expanding to 100 MW
Würth Solar GmbH	Germany	Glass	multi-source evaporation	30	45	12.6%	v	v	v	v	v	Begins to license production technology; downstream-integrated into systems sales, integration, development, EPC, and operation; divisions brought 10.9 MW system to completion

Table 2. Leading CIGS manufacturers and current status.

across all technologies. Production in 2010 is expected to be around 1.4GW and more than 2.1GW in 2011. The company's capacity has been sold out for 2010 since the beginning of the year, as it sells most of its modules through long-term contracts. At this point, First Solar's modules have been established in the market as reliable and bankable.

- **Efficiency.** Consistent progress was also made on the efficiency front: module conversion efficiency has increased from 10.9% in Q2 2009 to 11.2% in Q2 2010, reaching 11.3% in Q3 2010.
- **Costs.** Manufacturing costs also decreased by 13% over the last four quarters, from US$0.87/Wp in Q2 2009 to US$0.76/Wp in Q2 2010 (with a rise of one cent to US$0.77 in Q3 2010).
- **U.S. utility-scale development.** First Solar continued to expand its EPC/project development business in the U.S. utility-scale market in 2009 and 2010. First, it acquired a-Si producer Optisolar's 1.9GW pipeline, which included a 550MW power purchase agreement (PPA) with California utility PG&E. It also secured development rights to two projects totalling 550MW for SCE (another utility in California), as well as a contract for the construction of a 22MW plant in New Mexico. In April 2010, it acquired U.S. developer Nextlight, bringing its total utility-scale pipeline of projects in the U.S. to 2.2GW. At this point, First Solar and SunPower are the only PV companies to have integrated downstream with clear success.

Table 1 lists the most important manufacturers of CdTe. There are four other firms besides First Solar that merit attention: U.S.-based Abound, Solexant, and Primestar, and Q-Cells subsidiary Calyxo. At the moment, only Abound is producing modules in commercial quantities, and a US$400 million U.S. federal loan guarantee is expected to be used to fund the company's expansion beyond the 100MW capacity mark. Module efficiencies range from 9% (Calyxo) to 11% (First Solar). 2011 could be a very significant year for CdTe, with Abound expected to ramp into 50MW-plus production, and commercial shipments promised by a number of other firms on the list. Given the constant delays experienced by many thin-film firms, however, this cannot be taken for granted.

> "Most firms are still in the process of bringing their first major (non-pilot) facility online, or have recently done so and are ramping up production."

One advantage that CdTe companies have over other thin-film firms is that they are considered safer and thus more bankable than other technologies, thanks to First Solar's success, the availability of four to five years' worth of operational data for First Solar projects, and producers that can employ a blend of First Solar and other CdTe modules in projects to de-risk output. This is an important benefit for producers such as Abound, and it remains a key factor in developing market traction.

Copper indium gallium (di)selenide

Claims of low-cost, high-throughput manufacturing at crystalline silicon-like efficiencies have created much hype around CIGS over the last three years, making it the beneficiary of billions in venture capital investment. While CIGS was supposed to break into large volume manufacturing in 2007 and then again in 2008, producers have not had an easy time of it, being plagued by yield, efficiency, and throughput issues. Progress so far has been steady rather than spectacular.

Table 2 lists the 10 most important CIGS producers in the market today, with key information and recent developments; the U.S. and Germany are home to all but one of these firms. Although sputtering and coevaporation are the two most commonly-used absorber-layer deposition processes in the CIGS space, the specifics vary greatly across producers and form the basis of intellectual property and competitive advantage in the sector. Glass is the most popular substrate and is associated with higher-efficiency modules; however,

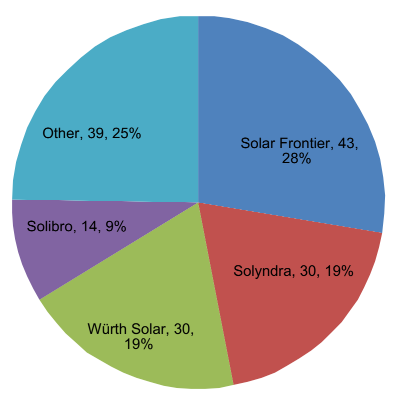

Figure 4. CIGS cell production for 2009 (MW DC).

a few companies (e.g., MiaSolé, Nanosolar, Global Solar, Odersun, SoloPower) are pursuing deposition on flexible metal substrates, which allows for a high-speed roll-to-roll process, though in most products made by these firms, the cells are still finally encapsulated in glass-glass packaging. Overall, most firms are still in the process of bringing their first major (non-pilot) facility online, or have recently done so and are ramping up production, which signifies that major hurdles in process control have been crossed.

It is interesting to note the wide variation in the types of markets these companies are targeting. Some, such as Solyndra and Nanosolar, are single-mindedly focused on a specific market (large commercial rooftop and utility-scale ground mount, respectively). Others, like Global Solar and Odersun, produce products for a variety of applications but have shifted focus to off-grid and BIPV modules given their high cost structure. Finally, there are a few that maintain the traditional grid-connected focus (residential/commercial/utility-scale), such as Solibro, Solar Frontier, and Stion. It will be interesting to see which product designs are better suited for different applications, especially in the commercial segment, where almost every company wants to participate. Although dedicated products (such as Nanosolar's Utility Panel) may have the edge in specialized markets, First Solar's success with a standard module design for all grid-connected applications proves that this is not necessary.

Fig. 4 breaks down 2009 CIGS production by manufacturer. The top four firms make up almost three-quarters of the 156MW of modules made in 2009, and most CIGS firms produced to sub-10MW levels. Still, the production numbers are notably higher than 2008, and three of these four (Solar Frontier, Solibro, Solyndra) will produce more than 50MW in 2010.

Fig. 5 indicates CIGS module efficiencies for the 15 CIGS manufacturers in commercial production. In 2008, the top CIGS module efficiency stood at 11.5% (Würth Solar) and 11 firms had module efficiencies of 9% and above; today these metrics stand at 12.6% and 14, respectively, indicating that manufacturers have made definite progress in boosting efficiencies. Of the deposition processes, thermal evaporation has yielded the best commercialized results so far (12.6% for both Würth and Solibro), although sputter-based Solar Frontier says it will be selling 12.2% modules in January 2011, indicating that the firm is not too far behind. At this rate, it is not inconceivable that CIGS efficiencies could soon catch up with those of traditional multicrystalline silicon, which has module efficiencies of around 14.3%.

Amorphous silicon

The business case for investment in amorphous silicon acquired significant momentum in 2007 and 2008, during the era of scarce and exorbitantly-priced polysilicon. Unlike its crystalline cousin, feedstock (silane) utilization was relatively insignificant, meaning that raw material availability was not much of a problem. In addition, unlike CIGS and CdTe, a-Si was already a relatively mature technology; companies like Sharp, Mitsubishi Heavy Industries, and flexible laminate producer United Solar had been shipping product for a few years. With ready-made manufacturing lines available, barrier to entry was low, meaning a producer could cash in on the then-current boom immediately. While manufacturing costs were still higher than US$2.00/Wp for most (aided by equipment costs of US$2.50/Wp to US$3.00/Wp), cost pressure was low in a supply-constrained market with high c-Si prices. If product could be made, it could be sold. The result was dozens of new entrants to the market, many of them purchasing turnkey equipment from numerous vendors.

The situation changed dramatically in 2009, as sharp c-Si price drops put most producers under heavy margin pressure; in the blink of an eye, a single-junction module that could easily fetch more than US$2.00/Wp had to sell for US$1.40/Wp to be competitive. Few a-Si manufacturers were then in a position to compete with the incumbent heavyweights, i.e., First Solar and Asian multicrystalline silicon. Combined with lower bankability relative to crystalline Si, this hit production and shipments hard; as of February 2010, for example, a mere 30MW of modules from Applied Materials had been installed. Compared to 2007 and 2008, when more than 40 firms entered the a-Si market, new orders for equipment almost completely dried up in 2009 and 2010, with only four firms purchasing equipment (all from Swiss vendor Oerlikon).

> "Low module margins for a-Si may necessitate movement downstream as a means of capturing the system/power purchase agreement margin."

Given these difficult circumstances and the sheer number of relatively undifferentiated and uncompetitive manufacturers in the space, some of whom had little previous experience or knowledge of PV, it was inevitable that casualties would occur. Table 3 lists recent market exits in the a-Si space; the highest-profile of these was equipment giant Applied Materials' decision to cease selling its SunFab turnkey line to new customers in July 2010. Along with Applied, three of the tool firm's customers also faced a struggle for survival, with German companies Sunfilm and Signet Solar declaring insolvency and Suntech Power ceasing production from its 50MW line.

The constant flow of bad news associated with a-Si companies has given the technology a negative image in general, and many observers do not consider

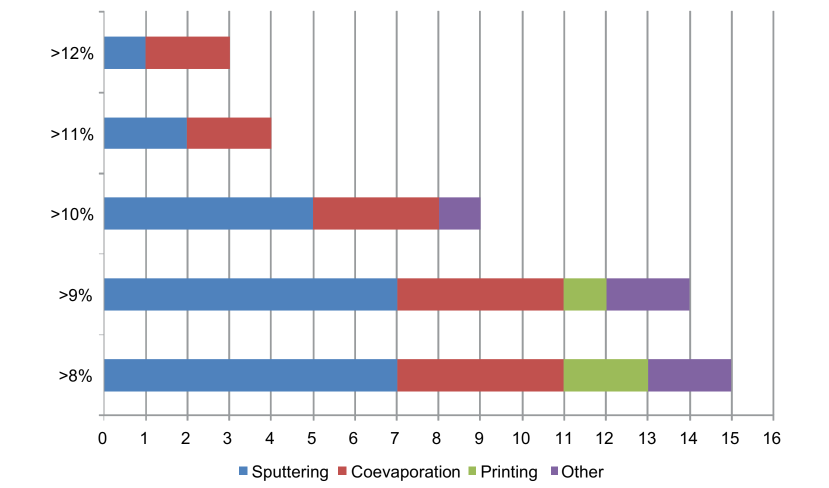

Figure 5. Number of CIGS firms by manufacturing process and efficiency.

Date	Firm	Equipment Vendor	Description
Apr 2010	Sunfilm	Applied Materials	Merged entity of Sunfilm and Sontor (Q-Cells subsidiary) w/total tandem-junction capacity of 145 MW; aiming to restructure and find new investors
Mar 2010	EPV Solar	Self	Equipment vendor and module producer filed for bankruptcy, reports of poor capital management
Jun 2010	Sanyo ENEOS	Self	Proposed JV b/w Sanyo and Nippon Oil to produce tandem-junction Si modules; canceled before commercial production began; cited c-Si price drops; employees returned to parent companies
Jun 2010	Signet Solar	Applied Materials	Single-junction producer w/20 MW capacity; aimed to obtain loan guarantee from U.S. Dept. of Energy for construction of U.S. fab; claims delinquent payments from customers; looking for new investors
Jul 2010	Applied Materials Sunfab	Self	Forced to discontinue sales of Sunfab to new customers; focused on selling individual tools to customers, continue selling to existing customers and research into thin-film
Aug 2010	Suntech Power	Applied Materials	Ceased production from 50 MW Sunfab line; costs likely not competitive; lack of commited resources also likely

Table 3. Recent market exits in a-Si PV.

its prospects bright. With more than 50 a-Si producers in the space, it would be unwise to write off the technology altogether; indeed, many firms have made significant progress on a number of fronts in recent months. Table 4, which profiles the most important a-Si producers in the world today, brings some of these accomplishments to light.

A clear trend is the shift from single- to tandem-junction as the representative technology. Most firms on the list are focused on the development and production of 9%+ modules; one firm (Sharp) has already breached that barrier. Interestingly, only two firms (ENN Solar and Tianwei SolaFilms) have opted for a complete turnkey solution from equipment vendors (Applied and Oerlikon, respectively), while the others have purchased individual tools from vendors, or have developed equipment internally. In a way, this is not surprising; one expects a high correlation between customers that bought turnkey lines and their competence (or lack thereof) in thin-film manufacturing.

An increasing number of a-Si companies, in contrast to their c-Si competitors, have integrated downstream into system sales, integration, and development. Partly, this has to do with the fact that after Germany, the biggest market for Chinese a-Si companies is China itself, where the lack of sophisticated developers makes it necessary for many module companies to enter into development. This may also be a good technology fit for downstream services when one considers that balance-of-systems (BOS) costs for a-Si are the highest of all technologies, meaning that a great deal of value can be added by owning installation and BOS segments. Moreover, low module margins for a-Si may necessitate movement downstream as a means of capturing the system/power purchase agreement margin; a-Si's real benefit is its kilowatt-hour per kilowatt performance advantage,

Firm	Ownership	Technology	Location	Equipment Vendor	2009 Production (MW)	YE 2010 Capacity (MW)	Module Efficiency	Recent Developments
Astronergy	Subsidiary of Chint Group (player in low-voltage electrical, power T&D industries in China)	a-Si/µcSi	China	Oerlikon/Self	8	75	9.0%	Claims will be at $0.71/Wp manufacturing cost by BOY 2011; providing system sales/installation/development services
ENN Solar	Spun out of natural gas company XinAo Group in November 2007; co-founded with ENN Group, a diversified clean energy company with $3 billion in revenue in 2008	a-Si/µcSi	China	Applied Materials	4	70	9.2%	Entered into systems integration/development; won bid to supply modules for 5-MW plant in Inner Mongolia
GS Solar	Private	a-Si (2)	China	Self	11	108	8.0%	Plans to construct 130 MW plant by 2011; offers production plant operating services; proprietary equipment design company, Apollo Solar, is publicly traded on HK Exchange
Inventux Technologies AG	Private	a-Si/µcSi	Germany	Oerlikon/Self	22	33	9.2%	Increased commercial efficiency from 8.9% to 9.2% in 2010; launched value-added services segment; running at full utilization in H1 2010
NexPower Technology	Subsidiary of IC Foundry, UMC Group	a-Si/µcSi	Taiwan	ULVAC	29	100	9.0%	Introduced product guarantee cover (i.e. module warranty insurance) in 2009, through Marsh and Munich Re
QS Solar	Subsidiary of Qiangsheng (QS) family of companies, which was founded in 1993 as an industrial manufacturer	a-Si (2)	China	Undisclosed	26	200	6.0%	Introduced product guarantee cover through Munich Re; entered EPC/project financing/development; expects to be at 500 MW capacity by EOY 2010
Sharp	Subsidiary of Sharp Co.	a-Si/µcSi	Japan	TEL/Self	94	320	10.0%	Began volume production out of 160 MW Sakai fab in Mar 2010; 10% module in production. Looks to sell 1 MW+ utility-scale systems in 2011
Tianwei SolarFilms Co.	Affiliate of the Tianwei Group, a state-owned international high-tech company with more than 50 years experience in the energy industry and the world`s biggest transformer supplier.	a-Si	China	Oerlikon	13	47	6.4%	Placed upgrade order with Oerlikon to switch over to 75 MW tandem-junction in 2011
Trony Solar	Private; investors include Intel Capital	a-Si (1)	China	Self	50	205	6.0%	Manufacturing cost of $1.09/Wp in July 2009; attempting to launch IPO on hong Kong Stock Exchange in 2010

Table 4. Key a-Si manufacturers and current status.

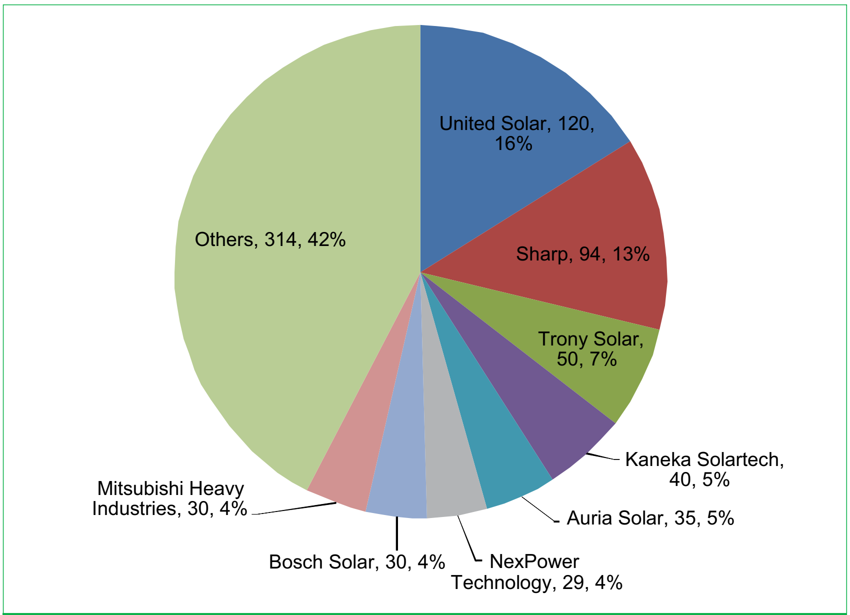

Figure 6. Amorphous-silicon cell production in 2009 (MW DC).

which is difficult to incorporate into a module price for an undiscerning buyer.

In the cases of Astronergy, ENN, QS Solar, and Sharp, this performance benefit is recognized and made possible by the existence of a large corporate parent with the balance sheet and reputation to leverage in the downstream business, particularly when it comes to the cost of financing. The protection afforded by a corporate parent is a definite source of differentiation and competitive advantage in this space.

Fig. 6 displays the largest a-Si producers in 2009. United Solar, Sharp, and Trony hold the top three positions, followed by Kaneka Solartech (Japan) and Auria Solar (Taiwan). Again, only one single-junction producer (Trony) makes the top eight. The fact that these eight players make up only 58% of production is an indication of just how crowded and fragmented the space is, which, along with the fact that many producers share the same equipment vendor, makes this space ripe for further consolidation.

Outlook

The thin-film sector should continue to increase its share of the overall photovoltaic market share over the next several years, going from 20% in 2010 to more than 26% in 2013. Thin-film module production will more than double, rising from an estimated 3.2GW in 2010 to more than 6.7GW in 2013. Revenues from companies in the sector are forecast to grow from US$4.8 billion to US$6.3 billion during the same period. Conversion efficiencies for the three main thin films will continue to improve, with CdTe expected to reach at least 12.4%, coevaporated CIGS 14%, sputtered CIGS 12.8%, and tandem-junction a-Si 11.3% by 2014. In a forward-looking analysis of the top 15 firms ranked in terms of projected efficiency/bankability-adjusted module cost in 2012, five of the companies come from the thin-film ranks, led by First Solar in the number-one slot, and Solar Frontier, Solibro, and Sharp occupying the eighth, ninth, and tenth positions, respectively.

Fig. 7 shows best-in-class module manufacturing costs by technology and region for 2012. As can be seen from the graph, First Solar will remain the cost leader for CdTe, and will continue to lead other manufacturers by a fair distance, but the best CIGS and amorphous silicon firms (Solar Frontier and Sharp, respectively) are expected to have costs under US$0.85/Wp.

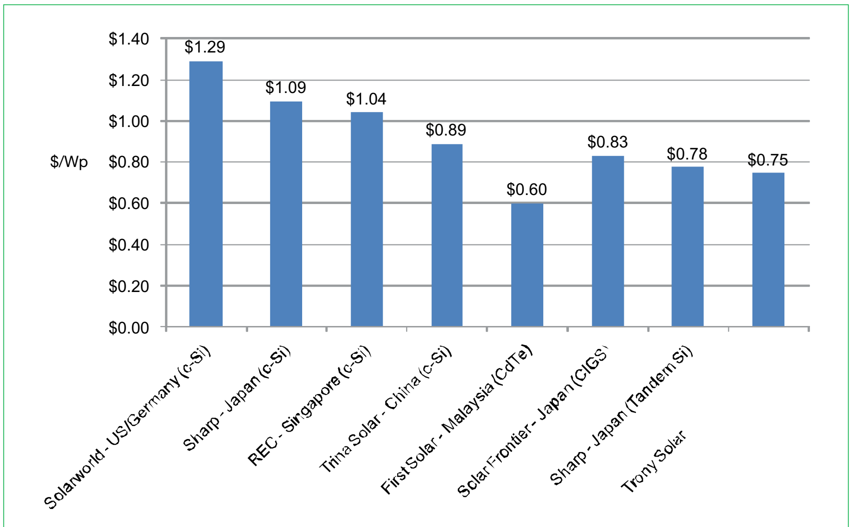

Figure 7. Best-in-class module manufacturing costs by technology/region, 2012E.

Conclusion

One clear market leader has emerged from the thin-film sector so far: CdTe purveyor, First Solar. The company's success can be attributed to its ability to scale to gigawatt-plus manufacturing capacity, achieve acceptable conversion efficiencies, maintain an industry-leading cost structure, and extend its business model downstream into utility-scale project development. Although other thin-film companies have been pressured by issues such as cheap crystalline-silicon modules, bankability, and relatively high production costs, several CdTe, CIGS, and a-Si contenders have emerged recently as commercially viable candidates, with growth potential across a wide variety of mainstream and differentiated market segments.

Acknowledgments

This paper is based on an excerpt from the GTM Research report, *PV Production, Technology, and Cost Output: 2010-2015*, originally published in October 2010. This report spans the entire breadth of the PV supply chain, from polysilicon to module production, and analyzes technical parameters, facility-specific capacities and production, manufacturing costs, and competitive analysis of module producers. The report is available from www.gtmresearch.com. Editing and additional information provided by the *Photovoltaics International* staff; used with permission.

About the Author

Shyam Mehta is a senior analyst at GTM Research, focusing on global solar markets. Before joining the Greentech Media unit, he was a financial analyst at Goldman Sachs Global Investment Research, where he covered equities in the alternative energy sector, primarily solar companies. Before that, Mehta was a research analyst at The Brattle Group, an economic consulting firm, where his work focused on problems within the electricity industry. He received his B.S. in mathematics summa cum laude from the University of California, Berkeley. Mehta has been widely published and has spoken at numerous industry conferences over the world on the subject of solar PV.

Enquiries

Email: mehta@greentechmedia.com