Organic Photovoltaics Material Markets: 2009-2016

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Executive Summary

E.1 Introduction

After a century of what has turned into a petrochemical-enabled energy economy, the race is on to develop alternative energy sources to fill the gap between the anticipated energy demand and the predicted shortage in accessible crude oil. Growing concern about global warming and the possible related role of fossil fuels also provides impetus to the search for renewable energy sources.

Photovoltaics already are a rapidly growing segment of the energy industry, dominated almost exclusively by expensive and fragile crystalline silicon solar cells. Thin-film inorganic solutions are beginning to show up in sizable portions. Many researchers and companies, however, believe that the real future for producing energy from the sun will be in fields of organic photovoltaic (OPV) and the closely related dye-sensitized solar cells (DSC) technologies.

For the most part, these thin-film solutions are well-suited to roll-to-roll (R2R) production processes, which will enable the high-volume and low-cost manufacturing that will be required for these designs to be successful. This is particularly the case for the near term because initially these devices will have lower energy conversion efficiencies than silicon-based products, and so the unit cost will have to be significantly lower in order to compete.

At present, however, the OPV and DSC technologies are just beginning to enter commercial production. As a result, it is difficult to judge just how fast the new technology will take hold, or how rapidly research will advance the efficiency of the devices. Add to this the worldwide recession that has depressed everything from crude oil prices to the credit markets, and in the short term, rolling out a new industry based on OPV or DSC becomes much more difficult.

All the same, many researchers and analysts see OPV and/or DSC as growing to take a measurable role in energy production, even though silicon solutions will still likely dominate most applications.

E.2 Summary of Emerging Opportunities for Materials Suppliers

The materials used in OPV and DSC devices fall into two main categories. One set is already in broad use in commercial quantities for a variety of applications outside of the PV industry. The other set includes some specialized materials that are in low demand outside the OPV and DSC industries.

E.2.1 Materials in Widespread Use

The first set of materials includes the common substrate materials, such as glass, plastic film, and metal foils. Glass has been the mainstay to this point, as most research has been done using glass substrates for batch processing of small samples under experimental conditions. As commercial production gears up, however, the industry will move to R2R processing in order to achieve the necessary economies of scale. As a result, the metal foil and plastic films will rapidly dominate. Of these two groups, plastic is likely the winner for a variety of reasons, including its transparency, light weight, and durability as a flexible substrate. The most likely candidates for use as OPV and DSC substrates are PET and PEN.

From a supplier's perspective, substrates for this application will not represent a significant portion of the total market. Even at its maximum, the total demand for substrates will be less than 20 million square meters in a year.

Another material included in this first set is titanium dioxide (TiO_2), which is a key material in DSC devices and is also used in a wide range of other commercial products from toothpaste to sunscreen. The peak demand in the forecast period calls for 364,000 kilograms for the year. Compared with the more than 4.5 billion kilograms of TiO_2 used worldwide each year, this is a small amount.

The same analysis can be repeated for many of the other "commodity" materials used in OPV and DSC devices. These include metals such as aluminum, silver, gold, and platinum, as well as transparent conductive oxides (TCOs) such as indium tin oxide (ITO) and fluorine tin oxide (FTO).

While these components do not offer enormous growth in their respective markets, there are still opportunities. The manufacturers of OPV and DSC devices require materials with high purity and consistent characteristics, for which they will likely pay a premium over standard commercial materials. This should be especially true during initial stages of production as the companies climb the learning curve of volume manufacturing. One key to success will be to manage the processes so as to maximize the yield of final devices that meet target specifications. Material quality will likely play a key role in developing consistent results.

Another key opportunity will be from the business relationship side. Many of the companies that will enter into commercial production of these devices over the next few years will tend to be new start-ups, and until they reach volumes and revenues that make them worthy of acquisition, these start-ups will likely not be aligned with a major company. As a result, they will rely on suppliers that are able to provide a level of support and flexibility that might not be required for a large corporation that is more self-sufficient. The willingness to meet requests for very small quantities initially stands a better chance of being rewarded with larger orders down the road.

E.2.2 Materials in Limited Demand

The second group of materials includes those that are not already in widespread use in high volumes. Some of these—such as PEDOT:PSS—have applications in other similar technologies, such as OLEDs, but many of them—such as ruthenium dyes—are fairly specific to OPV and DSC devices.

To make matters even more complicated, the current state of research into the optimal design of OPV and DSC structures remains in a state of flux. Not only is there no agreement on the specific materials to be used in a device, there is not yet agreement on what the physical architecture of the device should be. Researchers are still exploring new layers, as well as entirely new materials for the various layers. For example, ITO and FTO have been widely accepted as the anode material for OPV and DSC devices, but alternatives including nanostructure wire meshes are being studied as possible improvements.

As a result, the material supply chain for OPV and DSC devices is a bit of a moving target, both in terms of the materials required, and the quantity demanded. A supplier who chooses to work in these materials must be able to provide small quantities initially, as well as have the capability to ramp up—perhaps quickly—to larger quantities. And the same requirements for purity and high quality hold here as they do for the commodity items.

Many of these specialty materials currently command high prices that are attractive from a supplier's perspective. As volume production grows, however, the cost of production of these materials is likely to drop rapidly, based on the assumption that the bulk of the cost is in the initial batch and that the marginal cost of subsequent batches is much lower. If suppliers do not pass these lower costs to the device manufacturers, competing suppliers will be attracted to compete on price. As a result, considerable price erosion for the special materials is expected as the device manufacturing volume grows.

There is considerable risk in developing the supplies of some of these materials, as there may not be much demand for them outside of the OPV or DSC markets, and in many cases, demand may be limited to a single device manufacturer. The success of that one company could determine whether the need for a specific material continues at all.

E.2.3 Effects of Progress on Materials Demand

For both the commodity and specialty materials, the projected growth of OPV and DSC commercial production has a number of important implications.

During the initial start-up period, the absolute demand for these materials will be small. The amounts on a per device basis will be high, however, as manufacturers start by using processes that may not make as efficient use of the materials as possible. Furthermore, the production yields at the start will almost certainly be less than optimal, resulting in loss of material through defective end products.

As a result, the material demand will not scale in parallel with production. As the manufacturing processes mature and dedicated equipment is created for the fabrication tasks, less material is expected to be lost during production. At the same time, production yields will increase, which will act to decrease the total amount of materials required to make a given quantity of final product.

Another factor comes into play at this point. The expectation is that the massive research programs underway worldwide will find ways to commercialize many of the promising developments (as well as some that have not yet been identified) that are likely to greatly increase the energy conversion efficiency of these devices. With product demand cast in terms of peak watts, the demand for units will drop as efficiency increases. For example, if demand in peak watts remains constant, and efficiency increases four-fold—as is expected for OPV in the forecast period—then the quantity of materials required would be reduced by 75 percent over the period. And this is independent of the gains in production efficiency.

As a result, while the OPV and DSC markets may see substantial growth in terms of peak watt production, this is not likely to result in similar revenue growth for the materials suppliers. For the specialty materials, competition is likely to drive market prices down. And for both the commodity and specialty materials, increased manufacturing and device efficiency will drive down the amount of material required to meet the consumer demand for a given number of peak watts.

E.3 Implications for Equipment Makers

Equipment makers have two stages of opportunities as the OPV and DSC markets develop. Initially, manufacturers will need production equipment that is good enough for prototype production. The initial task will be to prove the practicality of the technology, and whether devices can be built that are suitable for their intended tasks in terms of output, lifespan, and reliability.

To a large extent, suppliers may be able to adapt existing equipment to meet the needs of OPV and DSC manufacturers. For example, the coating of plastic films is a relatively mature industry at this point, and much of this equipment can be adapted to OPV and DSC fabrication tasks.

The next step will be to create production equipment that is optimized for a given device. This could include all the layers and structures required—including encapsulation—in order to get a working device. In order to reach optimized production, this will likely be R2R processing, but there are many different deposition methods that could be used. Since fine patterning is not likely to be needed, inkjet printing will not likely be a factor. The monolithic structure of OPV and DSC devices are more likely to use ink-based techniques such as slot or blade coating. It is possible, however, that varieties of vapor deposition might also turn out to be a part of the production process.

It is worth noting that OLED production currently relies largely on batch processing of substrates, especially for pixilated and segmented displays. The growing demand for OLED devices for lighting applications, however, will fuel the need for high-volume, low-cost production processes to create monolithic devices. The demands for such processes are likely to be very similar to those required for OPV and DSC fabrication, so there may be some synergistic opportunities in providing R2R production equipment for both applications.

E.4 Implications for OPV Panel Manufacturers

What a difference a year makes. A year ago, crude oil prices were rising with no end in sight, creating a rosy future for alternative energy initiatives. Credit was readily available, making it possible to obtain funding to establish a new business or expand an existing one. And then everything changed.

In the near term, the current worldwide recession will put a damper on OPV and DSC projects on two counts. First, companies are trying to find ways to cut costs and survive financially. And with crude oil prices falling well below $100/bbl, there is little incentive for these firms to invest in expensive alternative energy programs. And the lack of credit will make it more difficult for OPV and DSC manufacturers to fund their start-ups, as this is when they need cash most of all to make capital investments and purchase materials that are most expensive in small quantities.

We expect this situation to continue for 12 to 18 months, after which time the worldwide economies are likely to start to recover. The recovery will also be marked by rapid inflation, which will drive energy prices up, improving the climate for investment in alternative energy sources. As a result, OPV and DSC manufacturers are likely to see slower growth during the short term, ramp-up phase, but demand for peak watts from their products should start to climb rapidly after that.

The conventional solar power market is not likely to absorb much OPV or DSC product. Instead, these products likely will do well in two major markets. The first is to provide lightweight, flexible, and durable solar chargers for electric devices to be used in areas where access to main grid power is either limited or inconvenient. This includes developing nations where electrical power grid coverage is sparse, and electricity is expensive. Small solar chargers could provide low-cost lighting and cell phone power. For more affluent consumers, solar chargers can provide power when participating in outdoor activities such as hiking and boating. Chargers built into clothing and carrying bags could also provide “electronic nomads” with extra power for their portable devices so that they can go for a longer time without having to connect to an electrical outlet.

The second potential market is to target products that could easily incorporate OPV or DSC devices to add value without adding a disproportionate amount of cost. For example, modern office building construction often relies on the addition of films to the window glass to control the amount and type of light that is permitted and then transmitted into the interior spaces. If those films could perform the same functions and generate electricity at the same time, without causing too great a price increase, they could be adopted at a very high rate. Another example is the coated steel material that is made for roofing and siding of commercial buildings. If the coating could incorporate photovoltaics at a cost that provides a reasonable return on the extra cost, it could enjoy wide adoption.

One essential aspect of launching this nascent market is the quality of the products that are produced. If a company comes to market too early with a product that fails to meet expectations or has a short lifetime, it could create a negative atmosphere for the marketing of other products in the future. The average consumer can tell you the shortcomings of plasma flat-panel televisions, but most of those problems existed in early generations of ten years ago and are largely fixed in the current models. It is difficult to overcome this negative reputation once it gets established, so manufacturers should be careful not to rush to market with sub-standard products.

E.5 Key Firms Shaping the OPV Materials Market

Several companies occupy keystone positions in the OPV and DSC markets.

First and foremost is **Konarka Technologies**, which started as a spin-out from the Universities of Massachusetts and California. In a short period of time, the company has amassed a commanding portfolio of both OPV and DSC IP, in part through the acquisition of Siemens' solar cell operation. Konarka has licensed its DSC technology to G24i, and now is focusing on OPV instead; in December 2008, NREL verified that the company had achieved 6 percent efficiency with an OPV device. Konarka also recently established a production facility in a New Bedford, Mass. factory that was formerly Polaroid's advanced printing operation. This makes the company the most likely candidate to achieve commercial R2R production of OPV devices.

Dyesol is the key company driving the DSC market at this point. It provides all the major materials, including dyes, host material, electrolyte, and sealants. The company continues to research DSC materials, and has demonstrated a tandem cell with 10 percent efficiency. Dyesol also has been very active in creating partnerships with manufacturers who could incorporate DSC technology into their existing products. One prime example is Dyesol's relationship with Corus, which makes coated steel roofing and exterior siding panels. The company estimates that this project alone could be worth $15 billion annually, just for the solar cell component.

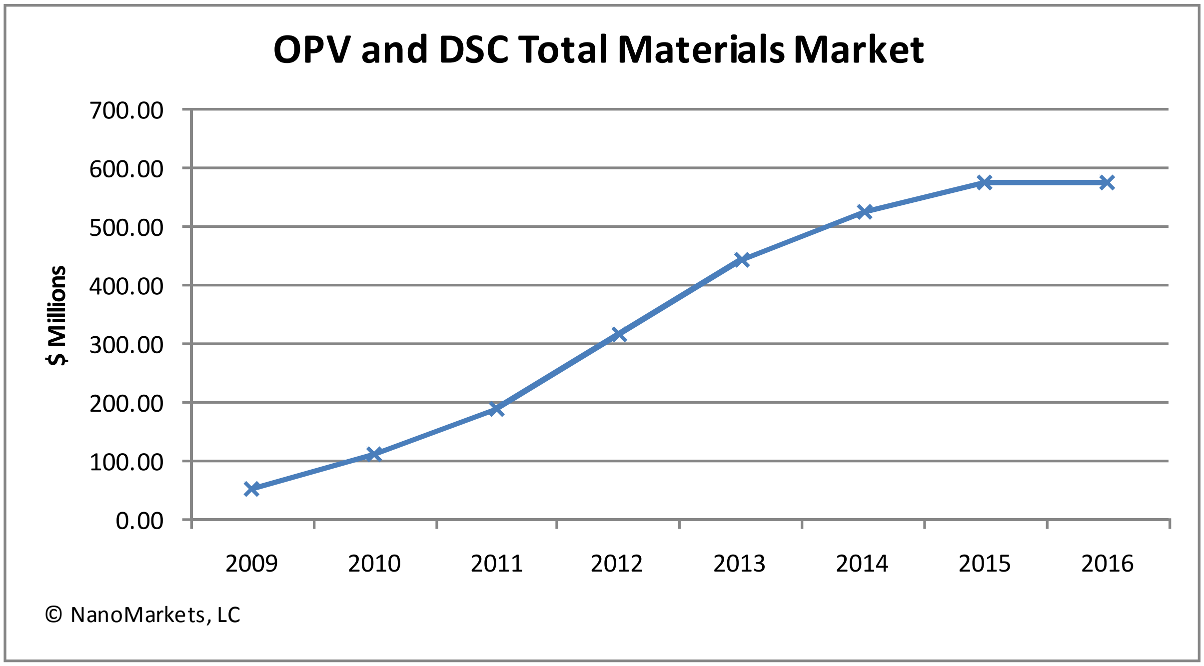
Plastic films will be an essential part of the OPV and DSC markets, as these technologies will require R2R production in order to achieve the high volume and low manufacturing costs that will be required in order to make the products price competitive. **DuPont Teijin Films (DTF)** is the world leader in polymer films including the PET and PEN that are the favorite substrates for many OPV and DSC experimental devices. DTF offers the material in a variety of forms, including heat stabilized versions that have improved dimensional stability and can be processed at higher temperatures. Since DTF's films are already in demand in very high volumes by other industries, it should have no trouble meeting the supply needs of the OPV and DSC markets as they grow.

H.C. Stark was originally part of the Germany-based chemical giant Bayer, and invented the PEDOT:PSS that is key to many OPV devices. Originally sold under Bayer's Baytron brand, the company now sells its PEDOT:PSS products under its own Clevios brand. The material also is used in photographic film, OLED devices, and printable electronics, so the supply chain does not depend on the success of OPV in order to have a healthy demand. Other companies, including Agfa, also produce PEDOT:PSS.

Many different encapsulation and barrier coat products and technologies are available or under development. One in particular is worth noting, if only to serve as a placeholder for this relatively new category of materials. **Vitex Systems** has developed its Barix product, which consists of alternating films of polymer and ceramic layers. Each ceramic thin film provides a fairly good barrier to oxygen and water vapor infiltration. By assembling multiple ceramic layers with polymer thin-film layers, the effectiveness of the individual layers is combined, resulting in a much more effective barrier. The process is compatible with R2R production, and is also suitable for use with OLED devices. As a result, it may well have demand beyond the OPV market.

E.6 Summary of Eight-Year Forecast of OPV Materials

As described earlier in this chapter, the demand for OPV and DSC devices will grow, at least in terms of peak watt output of the devices. Increased efficiency in production and in the power output of the devices themselves will mean that less material will be required over time to produce the same quantity of peak watt output. As a result, the materials markets for OPV and DSC will follow a bell curve pattern. They will rise initially, but then in spite of continued increase in peak watt demand, the square meters produced and the total revenues will begin to decline in the latter half of the forecast period. Total revenues are forecast to start at $902.7 million in 2009, peaking at $3.3 billion in 2013, and then declining to almost $1.9 billion in 2016. These forecasts are shown in Exhibit E-1.



The most dynamic factor is the cost of the active layer materials. Most of these are specific to OPV and DSC devices, and so there is a limited market for them at present. Currently, these materials carry high prices. As demand volume increases, the suppliers should be able to lower prices rapidly as the unit cost of the material production declines due to increased manufacturing efficiency. Suppliers that do not pass these savings along to their customers run the risk of another supplier entering the market and competing on price. As a result, we expect that prices for these materials will decline rapidly at the start as production volumes of OPV and DSC devices increase.

The total amount of materials used by the industry is expected to flatten out, even though the demand for peak watt increases. This is due to increased yield in the production of the devices, and due to projected increases in the energy conversion efficiencies of the devices.

These various factors add up to the result that the average cost of the OPV and DSC products will decline over the forecast period, ending the forecast period at about 60 percent of the initial amount.

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