NanoMarkets Report

Transparent Conductor Markets – 2012

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NanoMarkets believes that the next few years will be a turning point for the transparent conductor (TC) business. We foresee opportunities for novel TCs where, for the first time, newer materials have unquestionable market advantages over ITO. This report provides the necessary strategic insight into how TC firms can best generate new business revenues from the rapidly changing business environment in the display and solar panel sectors. It also provides insight into niche applications such as smart windows, BIPV, etc.

Manufacturers of alternative TCs have looked toward the day when flexible displays hit the market, since ITO cannot be used in such displays. That day is now at hand with the first flexible displays from Samsung hitting the market within a year. In this report, we examine how the revenue opportunities will play out for alternative TC makers in this exciting new application area.

TC makers can also look to this report for guidance on opportunities in the OLED display and lighting sector. ITO is not a very effective TC for OLEDs. In this new report, we show how firms offering TC solutions other than ITO can benefit from the considerable growth expected for OLED industry.

Other high-growth display markets for TCs are also analyzed in this report. For example, we see transparent displays as having considerable potential for growth for both signage and augmented reality applications. And we expect transparent displays—almost by definition—to have special requirements for the TCs that they use. In fact, the report discusses a broader range of opportunities for TCs in the "transparent electronics" sector such as those in smart windows and BIPV glass.

In addition, this report examines opportunities for TCs in more established parts of the display sector. It takes an in depth look at the use of touch-screen technology which is highly suitable for novel TCs. However, there are so many TC firms crowding into this sector that a legitimate question is whether this relatively small market is about to become saturated. This is a question that this report answers. And it also tackles the thorny issue of whether novel TCs can ever displace ITO in the LCD business.

The comprehensive coverage of this report extends beyond the display sector and includes pinpointing the best prospects for TCs in the solar industry. Recently, PV opportunities have been constrained by the influx of low-cost c-Si panels from China with limited need for TCs. In this report, NanoMarkets discusses how the logic of Chinese industrial policy now suggests a revival in the thin-film PV market that will create new opportunities for TCs.

In this report, Chinese industrial policy is also examined for what it will mean for ITO pricing and availability. Whether indium prices really have an impact on the TC market has been a controversial subject and this report cuts to the chase and shows

how the ITO supply chain is really likely to evolve going forward in context of what is planned for the Chinese display, PV and indium industries.

Finally, this report analyzes important developments on the TC materials front and it takes a peek at what the next generation of transparent conductors will look like and how these materials will extend addressable markets. This study also contains detailed eight-year forecasts in volume (square meters) and value terms. For each of the applications covered there are breakouts of demand for ITO, other TCOs, ITO/TCO inks, carbon nanotube films, silver-based transparent conductors, other nanometallic transparent conductors and conductive polymers. And there is also a forecast of ITO products by type (sputtering targets, films, coated glass, etc.). Finally, the strategies of the leading TC firms are also assessed in the context of the latest market developments.

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Chapter One: Introduction

1.1 Background to this Report

1.1.1 The Year 2012 Will Be A Quiet One for the ITO Alternative Business

In the past two years, there has been considerable excitement in the transparent conductor (TC) market, generated by the commercialization of alternatives to indium tin oxide (ITO). Broadly speaking, these alternatives have consisted of (1) transparent conducting oxides (TCOs) other than ITO, (2) various silver/nanosilver coatings and inks, (3) nanocarbon; mostly nanotube preparations, but more recently graphene too and (4) conductive polymers; mostly PEDOT.

And there have been some successes too. For example, the pioneering nanosilver inks firm, Cambrios, can point to touch-screen displays that will routinely use its material as a transparent conductor. Manufacturers of conductive polymers can also point to a few real successes; products that can be bought today, that use conductive polymers where they might have once used ITO.

This is all well and good. But ITO alternatives have not exactly boomed. Both alternative TCOs and nanocarbon solutions, in particular, have failed to show that they are much of a threat to ITO in the way that they were supposed to. When NanoMarkets talks with firms in the mainstream ITO business, they seldom show much interest or knowledge of ITO alternatives and are deeply skeptical of these alternatives as a paying proposition.

The first charge into the TC market by carbon nanotube ink makers—Eikos and Unidym—is now largely history, despite some breathless over optimism for these materials in the past. (We note that graphene is getting a similar treatment these days.) And on the TCO front, claims from a few years back that IZO would account for 30 percent of the TC materials used in the mainstream LCD business seem to have been way off. While one can point to Cambrios' success in the ITO alternative market, there are few other companies who NanoMarkets sees as being in the same league as Cambrios in this regard at the present.

Given all of this, NanoMarkets expects 2012 to be a fairly quiet year for TC markets, at least in terms of public announcements from the materials suppliers. This may partially reflect the generally poor state of the global economy and the absence of dramatic developments on the technology front.

Growing emphasis on business development: However, behind the scenes, NanoMarkets believes that there are important business development efforts going on that are either not public and—if they were—would not be especially newsworthy. For the suppliers of ITO alternatives, most of this BD work consists in the essential, but very time consuming, process of getting IP licensing squared away and working with important end users on six- to 18- month trials of new materials. Our impression is that, on the whole, this process is going fairly well, although no doubt there are stumbles along the way. *In any case, developments of this kind should be recognized as progress; albeit slow progress.*

Market reevaluation: What NanoMarkets also sees going on behind the scenes is a serious rethinking of what the appropriate markets for ITO alternatives really are and what are realistic

expectations for these materials. NanoMarkets believes that in the past, the arguments for why ITO needs replacing have not been especially well thought through.

What is prompting this reevaluation, we believe, is not just the current—and likely future—performance of the TC materials themselves, but also the emergence of new markets for TCs such as flexible electronics, transparent electronics and OLED panels that appear to enhance the competitive advantages of alternative TCs over ITO. Until recently, the alternative TC sector seems to have focused heavily on the relatively small touch-screen display sensor market as a way of generating first revenues.

From the perspective of the suppliers of ITO alternatives, the big question remains how far ITO alternatives can penetrate the mainstream LCD business in the long run. This is a core theme throughout NanoMarkets' analysis of the TC market, because if the LCD makers begin to adopt alternative TCs, manufacturers of these newer materials will suddenly find that their addressable markets will grow by an order of magnitude.

The penetration of the LCD market by non-ITO TCs will not be easy to achieve, but in 2012 and beyond, manufacturers of alternative TCs can at least imagine a prosperous future in which they can sell into some of the newer applications sectors mentioned above, where there is reason to suppose that their offerings will be more easily adopted than in the LCD market.

NanoMarkets believes that the reevaluation process described above is just beginning in the TC industry and most probably will also not be carried out very publicly. However, we also think that the end result will be a stable and profitable alternative TC business. For these reasons we think that 2012—while not an exciting year—will not be the end of the world; at least not for alternative TCs!

1.1.2 The Arguments Against ITO Should Be Reconsidered

The ITO alternative business got its start, almost a decade ago, when it was noticed that its potential market was growing rapidly, primarily because of the appearance of flat-panel displays. At the same time it was claimed that ITO was commercially vulnerable in at least two ways; ITO was a high-cost and it tends to crack relatively easily.

NanoMarkets' impression has been that what has really put the wind in the sales of the alternative TC market has been the view that ITO is a high priced material, which in turn is because of the high price of indium. For a while this seemed like a convincing argument; the price of indium had been going through the roof and finally reached $1,000 per Kg, with at least one forecaster saying it would go to $10,000 eventually. This, it was claimed, would raise the price of ITO to such a point that alternative TCs would rush into the market and do extraordinarily well.

This apocalyptic scenario never came close to being true. In fact, indium prices have now fallen to a fairly stable $500 per Kg; a price that does not seem likely to send display makers rushing out to buy alternatives to ITO. This has been widely acknowledged, to the point that in the past 18 months, deference has been given to an argument that the price of indium isn't really much of a factor at all.

What is typically being said here is that the cost of putting down a layer of ITO is in the $25-30 per square meter range and that indium's contribution to this cost is miniscule. This argument is easily "proved," it seems, by a fairly simple cost analysis that shows that the vast majority of the cost of

an ITO layer is in the processing and that the actual cost of the indium used in that layer is very small indeed.

One assumes that among other things, this argument means that there is not a great deal of point in pursuing ITO alternatives on the grounds of the rapidly rising price of indium.

In fact, and this is seldom pointed out, neither the "indium is too expensive" and "the price of indium doesn't matter" arguments are well thought out arguments; although they certainly seem that way at first hearing. The point here is that the end users of ITO don't care about the price of indium; they do care about the price of ITO. *So, from the perspective of ITO users, what would be most relevant would be an understanding of how the price of ITO varies with the price of indium.*

This is a purely empirical question, but one that remains to be answered, at least publicly. For while there is considerable data about the price of indium—it is a traded metal, after all— there is almost no such time series for ITO prices. So even a moderately accurate assessment of what indium price changes mean to the TC industry is impossible.

1.1.3 A Better Case for Alternatives to ITO in 2012 and Beyond

Faced with the fact that we may never know quite how ITO prices vary with the price of indium, manufacturers of alternative TCs have a number of options. They can, of course, continue to make unsubstantiated claims about the high prices of indium and how this makes the case for their alternative formulations. We have no doubt that this is what they will do to some extent and that these efforts will work to some extent. However, in the light of the above analysis, this strategic approach seems likely to have limited impact in the long-run.

Lower total costs: A more fruitful approach would seem to be to focus on a claim that alternatives to ITO offer lower total costs, primarily because they are associated with lower manufacturing costs. This case is relatively easy to make and, as it happens, is also often more valid than simply looking at changing material prices. Usually, this analysis is based on the undeniable fact that ITO deposition is a wasteful sputtering process using expensive equipment, while some of the most interesting alternative TCs use additive solution processing equipment with far less waste and lower capital costs.

At far as this goes, NanoMarkets thinks that the lower *total* cost argument is a good one and will be (and should be) part of the marketing strategy of any firm that is offering a new material for consideration as an alternative to ITO. The only problem with the total cost approach in this case is that this point has been made for a long time and clearly has not made major users of ITO rush to buy alternatives. We can see no reason why this would change in the future:

- One reason, that the total cost approach can be less convincing is that—whatever the total cost of ITO alternatives may or may not be—they are almost always of lower performance than ITO and to some extent that may be inherent in precisely those processes that are being touted as less expensive; solution processing being the main case in point. *This is one good reason why today's ITO users shy away from switching to ITO alternatives.*

- The other relevant fact is that comparisons of capital expenditures between conventional sputtering and less conventional solution processing technology are easier to talk about than assess in practice and vary from user to user. For example, using depreciated sputtering equipment may be less expensive than using new solution processing equipment. In addition, in a capital expenditure comparison in which much depends on depreciation, the choice of depreciation method used in calculations becomes important. Engineers tend to assume that the appropriate method is straight-line depreciation, but this is not necessarily the view that would be taken by a competent management accountant.

Uncertainties, China and the future of alternative transparent conductors: *The other factor that needs to be taken into consideration in any assessment of the prospects for alternative TCs are market uncertainties. NanoMarkets believes that various market uncertainties are currently powerful enough that they are in effect shaping the market for ITO and its alternatives. However, these factors work both in favor and against novel alternatives to ITO.*

On the negative side of the equation, is the fact that—to put it colloquially— "better the devil that you know." In the seven years or so that NanoMarkets has been covering the TC space, we have yet to come across anyone—user or supplier—that sees ITO as a wonder material. It is—some would say—a bad material, but just better than everything else. The point here is that ITO is a known quantity, while carbon nanotubes, graphene, silver nanowires and even conductive polymers come with many uncertainties attached to them in terms of both performance and lifetimes.

There is, however, a different kind of uncertainty that NanoMarkets sees factoring into the argument for alternative TCs, but in a positive sense. And this is the uncertainty associated with indium supply created by the present Chinese government's approach to industrial policy.

Depending on who one listens to, China currently controls between 50 and 70 percent of the world's supply of indium, so Chinese national policy with regard to this metal is very important to the future of indium. And since well over 80 percent of all indium is used for ITO, what the Chinese government says about indium is important to the TC business as well.

For the past few years, the Chinese government has made indium the focus of policy in two senses. First, it has closed some zinc extraction facilities that produce indium for environmental reasons. Second, it has taken the view that Chinese indium suppliers are not getting a high enough price for this metal; so Chinese indium exports have become the subject of export controls.

In the more recent past a new and important factor involving Chinese regulation has been thrown into the ring. Both formally—through its current five-year plan—and informally, the Chinese government is now strongly committed to shifting Chinese industry to one that produces higher-value products and is more concerned with supplying the needs of the burgeoning Chinese middle class. The government has targeted specific high-tech industries for rapid development and this includes some that make significant use of ITO; displays and PV panels, most notably. It is therefore fair to assume that Chinese indium will soon start to be reserved for domestic ITO makers and this domestic ITO will be used in Chinese displays, solar panels and other products.

Some of these "domestic" panel manufacturers may well turn out to be foreign-owned firms that move to China to benefit from a vibrant Chinese domestic market and therefore will have access to local Chinese-made indium/ITO. *Nonetheless, NanoMarkets believes that this radically new situation will soon create significant uncertainties for the ITO market.*

These uncertainties are uncertainties of *access*. To what degree will access to ITO through established channels dry up? And so on. Such questions will, most probably, translate into OEM and display makers' fears that can be exploited to some extent by the makers of ITO alternative materials.

So here is an uncertainty—which unlike the technological uncertainties associated with novel materials—is actually positive for the makers of alternative to ITOs.

Nonetheless, NanoMarkets believes that there is a window of opportunity for manufacturers of ITO alternative materials to exploit this opportunity. While there are some legitimate reasons for worrying about access to indium and ITO in the short- to medium-term as the result of the latest Chinese policies, there seems little reason for these worries in the long run:

- Indium is not a rare metal per se and there are plenty of other potential sources for it outside of China; in Latin America, for example. If prices start to rise above a certain point, there is little doubt that other sources will emerge in a few years.

- There are also some reasons to doubt the efficacy of Chinese indium policy in the first place. After all, there is no evidence that Chinese export policy with regard to indium has had much impact on price. *Demand from end-user markets seems to be a more powerful factor in determining indium/ITO prices.*

1.1.4 OLEDs, Flexibility and the Transformation of the End-User Market for Alternative Transparent Conductors in 2013

With this in mind, NanoMarkets believes that, while the changes in the indium supply that we expect to see as the result of Chinese indium policy will benefit the firms manufacturing novel TCs, the effect could be temporary.

What the alternative TC business really needs to develop a sustainable business, however, are new applications where (1) the advantages of alternative TCs are fairly clearly understood and (2) market penetration by these materials is not as hard to achieve as in the conventional LCD market. There are now several applications where alternatives TCs now seem well positioned. And some of these have only just begun to appear.

The ongoing market evolution and spread of touch-screen technology: The alternative TC firms are already crowded into the touch-screen sensor sector, which they rightly see as having performance requirements that are well matched with what these firms' new materials can offer right now. The alternative TC providers also correctly perceive that the touch-sensor firms do not have the same level of commitment to ITO that the mainstream display firms. And there are many touch-screen sensor firms, and just a few mainstream display firms.

The problem is that the touch-screen sensor market will probably never be that large and for the reasons just explained it is getting crowded with prospective TC suppliers. It is expected to grow

fast, so the current focus of the alternative TC makers on this sector will most probably be rewarded to some extent at least.

A resurgence of thin-film solar panels: For the past few years, crystalline silicon (c-Si) panels manufactured in China and sold at very low prices have been crowding out thin-film PV (TFPV) technology in the solar panel space. However, as noted above, current Chinese industrial policy favors moving Chinese high-tech industry to higher value added products and we think this will mean the end of the subsidized Chinese c-Si solar panel era within a year or so.

TFPV—unlike c-Si PV technology—makes extensive use of TCs and is the one applications sector where ITO has largely been dispensed with. Which TCs are the best for TFPV has not yet been fully determined, although non-ITO TCOs are by far the most frequently used alternative to ITO. The choice of ITO alternative being used depends on the specific absorber layer being used. But if the TFPV market revives for any reason—it is good news for ITO alternatives.

OLEDs and OLED lighting: 2013 shows every sign of being the "year of the OLED." For the past few years, active matrix (AM) OLEDs have become successful in the smartphone sector and seem likely to become even more popular in 2013. Beyond that, the first really commercial OLED televisions should be widely available by then and OLEDs are also expected to have a presence in the tablet computing market.

Although OLED lighting is not expected to go mainstream until the 2015-2016 period, we would also expect the availability of luxury luminaires using OLED panels to become more wide spread in 2013 and beyond, with their prices dropping to a point where the addressable market for these lighting products will have expanded to include the upper middle class and not just the very rich.

NanoMarkets believes that we can reasonably assume that OLED panels will emerge as an important market for transparent conductors over the next five to 10 years. Apart from in some trials, all OLEDs to date have made use of ITO. However, there are some major questions hanging over ITO's continued use as a TC. One major issue here is the fact that ITO does not make smooth films. This can result in color distortions and electrical distortions. In addition, ITO has a chemically active surface that can lead to ions diffusing into other layers of the OLED stack. And for large panels—notably large OLED lighting panels—ITO is inadequate to spread the voltage adequately resulting in uneven lighting.

It far from clear yet that ITO alternatives can offer better than ITO, but what is clear is that these and other similar problems open up a new front for manufacturers of ITO alternatives to battle on. We also note that the OLED community—especially those involved with lighting—are very open to replacing ITO and this has been a focus of important R&D projects. Materials cost is also of especial importance in the context of OLED lighting, because the business plans of most OLED lighting firms call for prices to fall to a point where OLED lighting panels are widely affordable.

While the touch-screen and TFPV market mentioned above offer opportunities for the newer TC materials, they are already markets targeted by the alternative TC sector. The OLED market because of its potential for growing to a very large size in a reasonably short period of time is an emergent market for new TCs.

For now, however, ITO seems to be fairly entrenched in the OLED space, but NanoMarkets believes that there are good prospects for OLEDs to migrate away from the use of ITO en masse

in the next few years. That said, one factor in the OLED space that is seldom mentioned though is that the OLED displays only need one transparent electrode, so a shift from LCD to OLEDs could impact the overall addressable market for TCs quite negatively.

Transparent electronics: Another new area, which NanoMarkets believes could yield new revenues for the transparent conductor market is "transparent" electronics. We take transparent electronics to be something of a catch-all category that includes transparent displays, smart windows, BIPV glass, and other "smart glass" applications.

This area may eventually include some very innovative products; panels that are windows by day and lights at night and may also have PV capability, for example. But this kind of thing would seem to lie well off in the future. For now, we are talking about mostly smart displays (for signage and augmented reality), smart windows (a market segment that is receiving considerable attention at the present time) and BIPV glass (another fast growing segment).

We are not aware that any of these sectors are crying out for new kinds of transparent conductors, but they all use transparent conductors to a significant extent and all these sectors are high growth areas, so at the very least we are looking at a new high-growth niche area for transparent electronics. With regard to growth potential a particularly exciting possibility is that the rise of "augmented reality" will push an additional (but small) transparent display into all high-end tablet and smartphone products. It is known that Apple is seriously considering this possibility for iPhones and iPads.

What will happen with this sector with regard to its use of transparent conductors is highly speculative. Obviously though, optical transparency could become a competitive issue in this sector. There is probably no alternative to ITO that could do a better job than ITO at the present time. But this may change going forward.

Flexibility and R2R: Flexible displays are also expected to appear in 2013, most notably from Samsung. This is an event of potentially enormous import to the TC community because even firms with their roots firmly in the ITO industry do not believe that ITO can take the punishment that a flexible display would create.

The point here is that potentially flexible displays could be something like a "killer app" for ITO replacements because it is the one area where ITO is not still seriously competitive with alternatives to ITO. So if the display market started to make wide use of flexible substrates, this would fundamentally change the opportunity space for alternative transparent conductors. Suddenly, the alternative TC sector would change from a niche business, which is apparently trying to pick up crumbs from the touch-screen display sector to one that addresses the needs of a much larger market.

The big question is then, how quickly the flexible display market can evolve. Unfortunately for the makers of alternative TCs, we now think its evolution will not be fast. There are already a few semi-flexible displays on the market and there will be a growing number of such products in 2013 and beyond. However, the big driver for intrinsically flexible displays was supposed to be as plug-in displays for smartphones that would enable users to have access to larger displays. But this type of demand now seems to be satisfied through the emergence of tablet computing.

Outside of intrinsically flexible displays, displays may also be fabricated on flexible substrates in order to derive the improved economics associated with R2R fabrication. Once fabricated, these displays are then rigidly encapsulated. This already happens to a limited degree with both OLEDs and e-paper. Whether ITO is flexible enough for a fabrication method in which it has to travel round rollers a few times seems to be somewhat controversial. We have been told by highly knowledgeable and unbiased sources that ITO could not survive such a process. But we have also been told that ITO is already being used in this way to a limited degree.

This question of the viability of ITO for R2R extends to some extent into the coming world of "flexible" displays. It seems that the first flexible displays, will not so much be flexible in the usual sense, but rather curved. It seems possible that ITO could be used in such displays. Whether ITO could be used in the next stage up for flexibility—i.e. conformability—is questionable. In any case, no one thinks that ITO could be used in rollable displays of any kind.

But while flexible displays are inevitably seen as the poster child for flexible electronics, it is certainly not the actual or potential example of it. Flexible electronics might be taken to include large area sensors, smart packaging, and flexible solar panels. The latter are especially important because flexible solar panels are already used to a limited extent. These tend to use TCOs, which may add something to the argument that ITO and other TCOs can survive if only limited flexibility is involved.

NanoMarkets believes that flexible PV will have increasing usefulness in BIPV installations where it helps to reduce costs in a number of important ways. As such, flexible BIPV may well turn out to be a significantly sized and growing market for TCs during the next decade.

1.1.5 The Next Generation of Transparent Conductors: Coming Soon?

As all of the above indicates there have not been many exciting announcements from manufacturers of TCs in 2012. Silver-based TCs have continued to demonstrate promise and some interesting announcements have come out of research labs about alternative approaches to TCs that will not be revenue generating for another five to seven years.

Such new materials fall outside the scope of NanoMarket's current analysis for the most part, but they do raise and issue that we think is worth serious consideration and will take up again. This issue is what the next-generation TC materials might look like. With this in mind, we note that, as we have indicated above, ITO is demonstrably not the perfect TC, while today's alternative TCs do not seem to be powerful alternatives.

This suggests that the search for better TCs will continue. In the past year, graphene has received some attention in this context. Also, while it has yet to get much airtime, our conversations in the TC community suggest that composite materials that, for example, mix silver and copper nanomaterials, or mix nanomaterials with polymers have some potential. These kinds of materials are not likely to generate significant revenues for quite a few years, but we expect them to account for an increasing part of NanoMarkets analysis in the TC space going forward.

1.2 Objectives and Scope of this Report

The purpose of this report is to examine the opportunities available for ITO and other TC materials as they are used in electronics, photovoltaics and smart-glass applications areas. This report analyzes the revenue potential for each relevant application areas in terms of using ITO or

other transparent conductors and how the TC requirements of these sectors are changing. As this is a new version of a report NanoMarkets has been publishing for several years, there is an emphasis in this particular report on what has changed since the last version was published in 2011.

The classes of materials that are considered for transparent conductive applications have not changed very much from our 2011 coverage:

- We still cover ITO itself in its "classic" sputtered form and as deposited by other methods—including printing.
- We take a look at new and arising TCOs that are on the verge of developments for TC applications. Despite some failures in this space in the not-too-distant past, TCOs are a topic of much research with regard to ITO replacement.
- The coverage of conductive polymers is similar to that in the 2011 report, since there have been few major developments with these materials with regard to how they might serve as TCs.
- The carbon nanotube discussion has been refocused to discuss the technical developments in this area. Not much has been heard of carbon nanotube TCs in the past year, which raises the question of whether this technological approach to TCs really has much technological viability.
- We have again increased our coverage of silver-based TCs. For a number of reasons discussed in the report, these materials now seem to be well on their way to attaining a significant market share. Not surprisingly in doing so, this market segment is itself fragmenting into segments and we have provided additional color on this phenomenon in this report.
- We also include coverage of other types of TCs that have yet to reach any level of commercialization. Of these the two that are of greatest interest are copper and graphene. In this report we speculate about how these materials may be deployed as TCs in the future.

Our analysis of applications for transparent conductors has changed since last year's NanoMarkets report on TCs in a number of ways:

- Most importantly, we are giving much more attention to flexible displays in this report than in previous NanoMarkets reports on TCs. It has always been acknowledged that flexible displays could be the "killer app" for non-ITO TCs, but now that flexible displays are beginning to be introduced on the market, there seems reason to increase our coverage of this area, since it seems to present more of a potential near-term opportunity than in the past.
- For similar reasons, we have stepped up coverage of the whole transparent electronic/smart glass segment. We include in this segment both the new breed of transparent displays and the emerging area of smart windows among other technologies.

This is such a new area that the role of alternative TCs in it is hard to determine. However, because it is evolving so fast, it seems warrant enhanced coverage.

- We are devoting more space to TCs used in OLEDs in this report. The reason is that (1) OLEDs have emerged as a very large market in the past year and (2) ITO does not seem to be the ideal TC for OLEDs, although ITO is precisely what is being used at the present time. The combination of growth in the OLED market and the unsuitability of ITO means that a very substantial market for ITO alternatives may be about to open up.

- We continue to deepen our coverage of touch-screen markets, since firms that are selling ITO alternatives continue to place most of their emphasis on this sector. Although our focus is on the dominant analog resistive and pro cap touch technologies, we also examine some of the new touch technologies and what their arrival might mean to the TC business.

- The coverage of the PV sector is extended to some extent in that we have looked more thoroughly at the prospects for TCs used in PV panels in the context of the current market environment in which the PV market has been flooded with low-cost c-Si panel from China, and how that situation is like to change in the future.

We also discuss as we did in last year's report, the possibility that alternatives to ITO may find their way into the LCD market. This is something that was not taken all that seriously two years ago. There were the first signs that this situation was changing in 2011 and we are returning to this point in this year's report too, but acknowledging that things in this area have not come all that far.

Other than the areas listed above, the coverage of TC applications in this space are the ones that NanoMarkets has covered in all our reports on ITO and other transparent conductors. These include plasma displays, e-paper, and IR shielding and ESD applications.

This report is international in scope. The forecasts herein are worldwide forecasts and we have not been geographically selective in the firms that we have covered in this report or interviewed in order to collect information. Where there are markets and opportunities that are oriented in one way or another to one particular region we note this. For example, many of the important OEMs for TCs are in the display industry, which is strongly focused in Asia, while thin-film PV makers tend to be in the U.S. and Europe.

1.3 Methodology of this Report

The information for this work is derived from a variety of sources, but principally comes from primary sources, including NanoMarkets' ongoing interview program of technologists, business development managers, and academics involved with emerging electronics of all kinds, including the application areas covered in this report. We have also conducted interviews specifically for this report covering firms that are traditionally in the ITO business through to firms that are developing non-conventional TCs. We also interviewed researchers that are developing or trialing new materials for TCs.

In addition, this NanoMarkets study drew on an extensive search of the technical literature, relevant company Web sites, trade journals, government resources, and various collateral items

from trade shows and conferences. Some of the historical and background information came from the various specialist reports that NanoMarkets has published in the TC field, as well as from last year's comprehensive review of the TC market. Other NanoMarkets reports have also served as an input for this report where appropriate. Where information has been used in an earlier report, it has been reinvestigated, reanalyzed, and reconsidered in light of current developments and updated accordingly.

Finally, we have collected insider opinions and views of the evolving TC market through attendance at relevant trade shows/conferences including some where NanoMarkets researchers were featured as speakers. Shows/conferences that NanoMarkets has attended that provided useful information for this report include those organized by the Plastic Electronics Foundation, the FlexTech Alliance, the Society for Information Display and the Society of Vacuum Coaters.

Forecasting Methodology: The forecasting approach taken in this report is explained in more detail in Chapter Three, but the basic approach taken here is to identify and quantify the underlying needs and markets that are served by transparent conductors; consider the specifics of the applications and the types of products available or under development; and assess the competitive landscape to determine the suitability and likely volume of each of the transparent conductor types over the next eight years. The stated plans of the key firms are of course of special interest, although NanoMarkets critically considers these claims in light of all available data.

In each of the chapters devoted to applications, we have included detailed eight-year market forecasts and we have expanded these from the forecasts in the 2011 report in line with discussion above. As in the 2011 report, we have also included forecasts of the ITO value chain, noting how the market is broken out by coated glass, films and sputtering targets.

Forecasting for the materials covered in this report is especially difficult at the present time, because of the many economic and other risks that seem to be present in the marketplace. As we discussed to some degree above, uncertainty extends not only to the quantities of the devices that will be shipped but also to the pricing of ITO and the other materials and the impact that broader market events will have on all of these variables. To this must be added considerable levels of technological uncertainty associated with many of the materials covered in this report.

1.4 Plan of this Report

In Chapter Two, we consider ITO and the other transparent conductor materials including their relative strengths and weaknesses, recent developments that are relevant to the market, and the strategies and prospects for achieving significant market penetrations. We also include assessments of the strategies in these areas being pursued by major firms active with each of the materials being considered.

As mentioned above, Chapter Three comprises an in depth discussion of the forecasting methodology being used in this report. This discussion applies to the forecasts that are included in the all the chapters that follow.

In Chapter Four, Five and Six, we analyze and forecast the applications that use ITO and other transparent conductors, covering the competitive landscape between ITO and the other materials,

the unique needs of each of the application areas, and the strategies that will produce the greatest opportunities for growth and new revenues.

Finally, in Chapter Seven, we aggregate the market forecasts and provide summary forecasts both for applications and for specific TCs.