PERSPECTIVES | THIN FILM

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What Really Matters in Thin Film Solar Startups?

Venture capitalist Vinod Khosla opines on thin film solar and the potential of “new Black Swan improbable pyro-nano-quantum-thingamajig technology.”

Thin film modules have always promised to disrupt the PV industry landscape because they utilize significantly less material and vastly simpler processing than traditional crystalline silicon panels. Thin films have pushed new cost and scalability frontiers. Unfortunately, many have relatively low efficiencies and yields. Most current thin-film startup efforts do not appear differentiated enough to justify the hundreds of millions invested in them.

Today, the industry's number-one panel manufacturer is a thin-film company, First Solar. First Solar (FSLR) has consistently demonstrated industry-leading manufacturing costs and margins. It has reached module costs of $0.80 per watt and is on a path to $0.50-0.60 per watt, with capex well below $1 per watt that is declining with scale, using a highly replicable production platform. It has grown from 25 megawatts to 1.3 gigawatts of annual production capacity in just five years, while operating with gross margins above 40 percent compared to 20 to 30 percent for most industry companies. With FSLR’s 10 to 12 percent efficiency as the benchmark , any startup, in my view, needs to show 13% efficiency now and a clear path to 15 percent or more efficiency at 90 percent production yield by 2011-12 on large sized monolithic panels to carve out a stable place in the marketplace. Of course they need to concurrently meet FLSR costs too, at much smaller scale (< 100 megawatt) in 2010, unless they have hundreds of millions of dollars of "staying power". Only with these targets can they claim "superior technology".

Having evaluated dozens of ventures among the 100+ (estimate!) that have started up in the sector and observed disruptive innovations across many industries, I have no doubt that First Solar will face competition more quickly than anybody expects. New materials, quantum dots, cheaper capital equipment, lower installation costs, fast CVD, nanoparticle coatings, organics, finely controlled bandgap shifting, light splitting into colors, dual and triple junction cells, intermediate band cells, enhanced absorption coefficients, better or cheaper light concentration, wavelength shifting, nanoparticles, even pyro-electric supplementation, foils, flexcells, BIPV and a million other loony or brilliant schemes have all been or are being attempted. Most will fail to meet the cost and scalability challenge, but a few will succeed. In the meantime, more importantly to current investors and to me, it appears that many (most?) of the high profile thin film startups will also fail to get enough of an advantage to overcome First Solar's head-start on scale, manufacturing optimization, experience learning and cost. They will fail to compete in the near future, and by the time they get to their "second generation," a new Black Swan improbable pyro-nano-quantum-thingamajig technology will disrupt their new plateau.

To this point, many of the Silicon Valley thin-film start-ups have raised hundreds of millions of dollars quickly in an attempt to take on the crystalline incumbents and First Solar. Unfortunately, most have suffered serious technical challenges and yield/reproducibility issues, and have been unable to scale up or hit their cost objectives. I believe most, including the most visible ones, are unlikely to. From an investor's point of view, it is not fun when a start-up uses $300 million to $1 billion in capital to achieve a $1 billion dollar market cap, as A123 has done and some thin film startups are struggling to do. Raising more venture funding is something that companies boast about, but generally is a negative from the investor's perspective. It is hard to get a multiple of invested capital if $300 million to $1 billion has been

raised by a thin film startup, to barely get to the incumbents cost structure when Sunpower is trading at similar valuations. Using three hundred million dollars usually reflects poorly, not favorably, on the management team unless the platform is already in production at high yield on large panels at cost and performance that more than marginally beats the incumbent. I have not yet seen a thin film startup show this kind of cost/performance advantage over FSLR yet.

Temporary advantages that short-sighted entrepreneurs target should be approached cautiously even if market entry seems fast. VCs backed many companies focused primarily on addressing the high cost of poly-silicon that resulted from material shortages starting in 2005. By 2008, the poly-silicon shortage disappeared, and today the viability of numerous thin film vendors whose business models were based on high silicon prices is in serious jeopardy. Personally, I don't think any technology from a startup (leaving aside some larger companies with very deep pockets and operational expertise) below 13 percent efficiency (First Solar++) in 2010 (15 percent by 2011-12) will carve out a sustainable market position in a large niche, no matter what its cost is. The balance of system (BoS) costs, which are about half of the total installed system cost today, simply become prohibitive at lower efficiency. I am even skeptical of some startups expecting to command very high price premiums because they have lower installation costs. A few tens of cents per watt advantage may be conferred or some specialty market niches may make sense but broad market penetration is unlikely. Even BPOS advantages will not support an extra $0.50-100 per wat in larege market segments. Of course, specialty markets such as building integrated photovoltaics (BIPV) or satellite cells have their own set of rules.

In addition to having undifferentiated products, many thin-film start-ups also suffer from relying heavily on highly customized or self-designed production equipment to deposit the films and reach long term cost targets. As a result, their capital cost is substantially higher as they struggle to replicate the skills of Applied Materials and other equipment vendors. Just as Applied Materials will struggle to develop a cost-effective solar cell process, solar cell vendors will struggle to develop the equipment expertise that Applied Materials has acquired through decades of learning. I personally expect that any startup that is developing their own manufacturing equipment will have a large gap between the promise of a technology and delivery time and its reality; those promised cost advantages will be hard to come by. Anecdotal feedback from the field seems to support this skeptical point of view to date. To achieve low prices, it is not enough to have low costs; you also need to scale quickly to amortize the massive capital investments required. Fast growth is only possible with a process that uses tested equipment, and with a proven material supply chain. An investor must be wary of an overly innovative and complicated process that uses custom equipment or the invention of a new supply chain. Some of the technologies with custom approaches/equipment like the foil guys or other custom cell configurations have ended up with significantly more complex process steps as well as reproducibility and yield issues. This further undermines their ability to hit cost targets/projections and no startup has shown ability to overcome these limitations. Projections are easy but achieving them in unique, complicated processes is hard. If they don't have 90 percent yield on a 10 megawatt pilot line six months after starting the line, they likely will struggle for a while getting it. On the other hand, a standard process invites direct competition by low-cost producers resulting in severe margin pressure. We at Khosla Ventures have generally preferred large material innovations to equipment/process innovations for this reason.

Often companies advertise their "champion cells" or their "target efficiency" rather than what their data sheet shows today. Is it circuit efficiency or module efficiency? Is it monolithic and at what yield (read low production cost)? Most PR departments play up these high one-off numbers (claims as high as 14 percent; Stion regularly achieves 15+ percent in 20x20cm modules for specmanship), but in reality their data sheets and shipped product are often at 10 percent to 11 percent. These are well below my

minimal 13 to 15 percent target for "investments worth considering" (this year, at high yield, on large panels, instead of specmanship of champion cells) that I think is needed to be competitive in any significant solar segment. My advice to investors is to look at datasheet efficiency, process distributions and production yields. First Solar is at 11% today and will likely get to 14% in the next two to four years. Their scale and manufacturing optimization advantages will give them another 25 percent cost advantage over "superior cost" technologies. Any company hoping to compete needs high efficiency at a high yield and low cost in the very near term and a clear path to industry leading costs in the near future. For startups, assume a 20 percent cost disadvantage relative to FSLR when starting up and a 10 to 15 percent decline in costs per year from learning. For experienced semiconductor companies assume a 20 percent cost advantage relative to startups and for large "other non-semiconductor corporates" (like Dow, BASF...) assume a 10-20 percent cost disadvantage relative to startups, all assuming the same technology. Then add fundamental technology cost advantages/disadvantages on top of this "learning curve". If costs are not around $0.80 per watt (fully loaded) in 2010-11 at 100 megawatt scale, then I am suspicious the technology can be competitive. Lower balance of system costs (BoS) may allow a technology to be competitive with a few tens of cents additional module cost but not much more.

The question today as so many companies ramp up production and commercialize their initial products is what technology will meet these challenging criteria? Although panels based on cadmium telluride (CdTe), First Solar's core technology, and copper-indium-gallium-selenide (CIGS) technology promise higher efficiencies and competitive costs, I doubt they can beat First Solar at its own game. 10-11 percent efficiency CIGS panel technologies are becoming a dime a dozen and will be in a bloodbath. One particular thin-film company allows for less expensive rooftop mounting for given wind conditions, both of which confer significant advantages to them. If they have a clear path to low cost production at small/medium scale (Personally I do not know enough to comment on their cost structure given it is different but my tests still apply), the company can be successful, but in which market? This company may become a player in commercial rooftop markets with white or highly reflective roofs, but does this market warrant the capital investment of a billion dollars? For many thin film technologies applicability dwindles (for example CdTe panels are not allowed in some European and Japanese markets) and it is likely that use of things like heavy metals will be become even more restrictive in the future and applicable niches shrink as they face the requirements and limitations in the field. For example, some technologies with balance of system (BoS) advantages lose them when they have to comply with California's seismic requirements, which often trump the wind constraints.

At a high level, First Solar currently dominates utility-scale solar and faces potential competition from Chinese silicon vendors and CSP at the large plant level (limited to certain geographies). Large commercial rooftop solar is mostly the domain of higher efficiency crystalline silicon vendors such as the Chinese manufacturers (Suntech, Trina, Yingli, etc.), Kyocera, Sharp and Sunpower, with the numerous startups I have discussed challenging them. Investors who don't examine the competitive dynamics within each of these sub-segments and determine what type of market value or total equity investment is justified for companies competing in them, fail to do so at their own risk. A careful analysis of the "sub-segment" market sizes and potential for sustainable differentiation is required or investors will be disappointed. There are good investment and segment opportunities but many (probably most) that are being paraded around will fail.

In the interest of full disclosure, one of our portfolio companies, Stion, has produced one of the highest performance thin-film solar panels with significantly less time and money than its competitors. On less than $50 million spent, including capex and pilot lines, they are producing 120 and 130 watt panels, and yielding to 13 percent efficiency, 2 ft x 5.5 ft panels made using monolithically integrated circuits, and

have exceptional yields and process distributions. To me, demonstrating repeatable results on commercial-scale product is much more meaningful than one-off champion results that are not reflective of production. Stion's efficiency advantage will make it competitive for the time being, and its product also has other significant advantages such as a lack of cadmium (an issue for First Solar in some markets) and superior aesthetics (which Sunpower has effectively leveraged). But to me even that may not be enough to justify a billion dollar capital raise that many other thin film companies have jockeyed for and received (you can always generate a small fortune if you start with a big one. The real question is, how good are the returns?). Fortunately Stion is able to get to positive cash flow on about $100 million in equity, about the same as a typical chip startup takes. I wonder if even Stion is competitive enough in big enough niches to be viable, and as a result I had personally encouraged the company not to go into production even with this "best in class" 13% thin film technology which they are already yielding very well on. Therefore I encouraged them to take a licensing strategy for this segment to gain additional capacity at little or no capital cost as their technology license fee.

So why did we invest in Stion when I am skeptical that any current thin film company can compete with First Solar beyond an interim 2-3 year period? To achieve sustainability one needs real, long term differentiation! It's because Stion is developing a multi-junction (tandem) product that can compete with all the incumbent silicon (not thin film) players by matching the efficiency of silicon cells with the costs of thin film. That upside gives the company "legs" beyond the first few years of sprint, and I think every company needs to have a similar, short term, vector for future improvement. Otherwise, they will be resigned to the world of low margin bloodbaths in an oversupplied market with few sustainable advantages. Stion has demonstrated a >15% efficiency "tandem junction" technology at prototype scale (20 cm x 20 cm fully integrated circuit) which will allow it to become directly competitive with silicon panels in efficiency, and eventually challenge the Chinese silicon solar vendors and SunPower's industry-leading efficiencies (18-20%) at about half the cost. Given the strong leadership position First Solar has established, it will be virtually impossible to challenge them with anything less. And even with what Stion has accomplished, the risk exists that some clever technologists re-invent silicon or jump ahead with a Black Swan… and there are more than a few attempts at doing just that. Happily, innovation in solar is thriving and will continue to do so, and today's impossible is tomorrow's conventional wisdom, so don't underestimate what types of cost and performance targets this next wave of technology could hit.

With all of this in mind, here is a good checklist for what I think makes a thin-film solar cell company both a competitive presence in the market and a viable investment opportunity:

- High efficiencies (13-15 percent) on commercial-scale modules at 90 percent yield or greater in 2010-11 in first production line.
- Capital costs below $1 per watt on the first 100MW line (and declining from there), and a production platform that leverages proven equipment
- Panels made using larger (than FSLR) monolithically integrated circuits as opposed to small unit cells, which generally have higher costs as well as significant manufacturability and performance issues
- Designs that drive installation and BOS costs lower.
- Advantages that are particularly valued by a substantial market; e.g., a uniform, all-black panel with superior aesthetics makes a big difference in the residential market. (Likewise, pay attention to potential disadvantages for markets.)

- Attributes that exclude others from a substantial market; e.g., completely cadmium free / lead free product is critical for some geographies. (Likewise, pay attention to attributes that may outright ban it from markets, now or in the future.)

- DOE loan guarantees are usually a good thing but only if the company has an economic product and is ready to scale. I would not interpret a DOE loan guarantee as "validation" of costs or a reason to IPO. Would you rely on somebody in government to understand the dynamics of competitive costs in the global marketplace? Nor would I rely on bankers offering IPO's to have validated a technology either, especially if they are getting commissions for the deal. Also remember that a big loan gets the treadmill running and cash flowing out to repayment of the loan. Great product margins are the only source of cash for paying off a big loan (without dilutive equity raises).

- If the total equity in a company is approaching $500m prior to production startup, I would ensure that the startup is going to beat the pants off First Solar, Chinese low cost Si, and solar thermal in utility scale installations. Otherwise it is going to be a successful niche play and deserves a niche company valuation. Bear in mind that Sunpower is among the largest niche players and even its valuation does not justify a billion dollars of investment.

2010 and 2011 will be a very interesting growth phase for the more recent entrants into the PV arena. Many of them will not raise adequate funds to continue their development and scale-up efforts, and will fail. Others will be acquired; a fair degree of consolidation is likely amongst the marginal or poorly differentiated players and half a dozen players will have10-13% thin film cells that need "elusive" scale to reach costs targets and "when at scale/maturity" will remain "when's" while cash flow hemorrhages.. In the end, for the current thin-film players missing efficiency targets by just 1 point translates into 10 percent+ cost bump in an increasingly competitive 20-30 percent margin business. Innovative startups may re-invent silicon technology but probably only if efficiencies of 25 percent or more are achieved. Today's conventional wisdom targets are the wrong ones for them to shoot at.

Over time, Chinese manufacturers are likely to gain market share as they continue to drive costs down. Very little innovation seems to be happening in Europe (likely due to the economics of feed-in-tariffs that are only now starting to be updated in some countries). A few large companies that have recently entered the market with aspirations to become global leaders, will be relegated to fairly narrow niches. Those DOW-like promises of building integrated solar will die as the big behemoths fail to keep up with small innovative competitors. The more than 200 PV companies in the world today will undoubtedly shrink, while a select few new entrants will break away from the pack based on superior cost and products, and join the heated battle for market share that is already taking place among established incumbents. There are other niches which will continue to develop, like the 25-40 percent+ efficiency cells usually made out of exotic materials. Silicon vendors will generally start declining rapidly by 2015 unless they re-invent silicon, and get well above 20 percent efficiency cost effectively. The high concentration based 40% efficient multijunction cells will stay in the high concentration niches unless they offer 25-35% efficiency at "one-Sun silicon $/watt" costs. Yes, this is possible and companies are already attempting this seemingly impossible feat. And no, I am not bullish on high concentration solar. Low concentration solar for utility markets may work well with high efficiency silicon or next generation cells at low enough costs, though they will face stiff competition from incumbents and may need to be creative in their value proposition.

So my last words to startups: be competitive with silicon cells at thin film costs or be competitive with III-V cells (well over 20 percent) at silicon costs. Then you have a 50/50 chance of making it. But a billion dollars of capital and billion dollars of debt will be hard to pay off.

PS: Those of you who will critique me for having my views match our companies' strategies; I suggest that we invested in companies that match our views and not the other way around.

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Khosla Ventures offers venture assistance, strategic advice and capital to entrepreneurs. The firm helps entrepreneurs extend the potential of their ideas in breakthrough scientific work in clean technology areas such as solar, battery, high-efficiency engines, lighting, greener materials like cement, glass and bio-refineries for energy and bioplastics, and other environmentally friendly technologies, as well as traditional venture areas like the Internet, computing, mobile and silicon technology arenas. Vinod Khosla founded the firm in 2004 and was formerly a General Partner at Kleiner Perkins and founder of Sun Microsystems. Khosla Ventures is based in Menlo Park, California.