Materials Matter™

DUPONT PHOTOVOLTAIC SOLUTIONS

The Importance of Selecting the Right Materials for Solar Modules

DuPont Photovoltaic Solutions has established an extensive fielded module evaluation program to develop a knowledge base that will allow a better understanding of how solar modules and materials age and degrade in the real-world environment. This program is a collaborative effort between DuPont and selected engineering, procurement and construction (EPC) partners who have made their solar installations available for technical inspections. Through this program, DuPont is sharing its extensive knowledge in photovoltaics and materials, as well as detailed analysis and results, with these partners.

Through this report, we are sharing a comprehensive summary of these findings from Europe and the Middle East with the industry. DuPont has inspected more than 60 solar installation in the United States, Canada, India, China, Japan, Europe and the Middle East. These fields have ranged from newly commissioned installations to 30 years old installations.

In addition to the field visits, hundreds of modules from the field have been collected and analyzed to gain a clearer picture of the impact of materials changes on the performance of the modules. By using both the field inspections and laboratory analyses, more than 30 different degradation modes have been observed and characterized, allowing DuPont to design better accelerated testing protocols for materials and modules.

DuPont has also collaborated with numerous government research centers, including the Solar Energy Center in India, Sandia National Laboratories in the United States, Joint Research Centre in Italy, CanmetENERGY in Canada, the National Renewable Energy Laboratory (NREL) in the United States and the National Institute of Advanced Industrial Science and Technology in Japan.

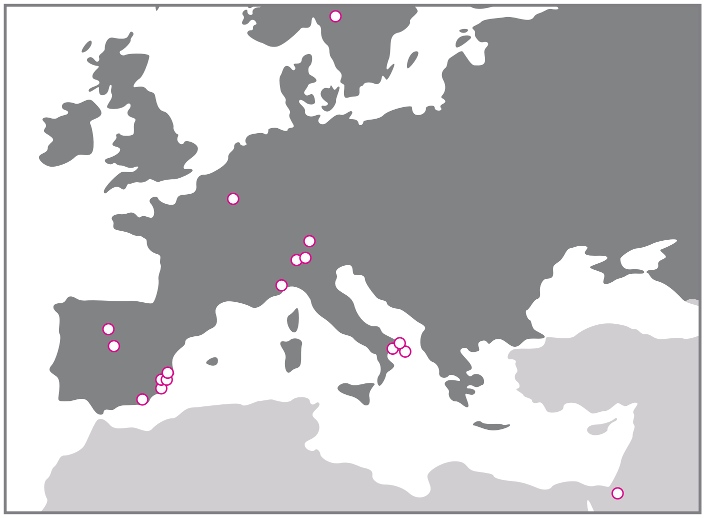
This document will focus on key findings and recommendations based on the extensive solar installation inspections that were conducted in Europe and the Middle East during 2013.

Solar Installation Inspections in Europe and the Middle East

DuPont developed an inspection protocol checklist based on sound knowledge of materials, module fabrication and accelerated aging test data. During field inspections, a Fourier transform infra-red spectrometer (FTIR) was used to identify the chemical composition of the outer layer on the back of the module, which is known as the backsheet, a critical component responsible for protecting and electrically insulating the module. Using an FTIR aided in determining the specific backsheet material used by the module manufacturers.

The inspections focused on visual changes in the module, such as yellowing, cracking or other issues such as snail trails. Statistics were reported based on either inspection of an entire solar installation or, in the case of larger solar installations, a representative sample of several hundred modules to extrapolate for the entire installation.

Across Europe and the Middle East, 22 crystalline silicon (c-Si) solar installations were surveyed with a very wide distribution of sizes from 1.4 kilowatts (kW) to 13.3 megawatts (MW), for a total of approximately 61 MW of installations. The solar installations ranged in age from 2 to 12 years. Only 3 of the installations surveyed were rooftop-based. The majority were ground-mounted on a mixture of fixed structures, single axis trackers and double axis trackers.



Locations where solar installations were inspected.

Overview of Findings

During the field inspections, the focus was on the visual aspect of the solar modules as this can be an early and first indicator of failure that can lead to more serious problems.

The visual changes and types of defects that were noted during inspections included: Ethylene Vinyl Acetate (EVA) yellowing, ribbon corrosion, snail trails, backsheet cracking, backsheet (backside yellowing and backsheet frontside) yellowing.

After totaling the visual defects, 32 MW out of the 61 MW showed visual signs of degradation or changes. Defects such as Potentially Induced Degradation (PID) or hot spots were not included in this survey. These degradation modes are well documented and have led to safety and performance issues.

Although solar installations of all ages showed signs of visual defects, an alarming finding was that these defects are occurring on a large scale in relatively young modules with less than six years in the field, as shown in Figure 2. Current qualification testing is not finding these early degradations.

Results and Discussions

Figure 3 shows the percentage of each type of defect that was observed during visual inspections of the solar installations. Ribbon corrosion represents the largest visual defect observed (see Figure 4A). Ribbon corrosion is any change in color that was observed on the solder ribbons. This includes darkening of the ribbon surface, which can be due to darkening of ultraviolet (UV) sensitive flux residues, a change that would only impact the aesthetics of the module. However, it is important to note that in extreme cases, ribbon corrosion can lead to backsheet degradation by resistive heating, which will eventually affect the safety and power generation of the module.

An example of snail trails, which are a discoloration of the fine conductor lines overlaying a crack or micro-crack in the cell, is shown in Figure 4B. This is believed to be a fairly recent problem (approximately six years old), resulting from the interaction of EVA encapsulant additives and silver.

Snail trails can be an early indication of future issues. For example, thermal cycling can eventually enlarge the cracks and separate the fine line connections, resulting in power loss. The questions that remain are: when will this occur and what will the impact be on power loss and hot spots?

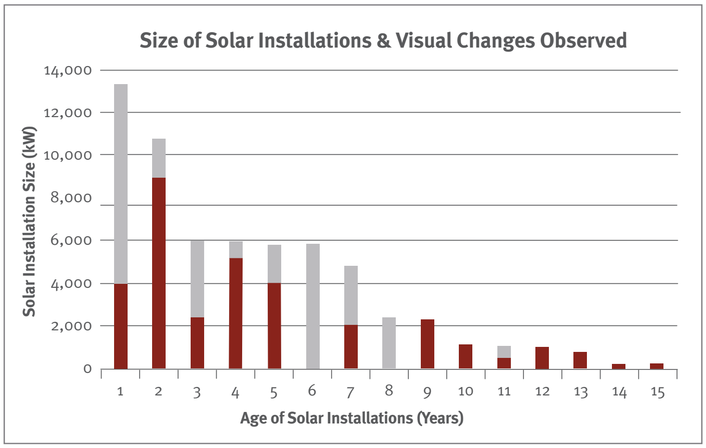


Figure 1. Solar installations in order of decreasing size showing the proportion of visual change in brown to the intact proportion in gray.

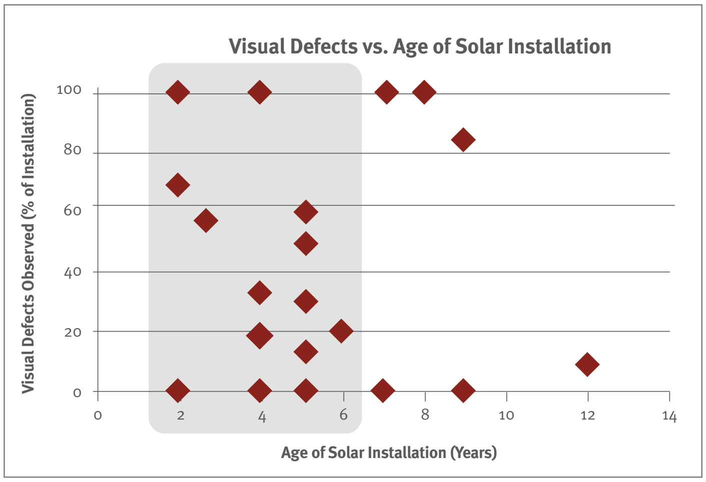


Figure 2. Age of the solar installations versus the percentage of the installation displaying visual defects. Note the large percentage of visual defects on modules with less than six years in service.

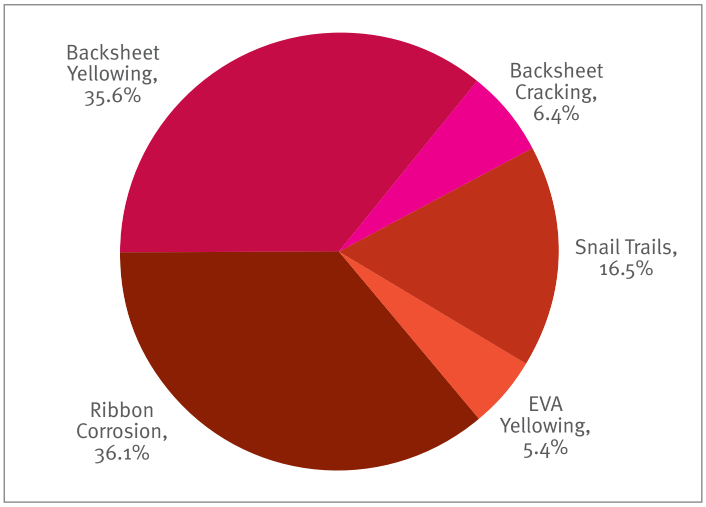


Figure 3. Percentage of defects observed by type for all solar installations combined (61 MW).

Results and Discussions

Along with ribbon corrosion and snail trails, a third defect that can be found in numerous types and styles of modules is encapsulant yellowing. Typically, encapsulant yellowing is a result of UV light exposure. The encapsulant is formulated with cross-linking agents, free radical scavengers and UV blockers to prolong the life of the module. Although the EVA can yellow on its own, these additives have also been known to yellow. This yellowing phenomenon can reduce transmission by up to 5%, directly impacting power.

Of the 32 MW of modules with visual defects, backsheet defects alone accounted for 42% of all defects. The backsheet is responsible for the electrical insulation and protection of the sensitive circuitry within the module. With the backsheet representing such a large percentage of the defects observed, a substantial risk exists in terms of safety and long-term power generation to be negatively affected.

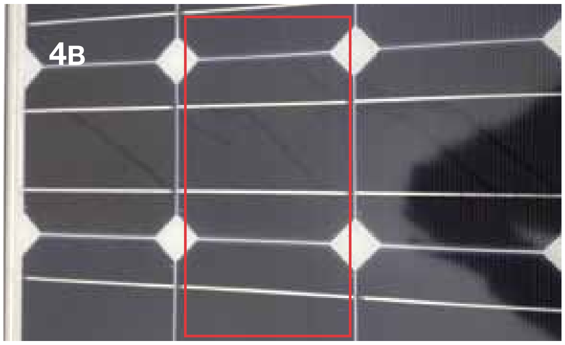
The defects of the most concern for backsheets include cracking, yellowing and delamination. Figure 4C shows an example of backsheet cracking and delamination on a polyester-based backsheet in Spain. This particular field had two different models of modules, with 100% of one model showing degradation after only four years in service.

While modules containing backsheets that have cracked and delaminated represent actual failures of the backsheets, yellowing of the backsheet known to be an early potential predictor of backsheet failure. It is typically associated with degradation of the polymer which, in severe cases, can result in the embrittlement of the backsheet.

Day-night thermal cycles on a brittle backsheet can lead to cracking and/or delamination, resulting in loss of electrical protection of the module. Figure 4D shows a polyester-based backsheet displaying severe yellowing due to environmental stresses (UV, thermal, etc.) after nine years in the field.

It is important to highlight that not all yellowing occurs on the backside of the modules. Frontside yellowing of the backsheet is caused by a degradation of the polymer used to promote the adhesion of the specific backsheet to the encapsulant. In addition to showing ribbon corrosion, Figure 4A shows an example of frontside yellowing of a PVDF-based backsheet after only five years in a field in Spain. This type of frontside yellowing has been reported as occuring within 6 months of installation.

4A An example of ribbon corrosion, as well as frontside yellowing of PVDF-based backsheet after five years (Spain).



4B An example of snail trails that affected 50% of modules in a four-year-old system (Spain).

4C Backsheet cracking in a polyester-based backsheet after only four years (Spain).

4D Polyester-based backsheet yellowing after nine years (Italy).

Conclusions

All of the solar installations inspected had some level of visual defects. After inspecting 22 solar installations, a large percentage (32 MW out of 61 MW) were found to be showing early signs of visual defects and degradation. This included installations that have less than five years in service.

Snail trails, ribbon corrosion and EVA yellowing defects all have the potential over time to negatively affect power generation. Backsheet visual defects accounted for 42% of all defects.

A high rate of backside yellowing was observed in polyester-based backsheets, while frontside yellowing occurred most prominently in PVDF-based backsheets. Yellowing typically represents degradation of the polymer that can lead to backsheet cracking, which can represent a safety hazard for anyone conducting operations or maintenance procedures.

DuPont™ Tedlar® film-based backsheets had the lowest occurrence of these defects. Nine of the 22 inspected solar installations used a backsheet constructed with at least one layer of DuPont™ Tedlar® polyvinyl fluoride film and most likely two layers on either side of a core layer of polyester, also known as TPT backsheet.

These TPT backsheets performed well with no major defects. In fact, only one of the nine fields had barely visible frontside yellowing after 12 years. DuPont™ Tedlar® film-based backsheets remain the only material proven to protect solar panels for more than 30 years, even in extreme conditions. Because polyester and PVDF-based backsheets have only been used for less than 10 years, their durability over the full lifetime of those modules could not be assessed.

This study reinforces that the best indicator of the performance of materials is actual exposure to the environment. This study also draws attention to the fact that many of these early failures were not found by current qualification testing. Similarly, current industry standards are not predictive of long-term performance in the service environment. Therefore, field performance remains the ultimate test for PV modules.

During its lifetime, a solar module will be exposed to the environment and challenged by UV radiation, temperature cycles and mechanical loads, including snow and wind. Given the no-replacement policy of module makers for many of the defects discussed in this document, the way to ensure reliable, long-term module performance is to select materials that have been proven in use for more than 30 years, such as Tedlar® PVF film. With an investment meant to last 25 years, Materials Matter™.

For more information on our field inspection program, or to request the visit of a DuPont representative to conduct a field survey of your solar installations, please contact Dr. Lucie Garreau-iles, DuPont Photovoltaic Solutions, Europe, Middle East & Africa.

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