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Silver Markets for Photovoltaics

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NanoMarkets, LC | PO Box 3840 | Glen Allen, VA 23058 | TEL: 804-360-2967 | FAX: 804-270-7017

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 industry. In the specific case of this report, the target audience is interested in silver as it is used or potentially used in PV. Such an audience would be interested in portions of the content of NanoMarkets' recent reports on Silver Inks and Pastes, individual TFPV technologies, or on the range of materials used in TFPV. But even combining those reports would omit some valuable information relevant to silver'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 Key Developments in the Use of Silver in PV Manufacturing

The most significant developments in the PV industry that are relevant to the use of silver are the tremendous growth of TFPV and the resulting lessening proportion of conventional, crystalline silicon PV in the overall PV market. These phenomena will lead to a fundamental shift in the quantities and types of silver materials needed by the PV industry.

That is not to say that c-Si PV is in decline. It will certainly not go away, and we expect it—and the silver inks that are used for it—to grow in volume throughout the forecast period. The silver inks used for this technology are well established as the standard material for a number of reasons, and we expect them to continue in their dominant position. Of course, innovations are possible and expected, but for the most part we expect these developments to be mainly with the ink formulations themselves. As they emerge, these newly developed inks for c-Si PV will still use silver but possibly as nanoparticles or as a composite or alloy with another metal.

While c-Si PV will continue to experience rapid growth, the TFPV technologies will grow even faster, and will make up the majority of the PV marketplace by 2015. The implications for the silver industry are significant. Silver is used in a similar way in some TFPV cells as it is in c-Si PV cells (as an excellent conductor, especially because it can be easily printed in patterns with low visual density, allowing most light to pass through). Some a-Si, CIGS, and OPV cells use silver in this way. The difference is that the silver used is secondary to a transparent conductor like ITO, used mainly to boost performance of the transparent conductor by reducing the distance current must travel through it. Finer lines, and a smaller quantity of silver, are permitted, and most cells do not even use the silver grids. On the other hand, all TFPV technologies are currently lower in conversion efficiency than c-Si PV, so a greater module surface area is required for the same power output. But overall, TFPV will use much less silver for the front electrodes than does c-Si PV.

Silver is also frequently used as the back electrode for c-Si PV, and in some cases for TFPV cells. Unlike c-Si, however, when silver is used as a back electrode for TFPV cells, it is used for its reflectivity as much as for its conductivity. Due to the low conversion efficiency and thin active layer thickness of some TFPV technologies, it is advantageous to reflect light that makes it to the back electrode (by passing through the active layer without being absorbed) back through the cell for a second pass. The most commonly used material for this "reflector" portion of the back electrode is silver. The silver used in this application is typically printed because of the ease of application, but the required resolution is much lower than required for the front electrode since it does not need to transmit light, and its thickness can be less because of its greater width. This shift toward the use of silver for its reflective properties against the back of the active layer is an important change for silver's use in PV, although growth in this application will eventually slow, too, as less-expensive, similarly reflective metals are increasingly used to reduce cost.

Another new opportunity for silver use in TFPV is in alternative transparent conductive materials. There has been a growing level of dissatisfaction with the current standard transparent conductors, especially ITO, which has been exacerbated by the recent high price of indium. In general, these materials are not particularly transparent or conductive; they just represent an adequate trade-off between those two properties. Many of them are also fairly brittle, which is a big drawback as applications and manufacturing methods begin to call for flexibility of the cells. Silver is a component of some of the proposed alternative transparent conductors. Some of these are dilute suspensions of silver nanoparticles or rods, some are simply ultrafine silver grids, and some are composite materials including silver among other components. These developments are largely being pressed by the organic electronics industry, including OPV, and successful implementation of silver-containing materials will yield a new hyper-growth market for silver as OPV (and other organic electronics) begin to take off. The effects of such a development would not end with OPV, since solutions that work well for OPV are likely to eventually be tried by the other TFPV technologies as performance and cost requirements tighten.

The silver materials market impacts the PV market as well. Development of new materials is generally a two-way street and silver materials producers share in driving it. As they participate in developing new formulations and morphologies, they contribute to the potential for improvements in performance and reductions in cost for the PV technologies that use them, as well as increasing the rate of adoption of these new materials.

E.2 Opportunities for Mining, Refining, and Distribution Firms

The silver industry is obviously much bigger than just photovoltaics, but the use of silver in PV is growing much more rapidly than the overall use of silver in other applications. Beyond collaborating with the PV manufacturers and the firms that produce inks for them, some of the opportunities for mining, refining, and distribution firms are evident. They fall into the general category of being prepared for the growth in silver volume consumed by the PV industry. But silver firms should also be ready for a shift in the mix of silver materials that are demanded by the PV producers. There are important subtleties to these opportunities, mainly due to the changing market shares among the various PV technologies.

For instance, since TFPV is taking an increasing share of the PV market—and using less silver per unit area than c-Si PV—the growth of silver consumption will not be as great as the growth of PV device volume. But the market shift toward TFPV will also result in demand for different kinds of silver materials. The fingers printed on some TFPV cells can be thinner than those on c-Si PV cells, and manufacturers will benefit from higher-resolution inks, especially nanoinks. Cost concerns will also favor thinner silver layers for back electrodes, which can similarly benefit from finer ink materials.

Besides silver materials for inks, there is also a market for new types of transparent conductors for thin-film electronics, including PV. Some of these will be composites containing silver. The form of the silver used in these composites may be different from that used for inks. For example, some composites use needles, nanorods, or nanowires of silver in combination with other transparent materials like ITO or PEDOT.

Finally, there may be some opportunity to provide silver as an alloy or as a coating on other materials, mainly to reduce the quantity—and cost—of silver used. For instance, alloying silver with various metals reduces the quantity of silver consumed with only small or moderate reductions in conductivity (and can also have the benefit of reducing silver's tendency to form dendrites); using nanoparticles consisting of a shell of silver around a core of a less costly metal keeps the silver where it is most beneficial for conduction—at the surfaces of the particles and at the connection points between particles—while reducing the overall cost of the silver used.

E.3 Opportunities for Silver Paint and Ink Firms

Some of the same considerations for silver-producing firms are also opportunities for silver ink firms. Collaborations with the PV producers will be critical to developing new types of silver inks that will lead to performance and cost improvements. As the PV producing firms achieve truly high volumes of manufacturing (as has already happened with c-Si PV and some manufacturers of a-Si and CdTe TFPV) they will become very sensitive to changes in ink compositions and formulations, but there are still likely to be significant opportunities for improvement through collaborative modification of the inks. This opportunity is even greater in collaborations with companies and in technologies that are still undergoing a high level of development, such as CIGS PV and OPV.

The emergence of silver nanoinks is obviously a significant PV-related opportunity for ink firms. The shift toward TFPV is allowing thinner silver fingers on the front electrodes, where silver fingers are still used at all. For back electrodes, even for c-Si PV, cost concerns will drive manufacturers to seek thinner silver layers and silver nanoinks promise to provide the performance boost that will allow this.

Inks composed of an alloy or of core-shell particles, such as silver-coated copper particles, can provide a different path to cost reduction, by substituting some of the silver with a less costly material. Core-shell particles are particularly interesting because the center of a particle is the least involved in conduction. As far as composite transparent conductors containing silver, many of these will be in the form of inks and will probably fit well into a silver ink firm's product portfolio. The morphology of the silver particles may be different from the conventional silver inks, perhaps silver nanorods or wires instead of (roughly) spherical particles or flakes.

Another important opportunity for ink firms is the emergence of different printing processes for applying the silver electrodes to PV cells. Screen printing is, and is expected to continue to be, the dominant method of application, but with PV entering into high-volume manufacturing, there are opportunities for the use of new printing processes like gravure, especially for roll-to-roll production of the TFPV cells rely on flexible substrates. Ink formulations for gravure printing and other processes are likely to be a continuing area for development.

E.4 Opportunities for Solar Panel Firms

As has been mentioned in discussion of the opportunities for other kinds of firms, collaboration is also an important opportunity for PV device manufacturers. Silver is the most conductive metal available, and the fact that its oxide is also conductive makes it an excellent choice for conductive inks. Collaboration with ink suppliers and other silver material suppliers can yield lower-cost silver materials, either by improving the performance of those materials to enable the use of less, or by reducing the silver content of the materials while still maintaining high levels of performance. As the end-users of these silver inks and other materials, PV manufacturers are uniquely aware of the performance and processing requirements for the silver inks used in their processes. Naturally, they will also be the key drivers for performance improvements.

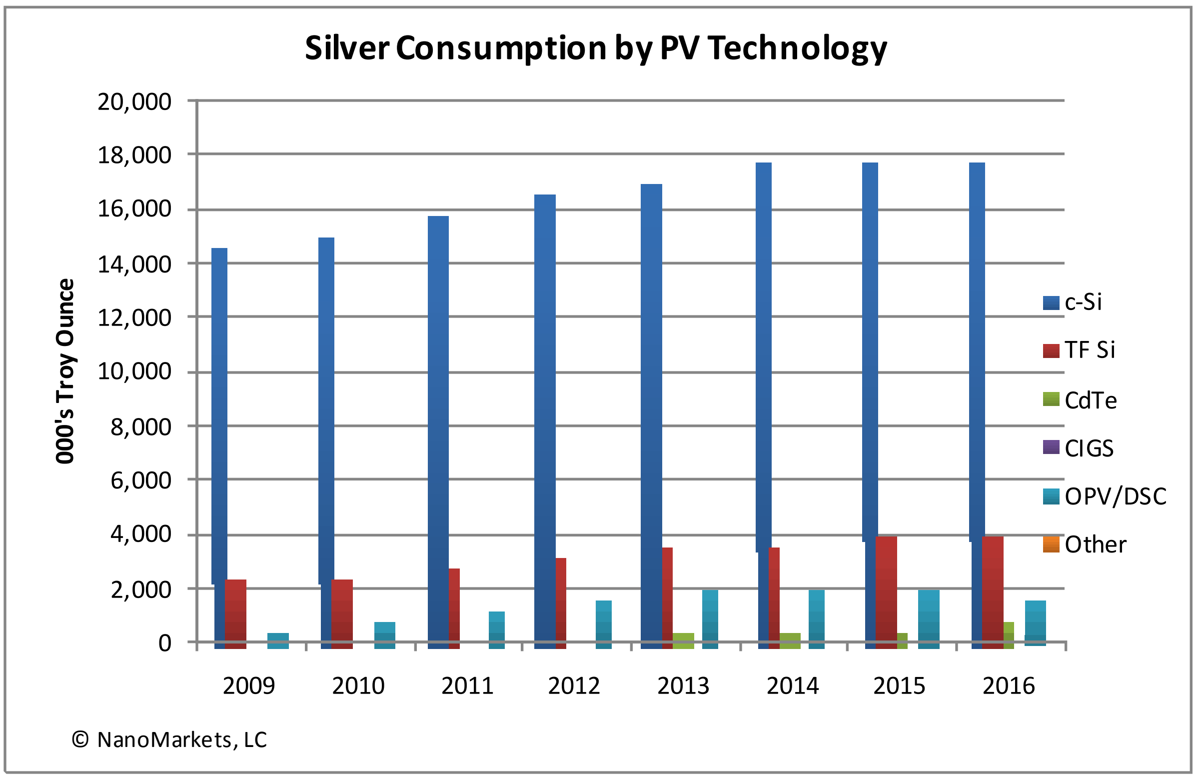
Photovoltaics is a broad field, and the other applications that use printed silver form an even broader field. Some of the less-established, still-developing applications, such as OPV and other organic electronics, are pursuing a wide variety of innovations with regard to conductors, transparent or not. PV manufacturers (and researchers) have an opportunity to learn from the use of silver and other conductive materials in the other PV technologies and even other non-PV fields. Developments in one area may yield similar opportunities in other areas. Because they are similar in their use of conductors (and reflectors), the other TFPV technologies are likely to benefit eventually from the development of new conductors for OPV.

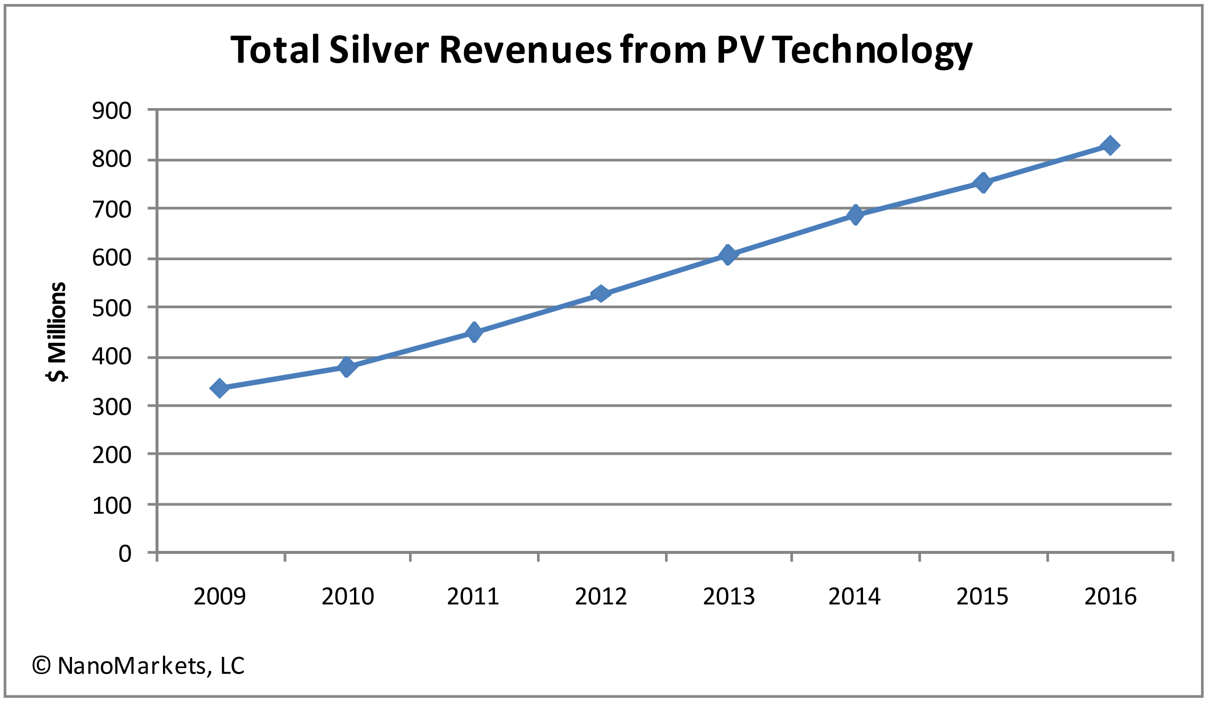
E.5 Summary of Eight-Year Forecasts

The growth of the PV industry over the last several years is quite impressive, driven by high and rising fossil fuel prices and growing concern about their geographical/political distribution and the environmental effects of extracting and burning them. Even more impressive is the growth of TFPV, which 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.

NanoMarkets expects both of these trends to continue throughout the forecast period, although they will both be somewhat subdued for the next couple of years due to a number of factors resulting from the current economic recession. 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 are slowing the growth of PV demand overall. Other issues—the end of the silicon shortage and a new shortage of start-up and venture capital funds—are slowing the growth of TFPV as a proportion of the overall PV market. But both growth trends are continuing even in the face of these challenges. As the economy improves in the mid-to-latter part of the forecast period, NanoMarkets expects these growth rates to pick up again as well.

The focus of this report is on silver's role in PV, so the relationship between silver and the PV technologies is explored in depth in the main body. The implications for silver consumption by each of these technologies are summarized in Exhibit E-1.





As is evident in Exhibit E-1, c-Si PV is by far the largest consumer of silver among the PV technologies. Besides its higher volume of PV cell production, c-Si PV also relies on thin printed fingers of silver as front electrodes, in contrast to TFPV which instead uses a transparent conductive front electrode and only occasionally adds silver fingers to it. Silver is frequently used as a back electrode for c-Si PV (and some TFPV technologies) because of its ease of application and, in the case of the TFPV technologies that use it, because of its reflectivity. When silver is used as a reflector in conjunction with its use as a back electrode, light that is not absorbed on the first pass through the cell can be reflected back through for a second pass, boosting cell efficiency.

As has been mentioned, TFPV uses a transparent conductive front electrode and only occasionally uses silver fingers on top of it. But included in the front electrode category, along with these fingers, is silver used as a component of a transparent conductor. Substitutions for the standard transparent conductors (especially ITO) are being sought for many applications but their development is being driven largely by the organic electronics (including OPV) industry. Some of these transparent conductors are composites that contain silver.

The growth rates of these different types of silver materials are interesting. While conventional silver inks will continue to be dominant throughout the forecast period, newer nanoinks (developed to improve resolution and other performance characteristics, perhaps also reducing the quantity of silver needed) are expected to grow in use more rapidly. The composite transparent conductors mentioned above, while not in significant use yet, are also expected to grow rapidly especially when (and if) they are demonstrated successfully in volume in OPV and other organic electronics devices, because they would then be likely candidates for adoption by the other TFPV technologies. This growth is projected to just be getting started by the end of the forecast period.

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