Materials can be key to differences in module durability

Defect assessment | DuPont Photovoltaic Solutions recently completed a five-year study of commercial crystalline silicon PV systems, amassing a wealth of new information about PV system field experience and PV module defects. Principal investigator Alexander Bradley discusses the findings, which, in addition to supporting the company's ongoing analysis of materials performance, are expected to provide benefits across the industry. Building on the industry knowledge pool contributes towards the standardisation of performance expectations across the solar industry, enables the development of more stringent risk mitigation techniques, and helps purchasers of solar power systems make educated and informed materials assessments

Testing solar modules in a laboratory setting provides valuable information, but the most representative performance data can only be achieved by measuring solar module performance under real-world conditions, in different climates and settings, and over an extended period of time. In turn, these real-world results help researchers develop realistic and representative methods for conducting accelerated durability testing in the laboratory.

The DuPont study, presented recently at the IEEE Photovoltaic Specialists Conference [1], was extensive. More than 60 global solar installations were reviewed, ranging in size from 1kW to 20MW projects, representing 1.5 million solar modules and a total power output of over 200MW.

Modules at sites of all ages were examined, from brand-new installations to those with over 30 years in service. The study surveyed residential, commercial and utility-scale installations, roof- and ground-mounted, across Asia-Pacific, the European Union and North America. In addition, over 400 modules, from 45 different module manufacturers, were analysed in the lab. Selected modules were subjected to non-destructive and destructive testing in the lab, to provide more information about the chemical and physical changes to the solar module materials.

Visual inspections of solar module defects becoming more important

Two recent developments contribute to the increasing importance of identifying defects in solar modules. As the solar industry shifts its focus from the 'design and build' stage to the operation and maintenance of systems, including asset optimisation and energy harvest, visual defects are becoming key markers, along with the evaluation of safety and power output, in determining the value of a PV system.

> "Visual defects are becoming key markers in determining the value of a PV system"

Another development is the extension of most module workmanship warranties to ten years (an increase from two years), exposing manufacturers to the possibility of claims for workmanship defects, and also for unsatisfactory performance/power output (Fig. 1). These developments are putting the spotlight on visual defects, as well as on performance and safety degradation.

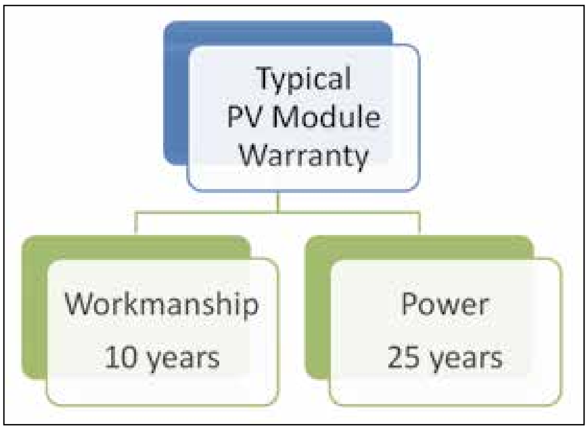


Figure 1. Warranty coverage breakdown: typical warranties cover both workmanship and power output. Visual defects, including yellowing and cracking, are potential workmanship defects, since they may lead to electrical safety hazards.

In addition, the growing secondary market for PV assets dictates the need for an evaluation, based on numerous criteria (including visual inspection), to determine the value of modules and systems. Defects that require replacement, or more frequent inspections, will add operational

Subcomponent	Visual defect
Superstrate	Broken, etched or hazed glass
Encapsulant	Discoloration or delamination
Cell/Interconnection	Corrosion, hot spot (thermal non-uniformity), broken interconnection, snail trail, crack, burn mark
Backsheet	Cracking, yellowing, delamination

Table 1. Description of visual defects for each subcomponent category.

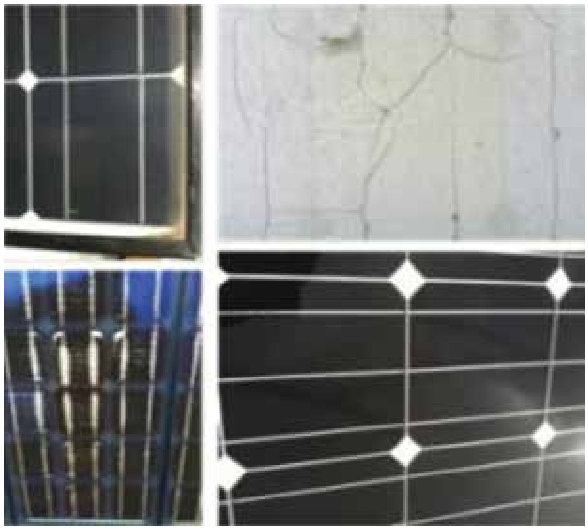


Figure 3. Representative visual defects (clockwise from top left): etched glass, cracked backsheet, snail trails and encapsulant discoloration.

expenses and drive up the cost of ownership, as well as reducing the secondary value of the PV asset.

For this study, module defects were identified via visual inspection using industry-accepted definitions, combined with the use of a thermal camera. Any PV module that deviated from a 'perfect' module was defined as *defective*. A PV module with a defect might not have a safety or power loss, but it differed in some way from a perfect module.

Survey results

All of the identified defects relate to one or more of the four major subcomponents of a PV module: superstrate, encapsulant, cell/interconnection and backsheet (Table 1). In many cases, the interactive effects of the subcomponents were responsible for the visual defect.

As part of the data analysis, degradation modes were combined into a small number of distinct categories. Out of all the modules surveyed, 59% had no defects; Fig. 2 shows the breakdown for the 41% with defects. In many instances, the defects were not uniform across all modules in a particular installation.

The superstrate accounted for only 2% of defects (Fig. 2). Twenty-four per cent of defects related to the cell, including hot spots (identified via thermal camera), visible corrosion, burn marks at interconnections, and cracks (identified by snail trails.) Encapsulants accounted for 4% of defects. While this percentage is low, it represents an important cause of defects, because of the resultant loss in transmission, as well as a shift in the transmission spectrum, which allows a shorter wavelength of light to penetrate the module.

The cell may be the most valuable part of a module, but the discoloration of encapsulants and backsheets can also exact a heavy price (see Fig. 3). Discoloration can cause embrittlement of these two electrical insulating components; this in turn can lead to delamination and the loss of mechanical properties, which can compromise electrical insulation. These issues are also grounds for potential workmanship warranty claims.

Backsheet material is key

The drive to reduce component costs has led some manufacturers to turn to alternative backsheet materials. The problem with many of these materials is the lack of in-depth, long-term performance testing, resulting in expensive field failures. Removing and testing modules part-way through their expected 25-year lifetime is expensive. Since operations and maintenance (O&M) is usually not always a fixed cost, it can increase significantly over a system's lifetime.

"The discoloration of encapsulants and backsheets can exact a heavy price"

The study highlighted the critical role that backsheets play in the performance of solar modules. The following materials for backsheets were investigated:

- **Polyvinyl fluoride (PVF)** film is used extensively as a backsheet material in solar module construction. It has proven to be reliable and durable in protecting solar modules for more than 30 years, even in harsh environments.
- **Polyethylene terephthalate (PET)** film is widely used in very low-cost solar modules. There is little standardisation between PET films, leading to inconsistent performance in the field and a high rate of early field failures, such as yellowing and cracking.
- **Fluoroethylene and vinyl ether copolymer (FEVE)** coating is a newer, relatively unproven material. No long-

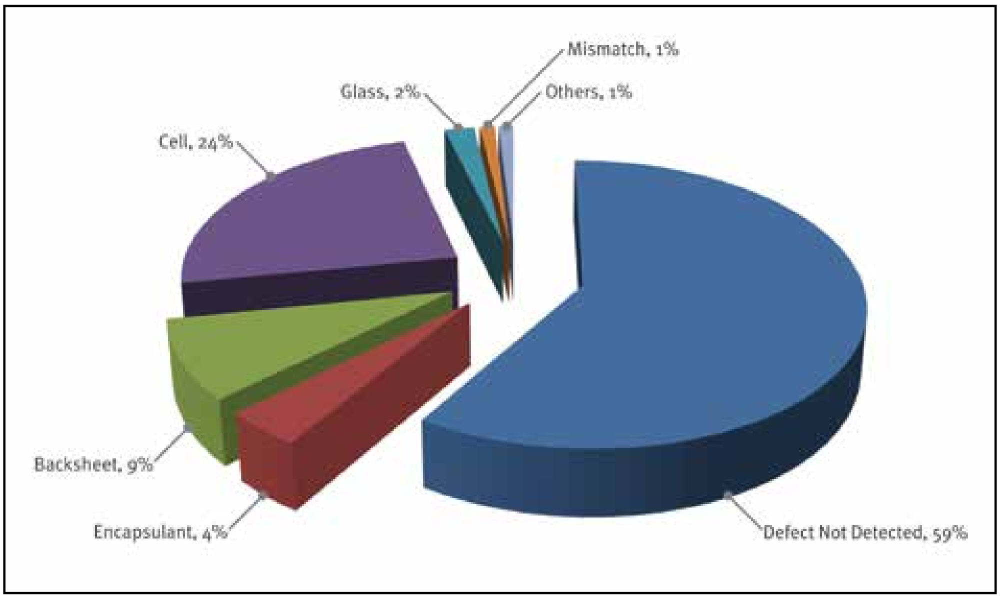


Figure 2. Subcomponent visual defect percentages.

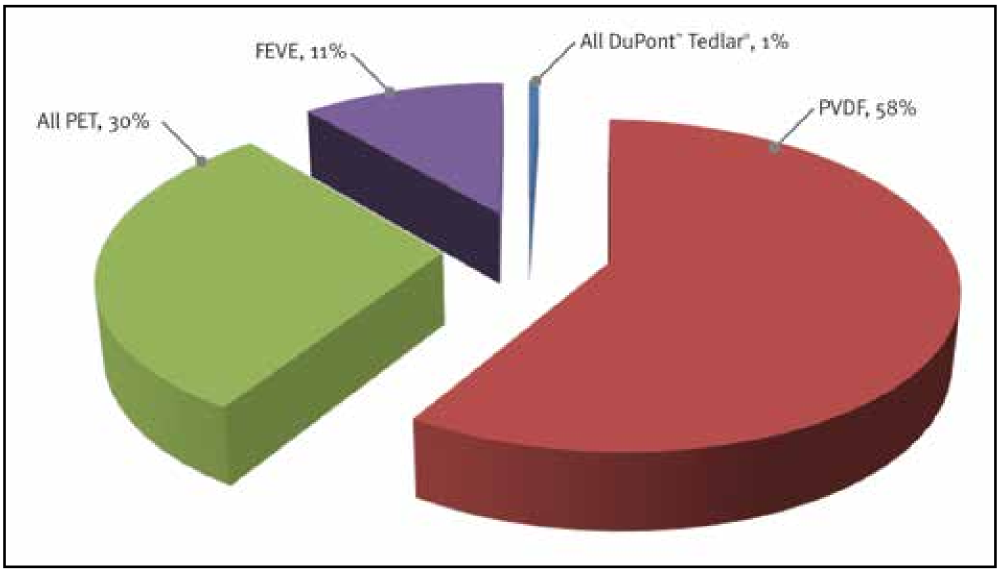


Figure 4. Backsheet visual defect percentages for different backsheet materials.

term studies have been completed on its performance in the field; recent studies, however, have shown evidence of issues, including cracking, within as little as three years of outdoor exposure.

- **Polyvinylidene fluoride (PVDF)** film is promoted by several manufacturers as a lower-cost alternative backsheet material. In the field, single-sided backsheets made using PVDF have demonstrated issues of yellowing, cracking and delamination.

Backsheet defects accounted for 9% of the total defects, and researchers found a significant variation in the percentage of defects across different backsheet materials (Fig. 4).

With the help of Fourier transform infrared (FTIR) spectroscopy, the outer surface of the backsheets were compared with reference backsheets, which provided a more detailed categorisation of the backsheet defects. The comparison also allowed a more specific categorisation of the defects relating to backsheets.

The most common backsheet defects found by the researchers were:

- **Yellowing:** discoloration of the backsheet material, caused by prolonged UV exposure, high temperatures and environmental stresses. An early indicator of serious mechanical integrity issues (including delamination and cracking), yellowing can compromise the backsheet's electrical insulating properties. Severe yellowing is frequently observed in modules with PET-based backsheets.

- **Abrasion and delamination:** visible cracking (macrocracks) in the backsheet's outer layer, along with outer layer separation from the backsheet structure. The abrasion and delamination defect presents safety issues, because it represents severe degradation of the backsheet's protective function, and exposes the inner PET core layer to the elements.

"Tedlar film outperformed all of the alternative backsheet materials"

- **Delamination and bubbling:** cracks in the outer layers of the backsheet. This defect has the potential to expose the core backsheet layers to the elements and compromise its structural integrity. Delamination can also result from hot spots (a bubble caused by the separation of the backsheet or encapsulant layers) or increased series resistance.

PVF outperforms all other backsheet materials

The study highlighted a significant performance advantage for solar modules constructed using Tedlar PVF film-based backsheets. As the only backsheet material demonstrated to protect solar modules for more than 30 years in the field, Tedlar film outperformed all of the alternative backsheet materials; the latter have not been proven to last over the expected lifetime of a solar module, since they have been in use in the field for only approximately half as long as PVF film-based backsheets.

New data shares benefits across solar industry

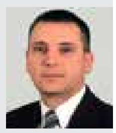
As the findings demonstrated, the long-term reliability and performance of a solar installation depend on the materials used in its construction. The most favourable system value based on the levelised cost of electricity (LCOE) is achieved when modules perform precisely as expected, delivering a high lifetime power output along with a long operating lifespan. Proven materials specified at the outset of a project can result in a higher system value and lower LCOE for the end user, as they help assure the longevity, durability and performance of solar modules over a system's lifetime. This fulfils the expectations set out in project plans and evens out financial returns.

Quantifying the range of defects found in PV modules, across installations and regions, will also provide benefits throughout the industry. A greater knowledge of solar module defects allows the solar industry to establish control plans relating to scheduled maintenance. It also enables insurance companies to more accurately anticipate replacement rates, as well as providing more comprehensive data for asset management companies for valuations of solar assets.

DuPont makes recommendations on the industry-standard bill of materials for solar panels on the basis of its extensive studies of material performance, and provides module manufacturers with materials technology that will best match power output and expected lifetime goals of solar installations.

Author

Dr. Alex Bradley is a principal investigator for DuPont Photovoltaic Solutions. He has studied and analysed PV systems for more than five years as part of an intensive field and laboratory research programme assessing the long-term performance of solar panels and materials in diverse service environments.



Reference

[1] Bradley, A.Z., Kopchick, J. & Hamzavy, B. 2015, "Quantifying PV module defects in the service environment", *Proc. 42nd IEEE PVSC*, New Orleans, Louisiana USA.