Tin Markets for Photovoltaics

July 2009

Executive Summary

This report is one of a series of "Metals in PV" reports intended to fill a niche, targeting an audience interested in the covered metals as they relate to the photovoltaics (PV) industry. In the specific case of this report, the target audience is interested in tin as it is used in PV. Such an audience would be interested in portions of the content of NanoMarkets' recent reports on tin-doped indium oxide (ITO) and some of the other individual thin-film PV (TFPV) technologies, or on the range of materials used in TFPV. But even combining those reports would omit some valuable information relevant to tin's use in PV, and would include reams of information not directly relevant to the niche audience. This report, like the others in the series, offers an opportunity for the user to absorb NanoMarkets' extensive body of knowledge in the specific subject area of interest to the target audience, in a more concise format and with more comprehensive coverage than achieved by assembling multiple reports intended for broader audiences.

E.1 Overview of Tin Use in PV Manufacturing

In high-technology markets for transparent conductive oxides (TCOs), tin has generally played second fiddle to indium, because such markets are dominated by ITO, which is 90 percent indium oxide. Besides making up a larger physical proportion of ITO than tin, indium's price has bounced around about two orders of magnitude higher than tin and these two factors render tin pricing and markets almost irrelevant to the ITO market.

However, there have been some changes this decade in the TCO market for the PV industry. Largely because of its cost, ITO has lost its dominance in the PV market in terms of physical quantity consumed. Now, the market leader measured in terms of quantity consumed is tin oxide, and as such the markets for tin have become much more relevant. ITO is still the leader in the PV space in terms of revenues, but there is a growing majority of firms and production capacity that are using alternative TCOs, most of which are tin oxide.

That is not to say that PV is a big part of the tin market, or even the tin oxide market. Lower-tech applications such as window coatings dominate the tin oxide market, and this market is nothing compared to the volume of tin used for solders and containers. But PV is a rapidly growing component of the tin market and there are gains to be had by focusing and investing properly in this area.

While the monetary value of this PV-related tin market is only projected to grow to about $10 million by 2016, this represents a 15-fold growth over 2009. This is driven by rapid growth in the TFPV industry, which will consume 10 times as much tin oxide as it does today, and by rising tin prices. The rate of growth of TFPV will drive increased consumption of ITO in addition to tin oxide, and ITO consumption for PV will increase by a factor of five even though it is in fact losing market share in the TFPV sector.

E.2 Key Developments and Trends in the Use of Tin-Containing Materials in PV Manufacturing

The growth in tin oxide consumption by TFPV is driven mostly by its use in CdTe PV. Since First Solar is the only significant producer in this market, there is very little variation in TCO materials. First Solar's cells—and the tin oxide used in them—currently make up nearly half of the TFPV market, and that share is growing. Tin oxide, especially FTO, is especially suited to being applied directly onto a glass substrate, which is how it is done in First Solar's superstrate-configuration cells, often making it easier to apply than ITO under these circumstances. Tin oxide is also fairly tolerant of high temperatures after deposition, allowing a wider range of options for processing subsequent layers. While tin oxide is not quite as transparent or conductive as ITO, it can often maintain its transparency and conductivity better than ITO after thermal processing, and thus could offer superior performance to ITO after such processing. NanoMarkets expects tin oxide to continue increasing its share of the market for TFPV cells built in superstrate configuration on glass substrates.

For similar reasons, tin oxide is making gains by replacing ITO in many a-Si PV manufacturing processes. While this may appear at first to be a wash for tin consumption since it is a substitution of one tin-containing material for another, it is actually a net gain in tin use. ITO only contains 10 percent of tin oxide as opposed to tin oxide, which is 100 percent tin oxide. It is still a net gain even when one considers that zinc oxide is chosen as the ITO substitute for a-Si PV nearly as often as tin oxide.

Where tin oxide will not have such clear advantages is with TFPV cells built on flexible substrates, and on substrate-configuration cells even when built on glass. While tin oxide is still a strong and inexpensive performer in these circumstances, it loses an important advantage in its superior compatibility for direct application onto glass. TFPV cells on glass substrates certainly are not going away; they will always have applications for utilities and other large-scale projects as well as many smaller-scale ones including building-integrated glass-based PV products. But as flexible TFPV cells begin to make up an increasing portion of the PV market, we can expect tin oxide's penetration to significantly decline in this segment. First zinc oxide, and then non-TCO alternative transparent conductors—once they are demonstrated in high volume—will have a greater edge as ITO alternatives for these flexible cells.

The current state of the economy also has an impact on tin consumption in PV. As we have already mentioned, the ITO market is dominated by indium and its market, and is almost oblivious to the tin market. Since ITO in the TFPV industry has been—and still is—undergoing a slow "phase-out" that is largely due to its cost, the current (relatively low) cost of indium will have an effect. That effect will be to reduce the impetus for the shift away from ITO and thus slow the conversion somewhat. This means that growth in tin consumption by the PV industry will be slightly reduced, since these conversions boost tin consumption.

The development of non-TCO alternative transparent conductors—such as organic conductors, carbon nanotube (CNT) films, and other nanomaterials—will also have an impact on the TCO market for TFPV.

The effect of these newer materials will be seen in the OPV/DSC segment because development of these new materials is being driven largely by the organic electronics industry, which includes OPV/DSC. While one objective for developing these materials is to reduce costs (relative to ITO), the goal most relevant to the TFPV industry will be the materials' flexibility and ease of application. They will not have much of a cost advantage over non-indium-containing TCOs like tin oxide, and where TCO application is already easy—as in FTO applied to glass while the glass is cooling—we do not foresee conversion in the next eight years. NanoMarkets expects the foothold that these materials will eventually gain to be in flexible cells, where there are difficulties applying TCOs and where greater flexibility would be a significant benefit. But this will do little to dislodge tin oxide from where we expect it to be in this time frame—the preferred choice for transparent electrodes applied directly to glass.

Finally, deposition methods will have an impact on the market for tin in PV. Tin oxide is usually sputtered but often applied by chemical vapor deposition (CVD). The equipment used for CVD is generally less costly than that for sputtering because the high vacuum levels are not needed. NanoMarkets expects the amount of tin oxide applied using CVD (or a similar process, spray pyrolysis) to increase over the forecast period, resulting in a change in the types of tin-containing precursors used. While sputtering targets are generally made of compressed tin and tin oxide particles, CVD precursors are instead liquid-phase tin compounds, often organometallics.

Similarly, ITO deposition is usually done by sputtering, but there are some efforts to improve efficiency of material usage and ease of application by printing ITO with inks. This is likely to have some impact by the end of the forecast period and will require nanoparticle ink precursors instead of sputtering targets.

E.3 Opportunities for Mining, Refining, and Distribution Firms

While the PV-related market is a fairly small one for tin, its rapid growth and the aforementioned trends create opportunities for producers and distributors of tin. The customer base will shift toward TFPV suppliers for the high-purity tin that is required by high-performance ITO and tin oxide coatings. It will be important to develop relationships with these customers in anticipation of their growing demand.

There will also be something of a shift away from producers of sputtering targets and toward those of tin-containing CVD precursor chemicals, and to a lesser extent ITO nanoparticles for incorporation into inks. These intermediate products, besides being in higher demand, will also be critical to the performance of the PV manufacturers' processes and the quality of their products.

We also expect an increase in the application of tin oxide to glass during the glassmaking process. This will boost demand for tin from suppliers of tin oxide precursors to glass manufacturers. Besides the simple increase in demand, the type and required quality of tin is likely to change as well, since tin

oxide—and the precursors from which it is formed—for PV coatings is likely to require higher quality than that for the architectural glass market.

E.4 Opportunities for Tin-Based Materials Firms

Besides the growing demand for tin oxide by the PV producers, it bears repeating that the mix of intermediate products is also predicted to shift. While the demand for sputtering targets for ITO and tin oxide will increase rapidly along with TFPV growth, demand for CVD tin precursors, and probably ITO nanoparticle inks as well, will grow even more rapidly.

The quality of the films required, and thus the quality of the intermediate materials, will also be more important as the TFPV market makes up a greater proportion of the use of these films. While the tin oxide market for window coatings will not be significantly affected by growing PV volume, the growing PV sector of the market for tin oxide films is more sensitive to film performance.

Developing relationships with the PV producers will also be very important. In this fairly new industry, there is always potential for a manufacturer to find a benefit from new custom formulations of tin oxide precursor materials; collaborations will help to bring about these developments and the market niches they produce. These relationships can also allow tin suppliers to sell PV manufacturers on the benefits of tin oxide over other TCOs that do not use as much tin.

E.5 Opportunities for PV Manufacturers

The relationships that we have promoted between PV manufacturers and the tin producers and materials suppliers are as much for the PV manufacturers as they are for the other parties. They will provide such benefits as: allowing rapid development of precursor products to improve cost and performance of TCO films, especially tin oxide; ensuring attention to the volume of material needs; and providing expertise on the different material possibilities for these films and their precursors.

The trends that we have described in this report point to the development of two kinds of TFPV cells in terms of tin oxide use: cells built on glass substrates with transparent conductors (usually tin oxide) directly applied to the glass, and other cells in which the substrate is flexible or, if glass, not required to transmit light. NanoMarkets predicts that tin oxide will have a firm hold on the transparent conductor market for the first of these kinds of cells. Tin oxide may also continue to serve a significant portion of the second type of cells, but it will face strong competition from ITO and zinc oxide (which can be applied at least as easily, if not more so, over flexible substrates or underlying layers) and from newer organic conductors and nanomaterials (which are often intrinsically flexible and thus well-suited to flexible cells).

E.6 Summary of Eight-Year Forecasts

The growth of the PV industry has been very impressive over the last several years, driven by high and rising fossil fuel prices and growing concern about their geographical and political distribution and the

environmental effects of extracting and burning them. The growth of TFPV within the PV market has been even more impressive; it has been driven by the shortage and high price of silicon (consumed in large quantities per megawatt of conventional, c-Si PV) and its lighter weight and potential flexibility, in addition to the factors driving PV growth overall.

Also impressive is the success that alternative TCOs (especially tin oxide) have had in replacing ITO in TFPV. From virtually nothing in 2000, tin oxide now accounts for nearly half of the overall TFPV market for transparent electrodes. This has been driven mostly by First Solar's adoption of tin oxide for its front electrodes and its subsequent rapid growth, but it has been assisted by a high level of substitution of tin oxide for ITO in the a-Si PV segment as well. Taking a larger view, both of these trends have been most directly due to ITO's high price.

NanoMarkets expects the volume of ITO used for PV to continue to grow even as ITO continues to lose market share. This is because the growth of TFPV (particularly a-Si PV, which uses the most ITO) will be more rapid throughout the forecast period than the rate of ITO's loss in market share. Even though the proportion of ITO usage will decrease, the rapidly growing volumes will more than make up for it. But that is not the major tin-related opportunity here. Since tin is such a small—in terms of physical proportion and of cost—component of ITO, ITO will remain only a small portion of the PV-related tin market.

Instead, the major opportunity for tin in PV is in tin oxide. Tin oxide for PV applications already accounts for 10 times as much tin as does ITO for PV, and its use will also grow more rapidly. By 2016, tin oxide will account for more than 20 times as much tin as ITO.

Wider industry and economic trends of course also have an impact on the PV-related tin market. The current economic recession has depressed PV demand and thus demand for all of the materials used by the industry. This demand slump is more dramatic in the PV market than in many other markets because the economic troubles play into the very factors that influence PV demand even in good times. Fossil fuel prices are lower, construction starts are down, and concerns about the current state of the economy are diverting attention away from environmental concerns; these issues cut to what have been the roots of PV demand growth over the past decade.

Other issues, such as the end of the silicon shortage and a new shortage of start-up and venture capital funds, are also slowing the growth of TFPV as a proportion of the overall PV market. But PV overall and TFPV are both continuing to grow, albeit at a slower rate, even in the face of these challenges. The rate of growth of tin consumption by the PV industry has slowed along with TFPV, slowing perhaps even a bit more because of indium's relatively low price, reducing the rate of conversion from ITO to other TCOs including tin oxide.

The details of tin's role in the PV industry are explored in more depth in the main body of this report, but in Exhibit E-1 we report a summary of the findings for the tin-containing materials used by the PV industry by material type.

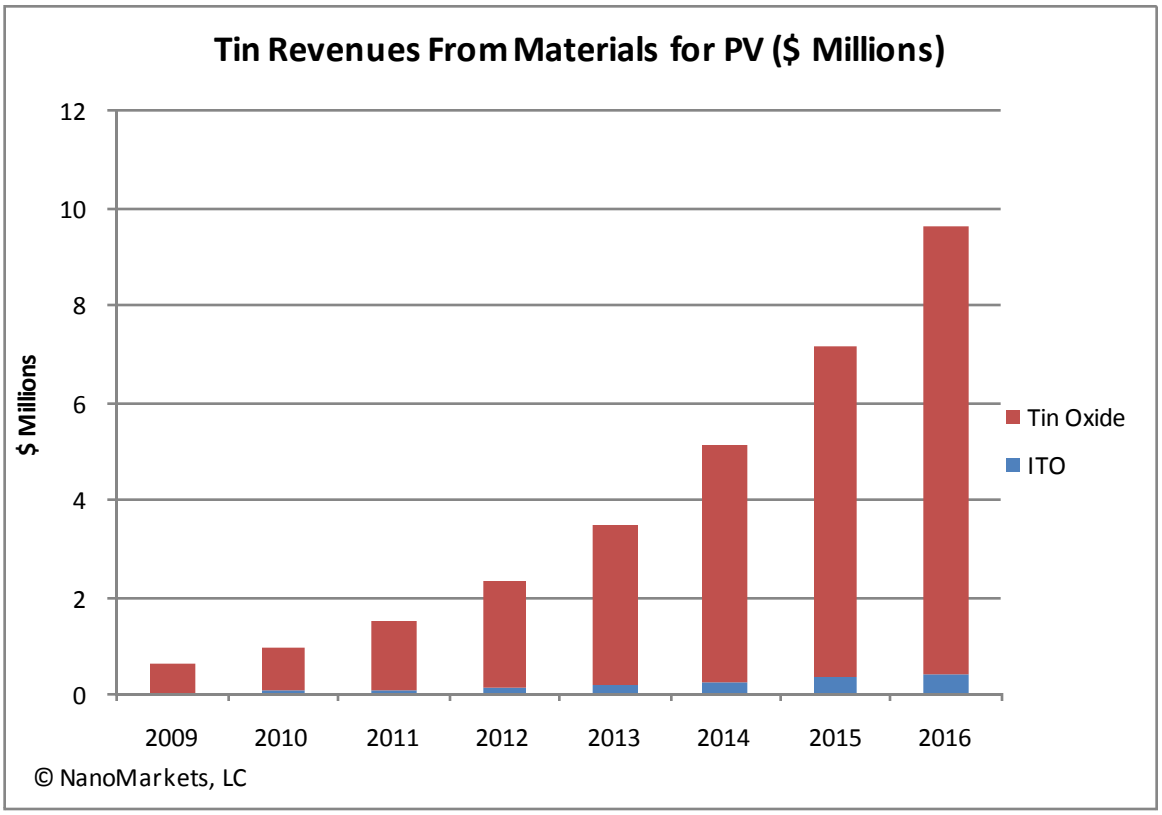
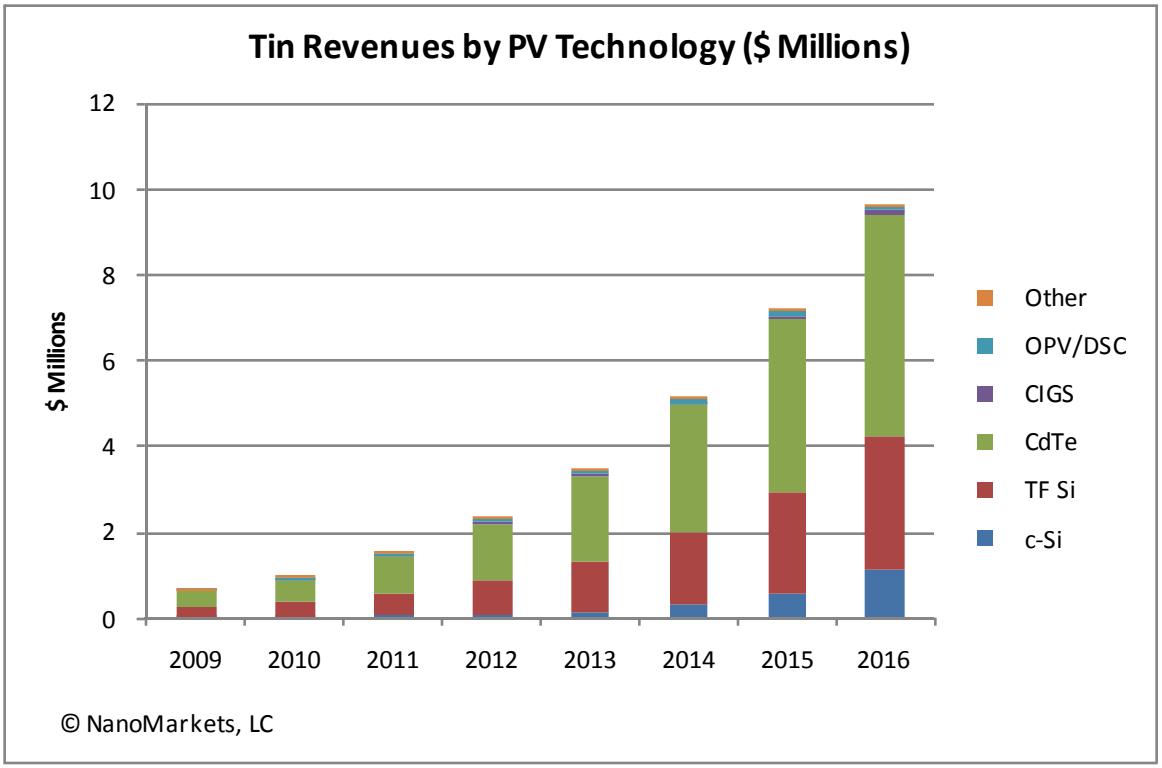


Exhibit E-1 makes clear another trend previously mentioned: the shift to different methods of depositing TCO films. ITO inks are being developed with the goals of improving required deposition conditions and the efficiency of material usage; growing use of CVD to deposit tin oxide is geared more solidly toward ease of application. NanoMarkets expects both of these trends to have some impact on the PV-related markets for these tin-containing materials. Tin oxide will be more affected than ITO, although both will continue to be deposited mainly by sputtering throughout the forecast period.

We have also mentioned that CdTe PV accounts for most of the tin oxide consumption by the PV industry; this carries through to the volume of tin consumed as well. Exhibit E-2 shows how tin consumption is distributed among the various PV technologies.


Tin Revenues by PV Technology ($ Millions)
$ Millions
12
10
8
6
4
2
0
2009
2010
2011
2012
2013
2014
2015
2016
Other
OPV/DSC
CIGS
CdTe
TF Si
c-Si
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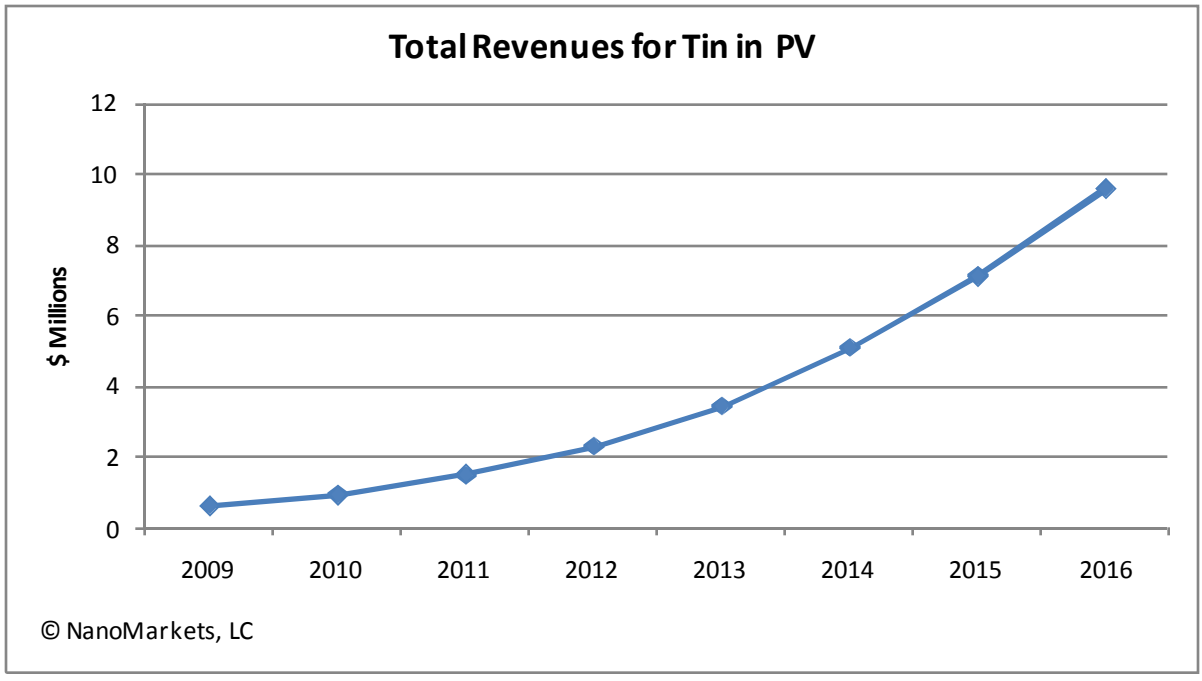
Total Revenues for Tin in PV
$ Millions
12
10
8
6
4
2
0
2009
2010
2011
2012
2013
2014
2015
2016
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After CdTe PV, TF Si PV accounts for the bulk of the remaining tin (and tin oxide) usage and growth, largely because it mostly uses superstrate configurations on glass substrates, which benefit from easy application of tin oxide directly to glass. Crystalline silicon is also shown to consume more tin-containing TCOs because of the growth of hybrid c-Si/a-Si cells, which use front electrodes similar to those used by a-Si.

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