It’s no secret that efficiency, lifetime and overall system costs for photovoltaic (PV) modules are driven in large part by the materials specified in their production. In fact, advanced materials are more important than ever in helping today’s solar cell and module manufacturers differentiate their products with superior power output and longer life performance that deliver increased investment rates of return (IRR) to PV system owners and financiers.

What is less apparent is that under the current climate of increasing cost pressures, module producers – even some of those deemed “bankable” – are considering, and sometimes taking, shortcuts to substitute unproven materials to help manage short-term costs. Poor material selection presents a significant risk not only to module performance, but also to the quality and reputation of module manufacturers. Ultimately, this has the potential to jeopardize the credibility of the entire PV industry at this critical time in its development. PV system developers, insurance companies and investors are beginning to closely scrutinize PV system failures, and educate themselves about the integrity of materials being used inside modules in order to mitigate their investment risk.

In recent months, we have seen module prices driven to historical lows. While this is great for customers and increases the speed of solar installations, it also puts tremendous pressure on the cell and module manufacturers as well as the supply chain. Module makers and material suppliers, to stay competitive, need to accelerate their cost-reduction roadmaps. While effects of process and material changes are easily verified in initial performance, reliability and durability tests have long timelines and are much more costly to perform. If not done thoroughly, the quality of the final product can suffer, sometimes only visible after years in service.

In the following article, researchers from DuPont review the materials their company is offering to the PV industry and the value they add in the current economic environment. New materials such as improved metalized pastes support innovations in the cell design and help advance cell performance and module efficiencies. Existing and proven materials, as, for example, DuPont’s encapsulants and backsheet materials, have advantages in long-term reliability, as they have a proven track record for stability and durability. In general, they make a strong case for increased collaboration between strategic materials suppliers and module manufacturers to decrease development time, but most importantly to maintain high-quality standards for reliable and durable products in a time that is dominated by cost reductions.

Why Materials Matter

The solar business is on track to become a $100 billion industry by 2015. It is in all industry stakeholders’ interests to continue to accelerate the growth and momentum of solar energy as a viable element of the world’s energy mix. Over the next five years, industry experts anticipate 20 percent average annual growth in installations, as PV reaches grid parity in more and more markets. The solar market still represents a mere 0.4 percent of the total global generation capacity today; however, it represents more than 15 percent of new electrical energy capacity being added on an annual basis. For PV technology to reach its potential, it must prove to be more and more efficient in terms of the amount of sunlight converted into usable electricity, in addition to delivering reliable performance over an expected lifetime of at least 25 years. Any PV system failure, either catastrophic or due to loss of power over time, could undermine solar energy’s viability as an economical and reliable energy source.

Careful selection of key materials can mitigate this risk. The three most critical materials used in the production of solar panels include silver metalization pastes,
used to efficiently conduct electrical power from solar cells, polyvinyl fluoride backsheets, the outer “skin” that protects the inner elements of a solar panel from damage from the harsh environment on a rooftop- or ground-mounted installation, and encapsulant materials used to protect the cells. All of these materials must be able to deliver the necessary high-performance specifications of a solar panel over 25 years.

Let’s take a closer look at how advanced materials can positively impact module efficiency and lifetime.

**Enhancing Conversion Efficiency**

Metalization pastes have been used in the electronics industry for over 40 years, and leading suppliers continue to make improvements in these critical materials in terms of cost, performance and quality.

In the PV industry, silver metalization pastes are used to collect and conduct the electricity generated on the surface of a solar cell. Due to advances in metalization materials technology over time, the amount of sunlight converted into usable electricity (referred to as the conversion efficiency of a solar cell), has dramatically improved, from about 12 percent in 2000 to 19 percent in 2012, thereby delivering significantly more electrical power output from a solar module. Every percentage improvement is significant, as it results in a 5 percent reduction in the cost of the overall solar power generation system.

Many leading module makers consider high-efficiency solar cells as a key differentiator in today’s competitive market.

Recently, new metalization paste materials have been developed that not only improve efficiency in standard solar cells, but also enable the production of new types of cell designs capable of delivering even larger step changes in PV conversion efficiency going forward.

For example, DuPont has developed a photovoltaic silver metalization paste called Solamet® PV17 that has become the leading silver paste on the market today, due to its ability to increase solar cell efficiencies by an additional 0.4 percent via its unique ability to enable doping diffusion optimization with lightly doped emitters (LDEs). This integrated material and process technology has opened up new avenues to increase solar cell efficiencies using advanced silver metalization pastes. Prior to PV17 being released to the market, the industry had no commercially available option for making a screen-printed front-side metalization that could economically and practically enable an LDE. The excellent silicon-to-silver contact of PV17 technology has demonstrated a wider range of diffusion optimization and higher cell efficiency.

PV17 technology is now being deployed in solar cell manufacturing sites throughout the world. RWTH-Aachen University recently published a comparative study that found Solamet® PV17 outperformed four competing products, demonstrating its ability to contact 100 ohm/sq., LDE emitters on multicrystalline cells – the first time this had been achieved - with lightly doped phosphorous surface concentration. This enabled an efficiency improvement of a full 1 percent.

DuPont is also producing metalization pastes that reduce dependence on silver metals and thereby reduce costs for manufacturers, without compromising solar cell efficiency.

![Diagram of PV module materials](image)

**Figure 1 – PV module materials must be carefully selected to ensure reliable power output over a system’s 25-year expected lifetime.**

But efficiency advantages gained through the use of advanced metalization pastes are quickly lost if the module structure is not properly protected. Long-term protection for the sensitive components in the module is primarily the role of two key components: PV encapsulants; and the outer-skin, PV backsheet.

**Extending Module Lifetime**

From an investor’s perspective, the cost of a PV system can be reduced significantly when the system can run efficiently and effectively for a longer period of time, making PV a more attractive investment based on the levelized cost of energy (LCOE), compared to alternatives. For example, investment returns can increase by over 40 percent over the life of the system if the lifetime of the PV system can be increased by 10 years.

Module lifetime can be broken down into three areas of importance: reliability; durability; and safety. All of these are vital in delivering the expected IRR for solar projects. Reliability means no early-onset catastrophic failure; durability means minimal annual power degradation; and safety means no injury to people or damage to physical assets.

From the earliest days of PV manufacturing, clear, soft, shock-absorbing ethylene vinyl acetate (EVA) resins were found to make ideal encapsulants. Converted into sheets that surround and protect solar cells and module circuitry, EVA resins have been shown to deliver decades of reliable service. However, EVA is susceptible to degradation in external environments, making it essential that the formulated sheet contain a robust stabilization package. Unfortunately, lab
tests of EVA encapsulant stability do not reflect real-life conditions, and as the number of EVA resin and sheet suppliers has multiplied, EVA discoloration, embrittlement or acid generation is increasingly observed. While it is tempting to consider all types of EVA equivalent to one another, and make selections solely based on cost, experience has shown this to be a dangerous approach – especially as cells get more efficient and sensitive to environment (e.g., acid, moisture) increases.

More recently, ionomer-based encapsulants, leveraging their intrinsic UV stability in addition to well-demonstrated properties of clarity, strength, stiffness, flow and adhesion are delivering not only long-term protection of PV cells, but also improved design, productivity and cost advantages. While slightly more expensive than EVA, ionomer has almost two decades of field use as an encapsulant, and these modules have demonstrated exceptional results in both reliability (elimination of PID) and durability.

However, by far, the largest surface area barrier protecting a solar module is the PV backsheet, and its performance is paramount. Its purpose is to protect the sensitive module components from the harsh external environment while providing electrical insulation for the expected lifetime of the module. Premature backsheet failure can result in significant power loss and investment loss.

Many PV backsheet materials are relatively new to the market, and have not been proven to reach the expected 25-year module lifetime. Examples include polyethylene terephthalate (PET), which has been around for about 15 years; polyvinylidene difluoride (PVDF), which has been in use for less than 10 years; and nylon, which has been in use for about five years. They have typically been sold on the basis of accelerated aging tests, which we are learning now cannot accurately predict lifetime performance.

Long-term outdoor exposure, specifically in PV applications, is the ultimate test for all module components, material quality and manufacturing quality. To date, PV backsheets made with DuPont™ Tedlar® polyvinyl fluoride (PVF) film remain the industry standard for reliability, as it is the only known backsheet with over 25 years of field proven lifetime. PV module backsheets made with Tedlar® provide critical, long-life protection to the module, safeguarding the system and enabling long-term PV system returns. Tedlar® and other DuPont materials have been time-tested in over 5 trillion panel-hours of outdoor PV field installations across the globe since 1975.

Recently, the industry is beginning to see far more failures due to other lesser-performing and unproven materials that have been introduced in the past five years and have been in the field long enough to show failures.

**PV Profitability**

Profit margins in several parts of the PV value chain have declined significantly over the last few years. Cell and module manufacturers have experienced significant margin pressure due to overcapacity and declining solar market incentives. Many manufacturers have declared, or are very close to bankruptcy. One industry source suggests that of the 256 module makers operating in 2011, we can expect to see fewer than 50 survive by 2016.

Prices for cells and modules have dropped rapidly as a result of overcapacity and overproduction. In 2008, solar modules were priced at $4.00 per watt, and in 2012, prices have dropped to a staggering $0.85 per watt. Hundreds of rapidly growing cell and module manufacturing companies that have sprung up in the last decade face the daunting challenge of reducing costs further and returning to profitability as the industry transitions to grid parity.

The solution – or part of it – lies in substantial increases in cell and module conversion efficiencies. As described above, if cells and modules are not protected by a highly durable backsheet structure that enables a long service life, the efficiency gains are meaningless. Materials do matter to help promote and protect PV module performance.

Evidence gathered from recent module failures is suggesting that some module manufacturers have substituted unproven materials in modules as a way to manage their costs and preserve profit margins. In one recent audit of module shipments, measured defect rates rose from 5 percent in September 2011 to nearly 25 percent by February 2012. Awareness is increasing for system owners and investors that unproven materials are having a negative impact and will lead to increased costs.

**When Modules Fail**

The fact is, if a module fails, it is expensive and time-consuming for end-

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**Figure 2** – Only 1 PV backsheet material has been proven to protect solar modules for over a 25-year lifetime.
users to replace and reinstall. Before that module fails completely, it is most likely operating at a notably lower efficiency, reducing the system’s output and pay-back. The reason that most modules fail is most likely that the materials used in the manufacturing the installation process were of lower quality, resulting in backsheet failure, glass delamination, backsheet delamination or encapsulant discoloration.

The consequences can often be dire. Faulty modules reduce conversion efficiency and IRRs, but can also damage suppliers’ and vendors’ reputations and threaten the well-being of their businesses. Widespread module failures have the potential to threaten the continued growth of solar energy.

Awareness among system owners is growing that warranties are an unpredictable means of protecting an investment in a PV system. It can take weeks or months to resolve a warranty claim, assuming a module manufacturer is still in business, and even when a module warranty claim is accepted by the manufacturer, it is possible the exact size and power output of a specific module won’t be available. Any replacement module almost certainly won’t be matched to the existing array in power output or in size, causing performance issues, increased costs and possibly safety hazards upon installation and operation of the replacement panel. There are aesthetic issues when the panels don’t match. Typical module warranties only cover the cost of the replacement module. Neither installation costs nor compensation for lost power output for the time period between module failure and replacement are covered. Other indirect costs may include brand damage and increased insurance costs.

Fielded Modules Demonstrate that Materials Matter

- **PET Backsheets**
- **Tedlar® Backsheet**

<table>
<thead>
<tr>
<th>Duration in Service</th>
<th>Nameplate Rating</th>
<th>Call Type</th>
<th>Backsheet</th>
<th>Wet Leakage</th>
<th>IV Measurement</th>
<th>% Degradation</th>
<th>% Degradation/Year</th>
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<tbody>
<tr>
<td>Module 1</td>
<td>12 Years</td>
<td>143 W mono-Si</td>
<td>PET</td>
<td>Fail</td>
<td>77 W</td>
<td>46%</td>
<td>9%</td>
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<tr>
<td>Module 2</td>
<td>10 Years</td>
<td>125 W poly-Si</td>
<td>PET</td>
<td>Fail</td>
<td>105 W</td>
<td>18%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Module 3</td>
<td>11 Years</td>
<td>100 W mono-Si</td>
<td>TPT®</td>
<td>Pass</td>
<td>91 W</td>
<td>9%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

**Figure 3** – PET backsheets were the first ‘material experiment’ in backsheet, carried out in Japan. They resulted in significantly shorter module lifetimes. Now many additional ‘experiments’ are playing out in the industry.

When materials fail, the consequence can be dire

- Encapsulant discoloration
- Backsheet failure
- Glass delamination
- Backsheet delamination

**Figure 4** – Backsheet failure, glass delamination, backsheet delamination and encapsulant discoloration are all modes of failure possible when unproven materials are used in solar module construction.
Large-scale warranty claims can be expensive. One company recently paid in excess of $250 million to cover warranty expenses tied to the replacement of modules that failed in the field after just three to four years. Few module makers have sufficient financial resources to provide warranty coverage for a failure of this size.

For these reasons, solar system owners are beginning to understand that they are more protected purchasing a system that uses proven design, materials and manufacturing processes so it is less likely to fail.

Strategic Supplier Relationships

Many leading PV module producers have discovered that strategic relationships with leading material suppliers can have long-term benefits. DuPont, for example, is the leading material supplier to the PV industry (ex silicon), and has announced several strategic agreements within the past year focused on material supply and technology collaborations. Those materials can be more readily optimized for highest performance within a specific manufacturing process. When brought to the table early on, suppliers can engineer materials that enable new and improved processes to accelerate manufacturers’ progress. New PV metallizations that enable high-efficiency cell architectures such as LDEs are one such example.

Manufacturers are increasingly working in collaboration with material suppliers, relying on them for process expertise and technical support to accelerate their achievement of technical and financial goals.

Compromising quality will not help overcome the current challenges in the PV market. On the contrary, improving efficiency, lifetime and overall system costs will continue to be critical to the success of PV. The world is watching what materials go into modules today. The sustainability of our industry is at stake.

About the Author

Homer Antoniadis is the global technical director for DuPont Photovoltaic Solutions, responsible for accelerating the introduction of next-generation DuPont materials into the solar energy market. He joined DuPont in 2011 with the acquisition of Innovalight Inc., where he held the position of chief technology officer and vice president of engineering. Dr. Antoniadis’ 20-year career includes positions with Osram Opto Semiconductors, Hewlett-Packard Labs and Xerox. He earned his Ph.D. and M.S. in physics from Syracuse University and a B.S. in physics from Ioannina University, Greece.