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Materials for Thin-Film Silicon Photovoltaics

March 2009

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Executive Summary

E.1 Introduction: Innovation in Thin-Film Silicon PV

Amorphous silicon (a-Si), a type of thin-film photovoltaic (PV) technology, is experiencing a dramatic growth curve worldwide and offers a compelling business opportunity in power generation, building-integrated solutions and consumer applications. Thin-film PV solutions are the most rapidly growing portion of the PV landscape with approximately 23 percent of the overall PV market in 2008 and a-Si represents the largest component at over 50 percent of the overall TFPV market production in 2008. Amorphous silicon is well positioned to become low-cost PV solution of choice for many applications in the eight-year time frame covered in this report. Lower cost per kWh is the main driver for the shift from crystalline silicon PV to thin-film PV, as well as the increasing acceptance of a-Si thin-film PV for new applications. Cost, product maturity, excellent reliability, and availability of product in high volume are all reasons a-Si has become the most popular of the thin-film technologies; other TFPV technologies include CIS/CIGS and organic PV, which have product maturity issues, and CdTe, which suffers from government regulatory issues at end of life disposal/recycling.

The economics of all photovoltaics involve a high upfront cost to pay for the solar panels, but free feedstock in the form of light from the sun and relatively low operating costs because of the relatively low, periodic maintenance costs compared to traditional methods of power generation. The PV technology that is able to provide the quickest path to lowering these upfront costs and deliver product in high volume is likely to become the dominant PV solution. Amorphous silicon thin-film PV is well positioned to be the PV solution that can provide both large volumes quickly and a roadmap to low cost faster than competing TFPV technologies.

Amorphous silicon solar cells were introduced initially in the late 1980s, with expectations that they would dominate the PV market and be competitive with fossil fuels by the mid-1990s. This did not come to pass as the efficiency was less than 5 percent and initial cell reliability was less than 10 years. These drawbacks coupled with the pullback in fossil fuel prices in the late 1980s, off of peaks in the early 1980s, eliminated almost all demand for a-Si PV except in low-cost/low-power applications such as solar calculators, watches, etc.

Despite a lack of large-scale commercial applications, research continued on a-Si, which resulted in a much better understanding of a-Si PV physics. This research resulted in the development of tandem a-Si/Si:Ge alloy and a-Si/μc-Si cells that had efficiencies nearing 10 percent and field reliability of over 20 years. This positioned the a-Si PV to capture market share when renewed interest in PV energy emerged in the early 2000s.

Several events occurred starting in the early 2000s that accelerated the adoption of PV in general and that of a-Si in particular. First was the spike in fossil fuel costs that increased interest in all PV solutions. With this increased interest, the PV demand exceeded supply. Because crystalline silicon dominated the market, the increased need for silicon combined with the robust demand for silicon in the semiconductor industry caused silicon prices to skyrocket and resulted in a silicon shortage. These high prices spurred companies to invest in capital to expand capacity for a-Si (<2 percent silicon consumption of c-Si) and CdTe-based thin-film PV, as well as accelerated research and development into CIGS and organic PV. Fortunately for a-Si, the renewed interest in PV solutions happened at the same time the industry was transitioning to tandem and multi-junction architectures with much more attractive overall efficiency and reliability than the single-junction designs, which were the dominant products available in the late 1990s and early 2000s.

In addition to the demand for alternative energy sources strictly due to cost of fossil fuels, the global warming/climate change movement helped drive demand for PV solutions as they have a zero carbon footprint. Government subsidies for PV solutions (especially in Germany and Spain where such subsidies can be viewed as either jump starting the PV industry or distorting the marketplace, depending on your point of view) have made it economically feasible to build large PV arrays. Amorphous silicon is very competitive for these applications and this has created demand for more capacity.

By the end of the period covered by this report, the roadmap for thin-film silicon PV cells will most likely transition from the a-Si/µc-Si cells, which are now becoming the mainstream a-Si product, to tandem-junction cells that most likely will be tandem- or triple- junction cells based on combinations of amorphous silicon, microcrystalline silicon and nanocrystalline silicon. The roadmap by the end of the reporting period will see the introduction of silicon-based quantum dots or silicon nanowire-based architectures ramping to high-volume manufacturing. This a-Si PV materials roadmap predicted in this report provides a path to 15-16 percent cell efficiency leveraging the cheap SiH_4 as a feedstock, no changes to the TCO or reflector materials (although there are certainly improvements in materials processing that can improve efficiency), and most likely will use much of the equipment infrastructure of the current tandem cell factories that are currently coming on line. This reuse of capital equipment and infrastructure represents an excellent value proposition to constantly increase efficiency, aggressively driving down costs, while not being saddled with heavy capital costs to improve efficiency with the exception of those to satisfy increased capacity.

E.1.1 Current Amorphous Silicon Cells and Near-Term Innovations

The roadmap for a-Si PV cells is to advance from the 8–10 percent module efficiencies available today with current tandem a-Si/a-SiGe or a-Si/µc-Si cells, to advanced nanostructured silicon thin-film cells with target efficiencies of 15–16 percent on the one hand while aggressively driving down costs on the other in the next five–eight years. By its nature, a-Si will never be the highest efficiency solution in terms of efficiency per unit area available, but it certainly can be the most economical solution in terms of cost per watt for low-cost power generation especially when land costs for the generating site are low. It is also very likely to be the solution of choice for integrated building applications and for mobile applications, where module weight (energy produced per pound and not area) and module flexibility (integration on curved surfaces/collapsible mobile collectors) are more important design considerations than energy conversion per unit area.

The newest-generation of a-Si cells, which are mostly in the pilot plant stage or ramping to full production at the present time, are tandem-junction cells with a-Si as the upper absorber and a fairly thick (1-3 μm) layer of μc-Si as the lower absorber. Because these cells have similar efficiencies as Si:Ge alloy cells and do not rely on expensive Ge feedstock, we expect this new generation of a-Si/μc-Si cells to effectively compete with other emerging technologies now and in much of the eight-year time frame covered by this report. However, additional performance enhancements/cost reductions discussed in this report will be needed to stay ahead of CdTe production and ahead of new thin-film challengers such as CIGS and organic TFPV, which have demonstrated high efficiency but are not yet in volume production.

The most likely path to these goals from a materials perspective is first a transition from current generation a-Si/a-SiGe tandem- and triple-junction cells to a-Si/μc-Si tandem cells. This is currently underway, and will be followed by large-scale adoption of a-Si/μc-Si in the industry. Further improvements in this generation of materials will come from increasing the light-trapping ability of the cells via improved texturing of both the back reflector and top conductor layers. Once these improvements are implemented, there may be slight incremental improvements in efficiency, but the final improvements to this type of cell will be in the form of cost reductions. These improvements will result in efficiencies above 10 percent, but there will need to be fundamental materials innovations discussed below to get to the 15 percent efficiency potential of thin-film silicon PV.

E.1.2 Nanocrystalline Silicon, Silicon Nanowires, Silicon Quantum Dots and Silicon Inks

As the current generation of a-si/μc-Si tandem cells matures, the next projected major materials improvement on the a-Si roadmap moving from development into production will most likely be a transition from μc-Si film to an nc-Si film for the lower absorber. Nanocrystalline silicon (nc-Si) for the purposes of this report is a film consisting of small (~ 10-30 nm) silicon particles randomly distributed in an amorphous silicon matrix. The transition to nc-Si for the lower absorber should result in stabilized module efficiencies of 10-12 percent. Another potential opportunity for nc-Si may be high-efficiency single-junction cells with low SW loss. Single-junction cells with stabilized 8.5 percent efficiency have been demonstrated and this would represent a significant cost reduction compared to tandem-junction cells. Like microcrystalline cells, PECVD deposition rates are low for nanocrystalline cells, so an opportunity exists to lower costs by developing higher deposition rate techniques such as hot wire CVD (HWCVD).

While nanocrystalline tandem cells represent an incremental improvement over today's cells, a significant materials improvement will be realized soon after with the likely adoption of silicon nanowires. By adopting Si in nanowires, efficiencies of 15 percent or slightly more should be viable and initial data indicates that SW effects should be < 5 percent for such cells. One of the most exciting things about this roadmap is that while there will be much research and development needed to realize the process improvements necessary to make such cells, the high volume manufacturing for the most part will be able to leverage the manufacturing infrastructure that is currently being put in place to support the current generation of a-Si/µc-Si cells.

In addition to nanowires, silicon quantum dots also represent an advanced Si-based thin-film PV that could provide an equally viable route to low-cost cells with final efficiencies over 15 percent (theoretical is efficiency of 60 percent based on work by Ross and Nozik, J. Appl. Phys., 1982). Quantum dots have been demonstrated as a way to tune the band gap of the absorber layer from the bulk value of silicon to anywhere between 1.1 eV and 1.7 eV. Such quantum dot materials are usually based on multiple thin-layer depositions of Si and either SiC or SiN, followed by heating to high temperature to coalesce the silicon into arrays of quantum dots. Because it is a PECVD-based route to deposit the materials, like the other paths to higher efficiency cells in this roadmap it will likely be able to leverage most or all of the current a-Si/µc-Si tool set. If capital purchases can be avoided to make these improvements to the current a-Si/µc-Si cells, it makes them very attractive vs. the infrastructure purchases that will be necessary to bring large volumes of CIGS, or eventually, organic PV on line.

A wildcard in the roadmap to advanced silicon-based thin-film PV cells is the use of silicon ink technology. So far, only one company has begun developing silicon ink-based inkjet printed PV cells, but this company has completed a 10-MW pilot plant and results should be forthcoming this year. If successful, it could shift the whole field to a new deposition strategy. No concrete efficiency results have been published yet, so until results are reported that demonstrate a path to efficiencies at or above those of traditional amorphous cells, it is difficult to fairly judge the technology. One other limitation of the technology is the high temperature anneal step required to cross link the silicon nanocrystals into a semiconducting film. This high temperature will likely limit its application to flexible organic-based substrates.

E.2 Opportunities for Materials Firms in Thin-Film Silicon PV

In the case of amorphous silicon PV, the source chemicals have extensive overlap with the semiconductor industry. Silane, hydrogen, NF_3, germane, etc. are all basic materials that are used extensively in the semiconductor industry, and as such these materials have pretty much reached their limits in development. Because of this, there isn't much innovation left for materials suppliers for a-Si.

This is not to say there aren't opportunities for materials firms. The expanding a-Si PV field does present an opportunity for the bulk vendors of semiconductor gasses to expand into these new markets. This will become more important to the bulk gas vendors as the semiconductor field matures and growth rates begin to slow. Because many of the manufacturers in the a-Si PV space have purchased their equipment and processes from turnkey vendors, there is an opportunity for the gas production firms to provide more of a turnkey gas services solution. The second opportunity for gas supply companies is to tailor the purity of gasses supplied to the needs of the a-Si manufacturers; these requirements are less stringent than those of the semiconductor industry. This should result in a cost reduction to the manufacturers and perhaps a profit margin increase to the gas firms.

Semiconductor-grade silane gas, for example, requires a purity of nine 9s, while that for a-Si is in the four 9s purity and some gas suppliers and manufacturers are already moving to provide semiconductor grade gasses to a-Si PV manufacturers.

E.3 Opportunities for Manufacturing Firms in Thin-Film Silicon PV

E.3.1 Opportunities for Amorphous Silicon Manufacturing Firms

The situation for a-Si is unique in the thin-film market place because of the presence of three large turnkey vendors of a-Si PV equipment and process knowledge in addition to several large companies that internally develop their own a-Si PV. The presence of the turnkey manufacturers lowers the risk to enter the thin-film PV market compared to other solutions as entities with capital can purchase the engineering to build the plant, the equipment, the process knowledge, and all of the related infrastructure and have high confidence of the yield and efficiency of the product they set out to produce. While turnkey processes do not create unique products, they offer a high degree of confidence that the product will perform as it was intended to perform. The internally developed processes on the other hand may leap ahead of the turnkey solutions if they offer a product that is more efficient or a process improvement that allows a lower price per watt, but the risk is higher as there is no beaten path to follow or resources to leverage if unforeseen issues arise.

The opportunities for both the turnkey vendors and the internally developed products companies are the same. The winners will be those that transition the fastest to higher yield processes (tandem a-Si/µc-Si to a-Si/nc-Si to either Si nanowires or Si quantum dots or silicon inks) while at the same time reducing costs and maximizing reuse of existing infrastructure.

E.4 Key Firms to Watch in the Thin-Film Silicon Materials Business

Key firms to watch in the thin-film silicon materials business come in three distinct groups. The first group is comprised of companies that do their own development and produce significant amounts of leading-edge cells in large volume. The second group consists of large manufacturers that purchase most or all of their equipment and process technology from an outside vendor, but produce significant amounts of product. While it is a significant volume, it can almost be viewed as more of a commodity application. The third sector is the widely diverse start-up companies that are developing novel processes, which may lead to significant efficiency improvements. This group is where the innovation will most likely come in the later portion of the timeframe covered by this report.

E.4.1 Amorphous Silicon Manufacturing Firms using Established Technology

a-Si/a-Si:Ge Tandem- and Triple-Junction Cells: United Solar Ovonic, a subsidiary of Energy Conversion Devices, is the leader in the a-Si/a-Si:Ge field. The company's technology, which is used by Fuji in high volume, is well established with high yields and in most cases is geared toward BIPV or power generation applications.

a-Si/µc-Si Tandem Cells: Tandem cells based on a-Si/µc-Si are becoming the dominant cell geometry and will remain so for most of the forecast period. The manufacturing model is unique in this area as the technical leadership in most cases is driven by the equipment vendors. Applied Materials, Oerlikon and Ulvac are the leaders in development of turnkey a-Si/µc-Si factory equipment and process engineering products. Others in the turnkey manufacturing space are EPV and Leybold Optics. Large a-Si/µc-Si manufacturers with internally developed equipment include Kaneka, Mitsubishi Electric, Sharp, and Sanyo. RWE Schott is a leader in building-integrated a-Si TFPV on transparent substrates.

Polymer-Based Flexible Substrate a-Si: PowerFilm and VHF of Switzerland are both leaders in a-Si PV cells deposited on flexible polymeric substrates. PowerFilm is currently expanding its internally developed tandem-junction a-Si flexible substrate production lines to meet increasing demand. Flexible substrates have many exciting possibilities in BIPV and consumer applications. VHF is producing tandem-junction a-Si TFPV on flexible substrates at the 25-MW production level.

E.4.2 Start-up Companies Leveraging Next-Generation Silicon PV Technology (Silicon Inks, Si Nanoparticles, Si Quantum Dots and Si Nanowires)

Innovalight is developing a-Si-based PV cells using an innovative inkjet-printed deposition strategy instead of the industry standard plasma CVD deposition method. If successful, the printed methodology could represent a major cost reduction compared to current manufacturing strategies.

Nanogram uses laser pyrolysis to deposit thin nanoparticle Si films. The deposition represents a new set of techniques to manipulate film properties and potential cost reductions through faster deposition rates than traditional PECVD technologies.

SunFlake of Denmark has demonstrated a novel Si deposition process, which deposits vertically oriented flakes of silicon with efficiencies of demonstration cells nearing 30 percent.

Solexant is said to be developinga flexible substrate based TFPV with a nanostructured or quantum dot based absorber, but current data on the company is limited.

Solastais a start-up that is developing a vertical nanowire cell that should have many of the same advantages as the SunFlake cells as both have long absorber lengths (Z direction) and short electron transfer path (nanowire radius).

Solexel is another start-up that is said to be using porous silicon. While details are sparse, the company's process also creates features with a long absorption path in the Z direction, but a short path across the P-N junction.

General Electric, while mostly investing in c-Si and CdTe based PV, has recently demonstrated some working innovative nanowire thin-film a-Si based cells.

E.4.3 Manufacturing Equipment and Turn Key Process Firms

As semiconductor equipment and large thin-film display markets began to mature in the early 2000s and interest in PV solutions began to intensify, **Applied Materials** made a strategic decision to aggressively pursue the equipment sales business and a turnkey factory/process flow amorphous silicon thin-films PV strategy. This was a smart move by Applied Materials to capture the increasing interest in PV and make up for the lack of growth in the semiconductor markets. As well, this strategy fits well with Applied's core competencies of equipment manufacturing, process engineering development with worldwide support infrastructure. Internally, the company has the experience in designing and manufacturing the tools necessary for the amorphous silicon PV market and the worldwide support network to support multiple engagements in the field. The strategy is also a logical extension of the company's expertise in designing tools for the display industry. As many of the tools are modifications of already existing tools, it keeps development costs low and leverages much of the existing infrastructure (software, etc.).

AMAT has sold its SUNFAB turnkey plants to at least 13 customers to date and plans to have 300 MW in place by the end of 2009 and close to 2 GW in place by the end of 2010. The first generation of the SUNFAB cell is single junction with a tandem micromorph a-si/µc-Si now ramping to production. Signet is one the first companies to get a turn-key factory up and running with 20 MW initial capacity.

Oerlikon is an equipment manufacturer based in Switzerland that is leveraging its expertise in thin-film display equipment manufacturing as a springboard into a vendor of turnkey a-Si thin-film solutions. Like Applied Materials, Oerlikon recognized an opportunity to apply its equipment solutions in the thin-film display industry to the thin-film PV industry. The company plans to have 300 MW of capacity in place by the end of 2009 and 1 GW by the end of 2010. Oerlikon's customers include Schott, Kenmos, Pramac, Next Solar, Inventux, ersol (*sic*), Chint Solar, Auria Solar CSG API, Sunways and Sunwell.

Ulvac is the smallest of the three major turnkey amorphous silicon PV providers. Their initial products were single-junction cells, but Ulvac has recently completed development of a micromorph a-Si/µc-Si tandem junction cell, which the company is now shipping in volume production. The company has been in the thin-film PV business for quite some time with over 30 years experience in the field and has delivered over 50 production lines. While Ulvac's substrate size and turnkey plant capacity is smaller than its competitors and thus may not be competitive in the long run, the upfront capital expense of the Ulvac turnkey solution is significantly less than those available from other turn-key vendors and may be suitable for manufacturers with smaller capacity needs. Customers include NexPower, Sunner Solar and China Solar Power.

Tokyo Electron, Ltd. (TEL) is one of the latest entrants from the semiconductor equipment manufacturing field to announce plans to enter the a-Si thin-film solar equipment manufacturing business. The company announced a large joint venture with Sharp in the middle of 2007 to develop advanced thin-film amorphous cells. Following this, in early 2008, TEL announced plans to enter the amorphous silicon PV business. TEL's current plan is to build a 1-GW production plant by March 2010 with planned module efficiency of 10 percent. By leveraging the Sharp jv to quickly come up the thin-film technology learning curve, TEL hopes to quickly become competitive in the turnkey solution/equipment provider space.

E.5 Summary of Forecasts

Exhibit E-1 summarizes the market for materials for a-Si over the next eight years. While the overall world economy is contracting, the demand for a-Si PV is still strong and growth is occurring in the a-Si PV field, albeit at a slower rate than predicted 12–18 months ago. Several firms—notably Uni-Solar and Sanyo—are ramping up production significantly in this sector. The turnkey equipment vendors have an important role in increasing the probability of successful technology ramps to volume production in the amorphous silicon area. They are currently now have at least seven factories in production with another 14 under construction producing advanced tandem-junction cells. The total number of a-Si factories running or under construction is approximately 32 with another 13 on the drawing boards. The current market situation will certainly cull some from the heard, but the volumes that are going to be available in the near future are significant.

The forecasts in this report represent NanoMarkets' latest expectations for the TFPV market in light of the current economic situation. These figures roughly assume an additional 18 months to reach a given revenue point compared to NanoMarkets' original thin-film PV market report.

Exhibit E-1 shows the negative impact to various TFPV applications of the current worldwide financial environment will have on amorphous silicon PV and the thin-film PV market in general.

While the short-term economic outlook for TFPV is bleak as outlined in Exhibit E-1, the medium- to long-term outlook for the TFPV markets exhibits high demand and constrained supply. First of all, the world economy will eventually get better and the underlying global demand that drove up energy costs in a growing world economy will become prominent again. If PV does eventually provide 20 percent of the energy needs of advanced countries, as some in the industry foresee, then there is nowhere near enough PV capacity available or under construction to meet this demand.

In the long-term growth scenario, there is a consensus that power generation will be provided by a mix of sources; PV will be one of these sources as it can reduce the energy price risk (the feedstock, solar energy, is free) and it is an ideal solution for power plants to meet peak loads without building new power plants, which is capital intensive. The ability to provide additional peak load capacity may be a very attractive market for a-Si PV. Even though amorphous silicon is not yet at grid parity, it provides an attractive additional source of surge capacity for power companies and may help defer extra traditional capacity necessary to meet peak load demand. A unique advantage of amorphous silicon compared to other thin film and crystalline PV technologies is that it is at its most efficient in the hot summer months when power companies most often experience peak loads.

Exhibit E-1
Impact on TFPV Market of Current Financial Environment

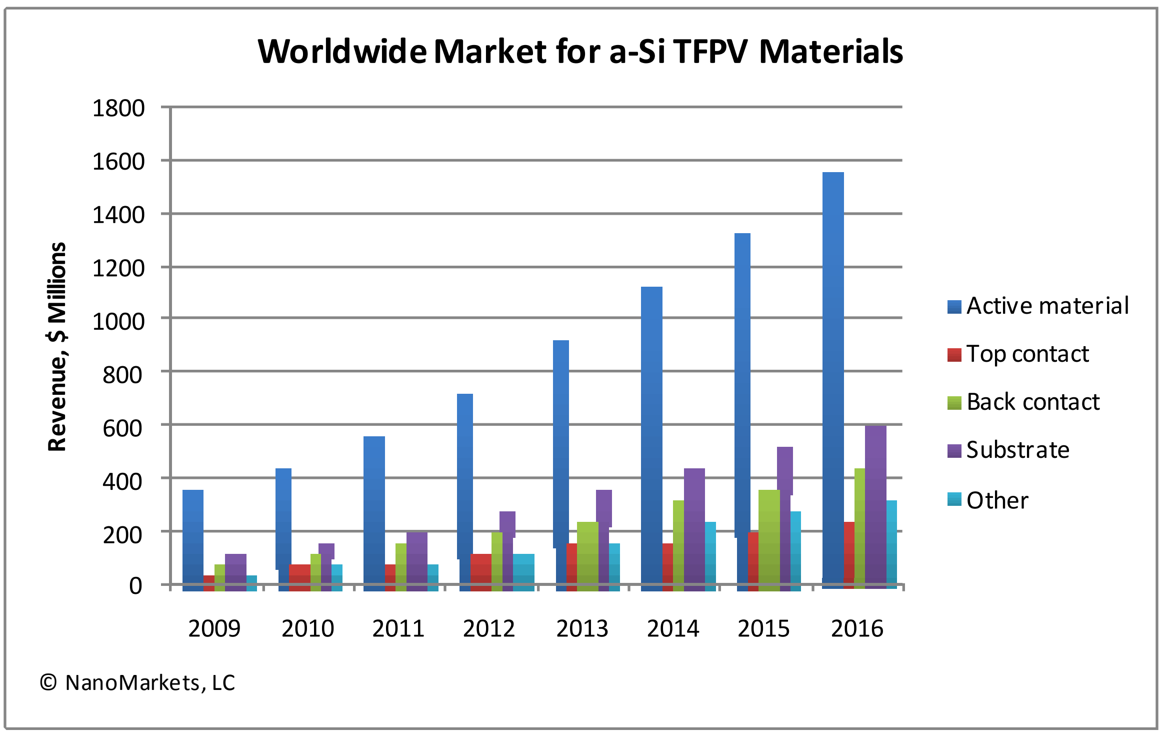
Topic	Comment
Construction activity	Building-integrated PV is a major market of amorphous silicon PV and since the cost of PV installation is far easier to justify on new construction the current contraction of commercial and residential new construction activity is certain to have a negative effect on amorphous silicon PV growth in the near term. The conventional wisdom is that it will be a year or longer before growth returns to this sector.
Energy prices	The current dip in energy prices makes all types of PV less attractive as an energy source. However, the consensus is that current measures being taken by governments to reinvigorate the economy will ultimately produce inflation and higher energy prices in the long run. The current dip in price may help amorphous silicon-based PV as most of the capital for production factories has been spent, with four factories in full production and at least 20 more under construction. CdTe is in a similar situation as it is available in high volume. CIGS and organic PV development may be slowed as they are further from volume production.
Investment levels and credit crunch	The lack of funding is likely to impact PV in the building of homes and power plants, but also in funding for new TFPV materials. This may benefit a-Si compared to other TFPV as a-Si- has the most capital already committed to plants already manufacturing modules and factories under construction. In the short term, little capital will likely be available, but a-Si may be one of the most attractive PV solutions to fund as it is well known and relatively low risk compared to other PV solutions. Bank funding of power plants is likely to favor conventional technologies all PV is still in the unconventional category of power solution.
Climate change declines in importance	With the current focus on worldwide financial policy and recession, climate change issues are likely to get less attention from governments and from the public. Since one of the main factors that has promoted PV over the past few years is that it does not emit greenhouse gases, this is a further negative for PV. However, a recent U.S. Supreme Court decision giving the EPA right to regulate C02 emissions could quickly change this situation, and make climate change a driver for growth in the amorphous PV industry. Also, the recently signed United States stimulus package has significant funds allocated for "green jobs."
End of the silicon shortage	One of the key factors that has promoted TFPV in the past year or so has been the ongoing shortage of electronics grade silicon, which is the critical raw material for traditional wafer-based crystalline silicon (c-Si). Amorphous silicon PV uses approximately 2 percent of the Si required for crystalline cells, and it can be made from less pure and cheaper silane than is used for semiconductors. In a recessionary environment this shortage is likely to disappear altogether, but there will remain a significant cost advantage for the active PV layer in amorphous cells vs. single or polycrystalline cells.

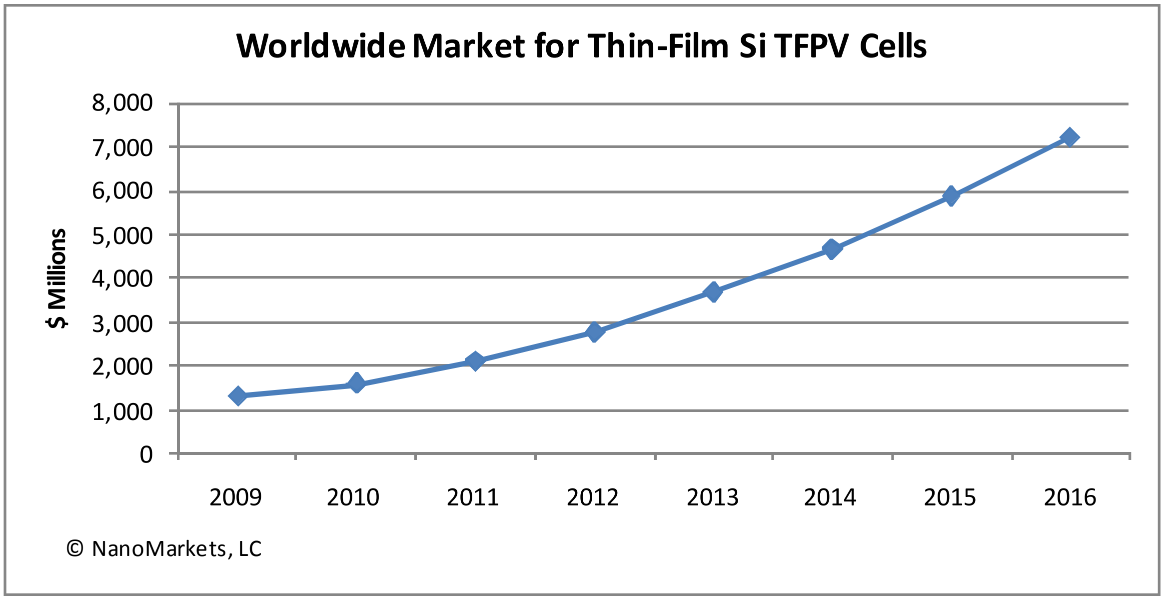
Ultimately, the keys for amorphous silicon to maintain its dominant position in the TFPV marketplace and to grow in the PV marketplace in general are to increase the efficiency of the cells and lower the cost of materials. Areas where efficiency gains can be made are through further optimization of the tandem-junction thin-film deposition, which in the short term translates into further optimization of the microcrystalline bottom absorber followed by a transition to a nanocrystalline bottom absorber. The second possible efficiency improvement from a materials point of view is modification of the current processes used to texturize the TCO, which will improve the light-trapping efficiency and thus overall efficiency of the cell. The longer-term materials challenge is to transition either to a silicon nanowire or silicon-based quantum dot absorber, which if successful will provide a path to efficiencies above 15 percent while using most of the existing manufacturing infrastructure.

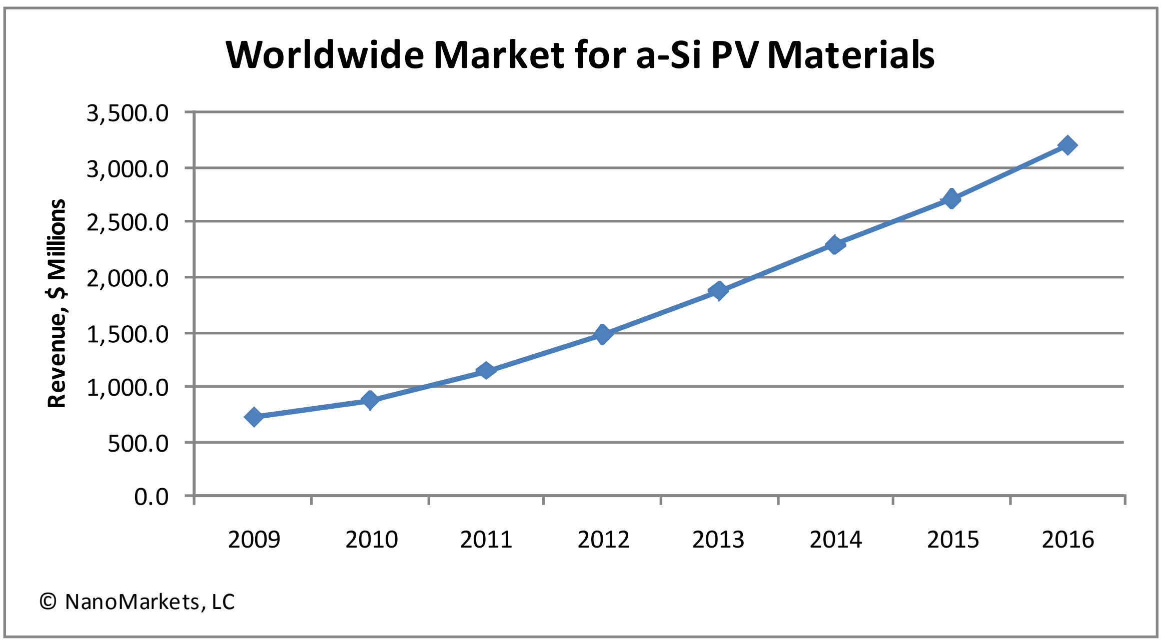
The other half of the equation is aggressive cost reduction. A significant cost reduction can be realized by higher levels of integration to the process flow. For example, the TCO can be integrated as an in-line process instead of a separate operation as is typically done today. Silane utilization and overall gas usage reductions are also areas where optimization and process improvements will result in cost reduction. Many of the other traditional fab metrics such as higher throughput, yield and uptime can leverage learning from the semiconductor industry and will also help, but these are second-tier improvements.

While a-Si is the dominant TFPV technology used today, near the end of the forecast period other approaches in the TFPV landscape will start gaining ground. For example, NanoMarkets expects CIGS to represent 8.6 percent of the TFPV market by 2011, and the organic cells are expected to take 8.9 percent of this market by 2011. However, there is a lot of installed capacity for a-Si with more in the works, so the relative decline in importance of a-Si will happen quite slowly. In addition, a-Si is the most likely technological route that will be taken by new entrants into the TFPV business, since manufacturing equipment and materials are readily available.

Exhibit E-2 and E-3 summarizes the eight-year market projections that are derived in more detail in the main body of this report.







E.5.1 Alternative Scenarios

The numbers used in the forecasts in this report are intended as a middle-of-the-road scenario for a-Si PV based on the latest available data. While this is the most plausible forecast, there are other scenarios that should also be considered. One scenario, the low-growth scenario, is a stagflation situation fueled by the recent massive increases in the money supply. A second scenario is long-term recession coupled with long-term deflation. A third possible scenario is a quick bounce back to high growth, and a fourth is high growth driven by government policy change.

The first low-growth possibility would be one similar to the stagflation of the late 1970s. In this case, the amorphous silicon BIPV market would be especially affected due to inactivity in the construction industry. In such a scenario, subsidies for the industry would likely be reduced or eliminated by cash strapped governments. We already see this happening with reduced subsidies in the largest TFPV markets of Spain and Germany. For amorphous silicon, one positive for the market is the fact that it is already well established.

The second scenario is a long-term recession coupled with long-term deflation. This is less likely than the stagflation scenario, but in this scenario the a-Si TFPV market and the entire PV sector would be severely affected. Much of the equipment for the newly constructed a-Si turnkey factories would be idled due to lack of demand, and there would not be any new construction for a-Si and competing technologies. The only opportunity for a-Si TFPV in this scenario would be as the economy emerges from such a downturn, the equipment that was idled going into the downturn for a-Si TPV would be available on the secondary market at a substantial discount.

There are several possibilities that could also drive a-Si PV back to higher growth rates. The first would be a quick end to the current recession. In this case, all of the drivers of growth in the early 2000s such as high energy demand and prices would drive demand for amorphous silicon PV.

A second high-growth scenario would be government policy changes that drive PV markets. The governments in one or more major countries may mandate either the use of PV or mandate carbon emissions standards that would drive demand for a-Si PV. The EPA now has the power to have a huge impact on the demand for PV without a new law ever being passed. Subsidies are another wildcard that can greatly affect growth of amorphous silicon PV. The recently passed stimulus bill has approximately $25 billion earmarked for green energy with $8 billion of that for wind power and another $10 billion in the area of low interest loans and grants for all renewable energy sources.

For additional information about this and other NanoMarkets' reports, please contact us at (804) 360-2967 or via email at sales@nanomarkets.net or visit us at www.nanomarkets.net.